**Title**

Design, Synthesis, and Analysis of Potent Antifungal Azole Synergizer Small Molecules and Computational and Deep Learning Approaches for Chemical Reaction Prediction

**Author**

Mood, Aaron David

**Publication Date**

2019

UNIVERSITY OF CALIFORNIA,
IRVINE

# Design, Synthesis, and Analysis of Potent Antifungal Azole Synergizer Small Molecules

# and

# Computational and Deep Learning Approaches for Chemical Reaction Prediction

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Chemistry

by

Aaron David Mood

Dissertation Committee:
Professor David L. Van Vranken, Chair
Professor Christopher D. Vanderwal
Professor James S. Nowick

2019

# DEDICATION

To

my wife, samuel, family and friends

in recognition of their unconditional love, support, and understanding.

“He is no fool who gives what he cannot keep to gain that which he cannot lose.”

- Jim Elliot

# TABLE OF CONTENTS

**CHAPTER 1: Antifungal Drugs and Azole Synergizers**

**CHAPTER 2: Phthalazinone and Isoquinolone Azole Synergizers**

**CHAPTER 3: Spiroindolinone Azole Synergizers**

**CHAPTER 4: Deep Learning for Chemical Reaction Prediction: Reaction Predictor**

**CHAPTER 5: Prediction of Nucleophilicity and Electrophilicity using Methyl Cation Affinity and Methyl Anion Affinity**

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF SCHEMES

# ACKNOWLEDGMENTS

First and foremost I would like to thank Dave for all the work he has put in in helping me and making me a better chemist and scientist. He is one of the best advisors one could ask for. He has put in countless hours helping, training, and advising me for the future. He definitely goes out of his way and puts in the extra effort to help one succeed. That is something that is rare to find in this world. Thank you Chris and James for being on my thesis committee and teaching me chemistry in your respective classes.

I would also like to thank my fellow graduate students and undergraduate students in the Van Vranken lab. Thank you Stan, Gene, Vanessa, Thi, and Udara for helping me in the lab and getting started doing chemistry. I would especially like to thank the undergraduates that I mentored and who helped me in my research: Pauline, Marina, Frances, Patrick, Steven, Kassidy, and Marlon. You have all helped immensely. Thank you also to the other undergraduate students during my time in the Van Vranken Lab: Nancy, Daniel, Bill, Michelle, An, Kevin, and John.

Completing my research would not have been possible without help from Phil with NMR, John, Ben, Felix and Ben with Mass Spec, and Nate with the modeling facility. The chemistry department staff and faculty have all been very helpful throughout my journey at UCI. Thank you also to my collaborators Pierre, David, Amin, Haoping, Fuquiang, Yi Sun, and Lingmei Sun. The research in this dissertation would not have been possible without you.

My passion for chemistry began in high school because of my chemistry teacher Connie Grosse. I hope on my best day I will be half the teacher you were on your worst day.

Thank you also to Dr. Johnson for sparking my interest in Organic Chemistry while I was in college.

Lastly, I would like to thank my family and God for always being there. I especially would like to thank my wife for being there throughout this process. I know it has been long and hard but it is almost over. It will have been worth it.

# CURRICULUM VITAE

**Aaron David Mood**

## Education

**B.S. Biochemistry** 2011 – 2014
Biblical Studies Minor
Biola University, La Mirada, CA

**Ph.D. Organic Chemistry** 2014 – 2019
University of California at Irvine

**Postdoctoral Teaching Fellowship** (Beginning August 2019) 2019
Vanguard University, Costa Mesa, CA

## Honors, Awards, and Fellowships

Biola University
- summa cum laude

University of California at Irvine
- NSF Research Traineeship Program Funded Fellow 2017 – 2019

## Research Experience

**University of California at Irvine**
Graduate Research with Professor David Van Vranken
- Design and synthesis of synergistic antifungal compounds
- Computational/machine learning approaches to predictions of organic reaction mechanisms
- Design and Synthesis of anti-melanoma flavonoids
- Palladium-catalyzed synthetic transformations

## Publications and Patents

**University of California at Irvine**
- Van Vranken, D. L.; Liu, H.; Premachandra, I. D. U. A.; Wang, F.-Q.; Chen, C.; Scott, K. A.; Lane, S. R.-A.; Mood, A. D.; Hiew, S. C. US Application No. 62/175,202: "Spiroindolinones and Therapeutic Uses Thereof", filed on 12 June 2016.
- Mood, A. D.; Premachandra, I. D. U. A.; Hiew, S.; Wang, F.; Scott, K. A.; Oldenhuis, N. J.; Liu, H.; Van Vranken, D. L. “Potent Antifungal Synergy of Phthalazinone and Isoquinolones with Azoles Against Candida albicans.” *ACS Med. Chem. Lett.* **2017**, *8*, 168.
- Fooshee, D.; Mood, A.; Gutman, E.; Tavakoli, M.; Urban, G.; Liu, F.; Huynh, N.; Van Vranken D.; Baldi, P. “Deep Learning for Chemical Reaction Prediction.” *Mol. Syst. Des. Eng.* **2018**, *3,* 442.

## Presentations

**Synthesis of Molecules that Exhibit Anti-Fungal Synergy with Fluconazole in the Pathogenic Yeast**
Department of Chemistry, Graduate Research Symposium Poster Presentation
March 4, 2016

**Potent Synergy of Fluconazole Against C. albicans by Phthalazinones and Isoquinolinones**
Biola American Chemical Society club meeting
May 3, 2017

**Spiroindolinone Synergizers of Azole Antifungal Drugs**
Moving Molecules from the Academic Lab to the Clinic Symposium
May 25, 2017

**Fast and Accurate Prediction of Chemical Reactions (Reaction Predictor)**
Machine Learning and Physical Sciences Symposium
May 26, 2017

**Fast and Accurate Prediction of Chemical Reactions**
NASA Data Intensive Research and Education Center for STEM UCI Workshop
August 18, 2017

**Deep Learning for Chemical Reaction Prediction**
NSF NRT Annual Meeting Poster Presentation
September 27, 2018

## Work and Teaching Experience

**University of California at Irvine** 2014 - 2019

Teaching Assistant
- Fall 2014: CHEM 1LD, General Chemistry Lab
- Winter 2015: CHEM 128L, Chemical Biology Laboratory
- Spring 2015: CHEM 51C, Organic Chemistry Lecture
- Summer 2015: UCI COSMOS laboratory program for gifted high school students
- Fall 2015: CHEM 51LD, Organic Chemistry Laboratory
- Summer 2016: UCI COSMOS laboratory program for gifted high school students
- Summer 2016: CHEM 51LB, Organic Chemistry Laboratory
- Winter 2017: CHEM 128L, Chemical Biology Laboratory

Mentor for Undergraduate Students
- Mentor for six undergraduate chemistry majors teaching them the skills, abilities, and knowledge necessary for research as well as giving career advice.

# ABSTRACT OF THE DISSERTATION

Design, Synthesis, and Analysis of Potent Antifungal Azole Synergizer Small Molecules

and

Computational and Deep Learning Approaches for Chemical Reaction Prediction

By

Aaron David Mood

Doctor of Philosophy in Chemistry

University of California, Irvine, 2019

Professor David L. Van Vranken, Chair

The research described in this work consists of two distinct fields of study. The first part of the work describes the design, synthesis, and testing of small molecule azole synergizers, while the second part describes work on computational and machine learning methods towards reaction prediction.

Five isoquinolones and phthalazinones were previously shown to increase the activity of fluconazole against *Candida albicans*. A dozen analogues were synthesized and one compound, **2.41**, was shown to have activity at 1 nM against a susceptible strain of *C. albicans*. **2.41** was shown to be potent against resistant strains of *C. albicans* but lacked activity against a resistant strain of *C. glabrata*. Previously synthesized spiroindolinone azole synergizers were tested against resistant strains of *C. albicans* and *C. glabrata* in the presence of fluconazole. There was activity against both strains. Over fifty new spiroindolinones were synthesized and three, **3.61**, **3.78**, and **3.71**, were found to have activity at or below 100 nM against both resistant strains.

Reaction Predictor was a system developed by the Baldi lab in the early 2010’s to use deep learning to predict reaction mechanisms. In collaboration with the Baldi lab, Reaction Predictor was improved in accuracy and performance through various ways including writing 1000’s of training reactions, modifying the architecture and features of the neural net, and using simple chemistry rules. Reaction Predictor was able to achieve a 80% top-5 recovery rate on a separate, challenging benchmark set of reactions drawn from modern organic chemistry literature. Using pathway search, Reaction Predictor was able to identify plausible products from organic synthesis reactions as well as drug degradation.

Methyl anion affinity has previously been shown to correlate linearly with electrophilicity only within specific sets of functional groups. Using a solvation model in the calculation of methyl anion affinity was shown to give a correlation with electrophilicity over a broad class of charged and uncharged electrophiles. Methyl cation affinity calculated with a solvation model was shown to correlate with nucleophilicity over a broad class of charged and uncharged nucleophiles. Using these correlations we were able to estimate the span of electrophilicity and nucleophilicity in the universe.

# Chapter 1: Antifungal Drugs and Azole Synergizers

## Introduction

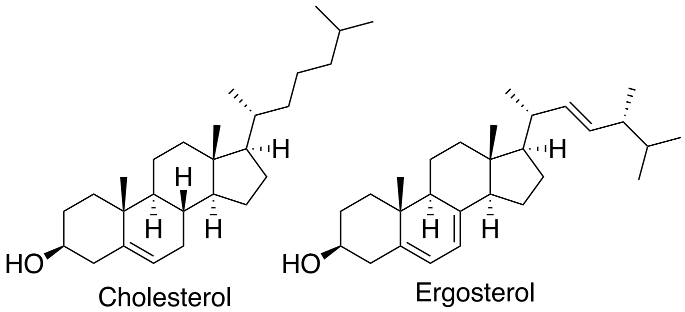
Fungal infections continue to be a major health concern in the United States as well as worldwide. Although there are many common fungal infections that are not life threatening, such as skin infections like ringworm, approximately 11.5 million people are infected with life threatening fungal infections every year. These are commonly systemic fungal infections. Annually, about 1.5 million of those infected people will die.[1] The incidence of fungal infections has been increasing worldwide.[2] Although healthy persons are susceptible to fungal infections, the highest mortality rates occur in people who have compromised immune systems. This includes HIV/AIDS, organ transplant, cancer, intensive care, and stem cell transplant patients, as well as others who take medications that weaken the immune system.[3]

The genus *Candida* accounts for roughly 80% of major systemic fungal infections. Approximately 40% of those with invasive *candidiasis* will lead to death.[4,5] *Candida albicans* and *Candida glabrata* are two of the most common fungal pathogens that cause *candidiasis*. Globally, *C. albicans* accounts for up to 70% of these fungal infections. *C. glabrata* is the second most invasive fungal species in the United States, UK, Northern Europe, and Australia.[6]

## Ergosterol Biosynthesis in Fungi

Over the years there have been many drugs that have been developed against fungal infections (this will be discussed in more detail below).[7] One of the most common modes of action for these drugs is the inhibition or disruption of ergosterol biosynthesis in fungi. Ergosterol is structurally similar to the molecule cholesterol in humans and also performs similar functions (Figure 1-1). Ergosterol is a sterol that is essential for membrane fluidity and permeability and the function of some fungal integral membrane proteins.[8,9,10] Without ergosterol the fungal cells will die.

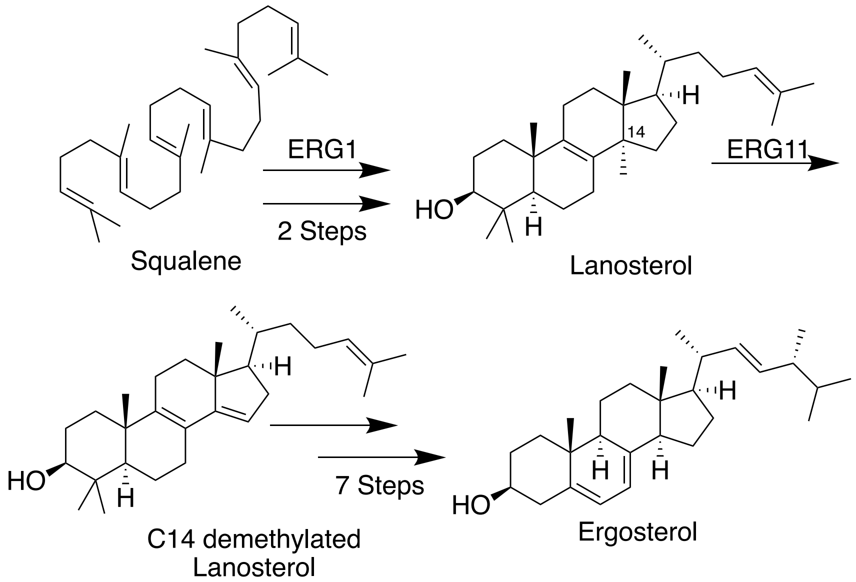
**Figure 1-1**: Cholesterol vs. Ergosterol Structure



Ergosterol is biosynthesized from squalene in ten enzymatic steps (Figure 1-2).[11] Squalene is a precursor to many sterol molecules, including ergosterol and cholesterol.[12] Squalene is converted into lanosterol beginning with the enzyme *ERG1* in the first of two steps. Lanosterol is then converted into ergosterol over eight steps beginning with the enzyme *ERG11*. The biosynthesis of cholesterol and ergosterol share some common intermediates and enzyme functions but the enzymes themselves are structurally different from one another.[13,14,15] For example, the synthesis of ergosterol and cholesterol both contain the intermediate lanosterol. In both pathways lanosterol is demethylated at the C14 position. In fungal and human cells this is accomplished through a cytochrome P450 enzyme named *CYP51*. Although the function is the same throughout the various kingdoms of life, the amino acid sequences are only conserved at about 20-30% between the various kingdoms.[16] The disruption in any of these enzymes will lower the production of ergosterol and lead to the death of fungal cells.

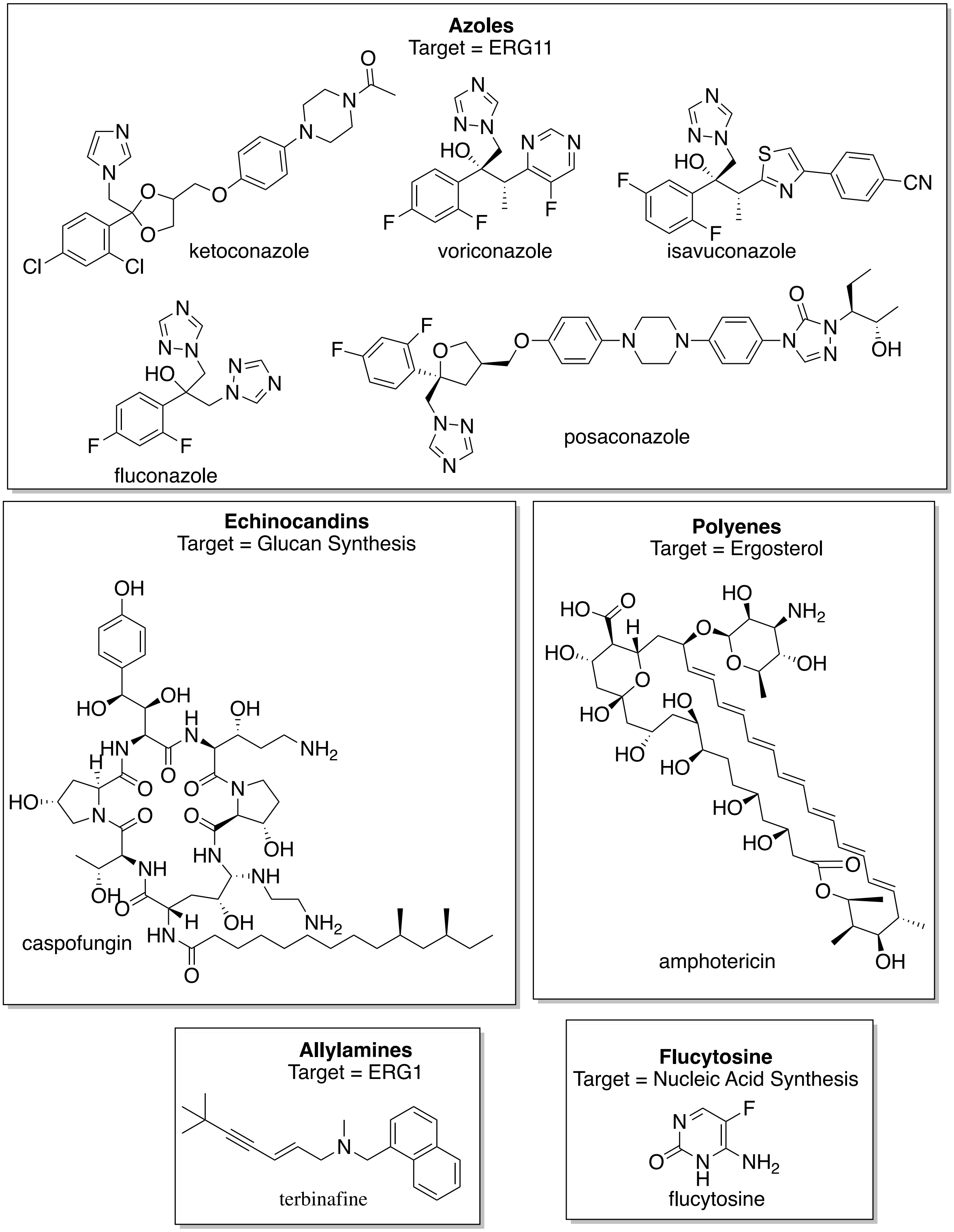
The biosynthesis of ergosterol is controlled by a transcription factor termed *UPC2*. This transcription factor acts through a classical negative feedback mechanism. At high concentrations of ergosterol, the sterol binds to *UPC2* and inhibits transcription. Low concentrations of ergosterol in the cell allow *UPC2* to promote transcription.[11]

**Figure 1-2**: Biosynthesis of Ergosterol



## Antifungal Drugs

**Figure 1-3**: Common Antifungal Drugs and Their Targets



Because of the high incidence of fungal infections and continual evolution of resistant strains, many drugs have been developed to treat fungal infections. The total value of the antifungal drug market was valued at 11.3 billion dollars in 2017. The increasing incidence of aspergillosis and candidiasis is a key component of this growing market. Potent antifungal drugs are lucrative.[17] There are five main classes of antifungal drugs currently on the market: azoles, polyenes, allylamines, flucytosine, and echinocandins, (Figure 1-3). Azoles, polyenes, and allylamines all target ergosterol or the ergosterol biosynthesis pathway. The structural differences between fungal and human enzymes involved in sterol biosynthesis are the reason this pathway has been a common target of antifungal drugs. These drugs can inhibit fungal enzymes while not affecting human enzymes that carryout the same function.

The azole class of drugs leads the antifungal drug market in sales and is still the most common class of drugs as the first line defense against most *Candida* infections.[18, 19] The first generation of azole drugs included ketoconazole and miconazole in the 1970s and 1980s. The second generation of azoles, including fluconazole, was introduced in the 1990s.[20] Fluconazole is the most commonly used antifungal azole. It is still used as the first line defense against *C. ablicans*. This is due to three reasons. Fluconazole is relatively inexpensive now that it is off patent, has low toxicity, and can be administered orally or intravenously. When first introduced, fluconazole greatly improved upon the safety, pharmacokinetics, and the spectrum of antifungal activity over the previous azoles. More recently, third generation azoles (voriconazole, posaconazole and isavuconazole) have been developed that have further improved upon safety, pharmacokinetics, and spectrum activity. Nevertheless, fluconazole still remains important, popular, and effective in the treatment of *Candida* infections. Fluconazole resistance has become so prevalent that echinocandins are now recommended as the first-line drug for invasive candidiasis in non-neutropenic patients.[21]

Azoles bind to a protein in the ergosterol biosynthesis pathway previously mentioned, CYP51 14-α-demethylase, also known as *ERG*11. Azoles bind to the heme iron in the active site and prevent the substrate lanosterol from binding to *ERG*11. Because ergosterol is necessary for fungal membrane integrity, lower levels of ergosterol affect the morphology of the membrane and inhibit growth.[22, 23] Azoles are selective for binding to fungal CYP51 compared to human CYP51,[24] but azole toxicity is often associated with off-target binding to other CYP enzymes.

Polyene antifungals and allylamine antifungals also interfere with ergosterol. Polyenes, typified by amphotericin, find wide use and have the broadest spectrum of any antifungal drugs.[25] Polyenes are primarily active antifungal drugs because they bind to ergosterol. This creates a polyene•ergosterol complex in the membrane of the fungal cells that leads to leakage of monovalent ions and other cellular contents.[26,27,28] Polyenes are also active against fungal cells because they impair membrane permeability by releasing free radicals through various oxidation reactions in the cell.[29, 30]

Allylamines such as terbinafine (sold as Lamisil®) target a different enzyme in the ergosterol biosynthesis than azoles. Allylamines target *ERG*1, which is a squalene epoxidase leading to inhibition and buildup of squalene in the cells.[31,32] As inhibitors of ergosterol biosynthesis, allylamines are similar to azoles. Allylamines are one of the best choices in treating fungal skin infections because they accumulate in the skin much more than other antifungal drugs. This is most likely because of their lipophilicity.[33]

Flucytosine is an antifungal drug that is almost always used in combination with other antifungal drugs because fungi tend to become resistant to them quickly when used as single agents.[34] When flucytosine enters a fungal cell it is converted to 5-fluorouracil by cytosine deaminase.[35] 5-Fluorouracil interferes with DNA and RNA synthesis and kills the fungal cells. 5-Fluorouracil does this by being incorporated into RNA strands that causes early chain termination.[36] As expected for agents that target nucleotide synthesis, flucytosine can lead to bone marrow toxicity.[37]

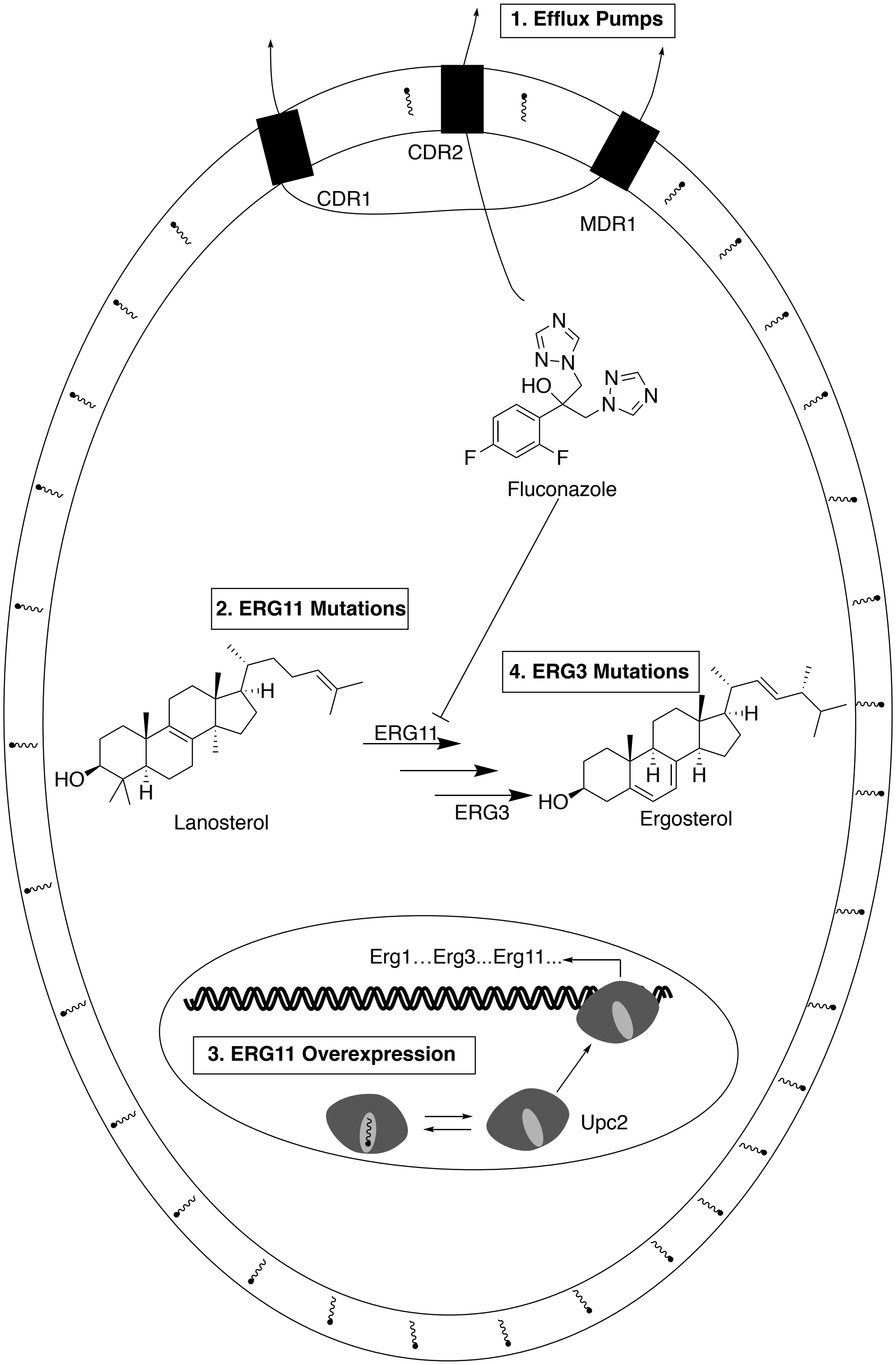
The last main class of antifungal drugs is the echinocandins, typified by caspofungin and micafungin. Echinocandins have been successful drugs because of their broad-spectrum activity and low drug-drug interactions.[38] In addition to azoles, they are also commonly used for invasive candidiasis.[39] Echinocandins are potent antifungal drugs because they inhibit the synthesis of glucans. Echinocandins inhibit 1,3-β-glucan synthase unrelated to ergosterol, causing cell walls to weaken and the cell to lyse.[40] To date, echinocandin resistance has not emerged as a major problem.[41]

## Resistance in Fungi Towards Azoles

The resistance of fungi to azole drugs had been extensively studied in *Candida* and is a growing public health problem. There are four main ways that fungal cells become resistant to azole drugs: (1) overexpression of efflux pumps, (2) *ERG*11 mutations, (3) *ERG*11 overexpression, and less commonly (4) ERG3 mutations (Figure 1-4).[42]

The first mode of resistance to azoles (and other antifungal drugs) is through the overexpression of efflux pumps sometimes over a thousand-fold over nominal expression levels.[43] These pumps are transmembrane proteins that can pump out different molecules, including azoles, outside of the cell. There are two main types of efflux pumps in fungal cells: ATP-binding cassette (ABC) proteins and the major facilitator superfamily (MFS) proteins.[44] ABC proteins are the primary efflux pumps fungal cells use and utilize energy derived from the hydrolysis of ATP. MFS proteins are used less than ABC proteins and use a protein electrochemical gradient to pump molecules out of the cell. *Candida albicans* possesses 28 different kinds of ABC efflux pumps that can contribute to azole resistance. The two main ABC efflux pumps used are CDR1 and CDR2. CDR1 is believed to contribute more to fluconaozle resistance than CDR2 compared to other azoles.[45,46,47] *Candida albicans* posses 96 different MDS proteins but only one is involved in azole resistance, MDR1. *Candida glabrata's* efflux pumps have been studied less than those in *C. albicans*, but the CDR1 and CDR2 are believed to be the main drivers of azole resistance in this species as well.[48]

**Figure 1-4**: Summary of Fungal Resistance to Azoles



In additon to efflux overexpression, fungal cells can become resistant to azoles through ERG11 point mutations. Point mutations change one amino acid in the protein sequence of ERG11. Point mutations often exert little effect on the three-dimensional structure of a protein but sometimes the effects on structure, folding and/or aggregation can be drastic. If a point mutation prevents ERG11 from carrying out its proper function the fungal cell will die. Azole resistance occurs when a point mutation on ERG11 lowers the binding affinity of azoles but ergosterol is still produced normally or is slightly diminished. Of the roughly 160 amino acid mutations identified in ERG11, 10 are known to lead to fluconazole resistance in *Candida.*[49] Substitutions of R467K, I471T, G464S, S405F, and K143R are involved in azole resistance of *Candida albicans.*[50,51,52] Point mutations in *Candida glabrata* have not been well studied.[53]

In addition to overexpression of efflux pumps and ERG11 point mutations, a third mechanism of resistance towards azoles is ERG11 overexpression. ERG11 overexpression is driven by the UPC promoter. All fungal cells will increase ERG11 expression is the presence of azoles[54] but azole resistant fungi naturally overexpress ERG11 even when there is no azole in the cell.[55] ERG11 overexpression can be driven in two ways in *Candida albicans*. The first mechanism for overexpression is the formation of an isochromosome that duplicates the genes that produce ERG11.[56] The second mechanism for overexpression is mutation of the transcription factor UPC2 that results in an overexpression of ERG11.[57] Other *Candida* species overexpression ERG11 but the specific mechanism of action has not been studied well.

The last main azole-resistance mechanism in fungal cells is mutation of *ERG3*, although this form of resistance is much less common. Azoles are effective because, in additon to depletion of the end-product ergosterol, azoles also lead to the accumulation of other toxic sterol intermediates in fungal cells.[58] Mutations in ERG3 can reduce accumulation of these toxic products.[59]

## Two Methods to Combat Azole Resistance

Because of the various resistance mechanisms described above, many efforts have been made to overcome azole resistance. The two main strategies to combat azole resistance is through the design of new azoles and the investigation of azole synergizers. Synergizers are molecules that are used in tandem with another drug that increase the efficacy of that drug.

The emergence of fluconazole resistance has led to the increasing use of echinocandins and the development of third-generation azoles (voriconazole, posoconazole, isavuconazole) with higher affinity for ERG11.[60] Of the third-generation drugs, posoconazole and voriconazole work against a broader range of fungal pathogens but are more expensive and have other disadvantages: posoconazole has a less flexible dosing and absorption profile than fluconazole; voriconazole may be ineffective against strains that have already developed resistance towards fluconazole.[61] Newer azole drugs like albaconazole and fosravuconazole are still in development.

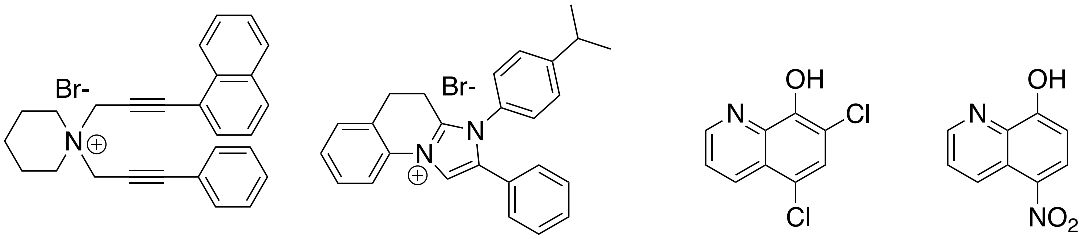
The development of improved azoles has been paralleled by the search for small molecules that enhance the antifungal effect of existing azoles,[62,63,64,65,66] but the efforts have been met with limited success.[67,68] A wide range of azole enhancers have been shown to exhibit antifungal synergy;[69] two approved drugs — flucytosine[70] and calcineurin inhibitors[71,72,73,74,75] — have been shown to synergize with fluconazole at low concentrations (< 10 μg/mL) against strains of *C. albicans* but have limitations for general use. Against other species,[76] flucytosine instead antagonizes the effect of fluconazole, so the benefits of flucytosine-azole combinations are not clear.[77] Calcineurin inhibitors such as sirolimus and tacrolimus depend on human CYP enzymes for metabolic clearance; azole drugs like fluconazole exert off-target effects on these human CYP enzymes. Buildup of these calcineurin inhibitors in plasma increases risk of nephrotoxicity, and, as immunosuppressants, may increase rates of infection from other pathogenic fungal species.[78,79,80] Given the limitations of these existing azole synergizers, new potent alternatives are needed.

## Screens of Large Libraries of Small Molecules in Search of Antifungal Synergizers

One way to search for small molecules that enhance the antifungal effect of existing azoles (mentioned above) was to screen massive libraries of small molecules in tandem with azoles against fungi. Three different screening campaigns have been carried out to identify synergizers; LaFleur and coworkers, [81] Spitzer and coworkers, [82] and Lindquist and Schreiber at the broad institute. [83,84]

LaFleur and coworkers screened a library of 120,000 compounds, to identify those that could enhance the activity of clotrimazole against *C. albicans* biofilms. They identified 19 compounds with synergistic activity against *C. albicans*, yet none had activity below 1 μM. Only 4 of the 19 compounds were nontoxic towards mammalian cells (Figure 1-5).

**Figure 1-5**: Nontoxic Analogues Tested by LaFleur

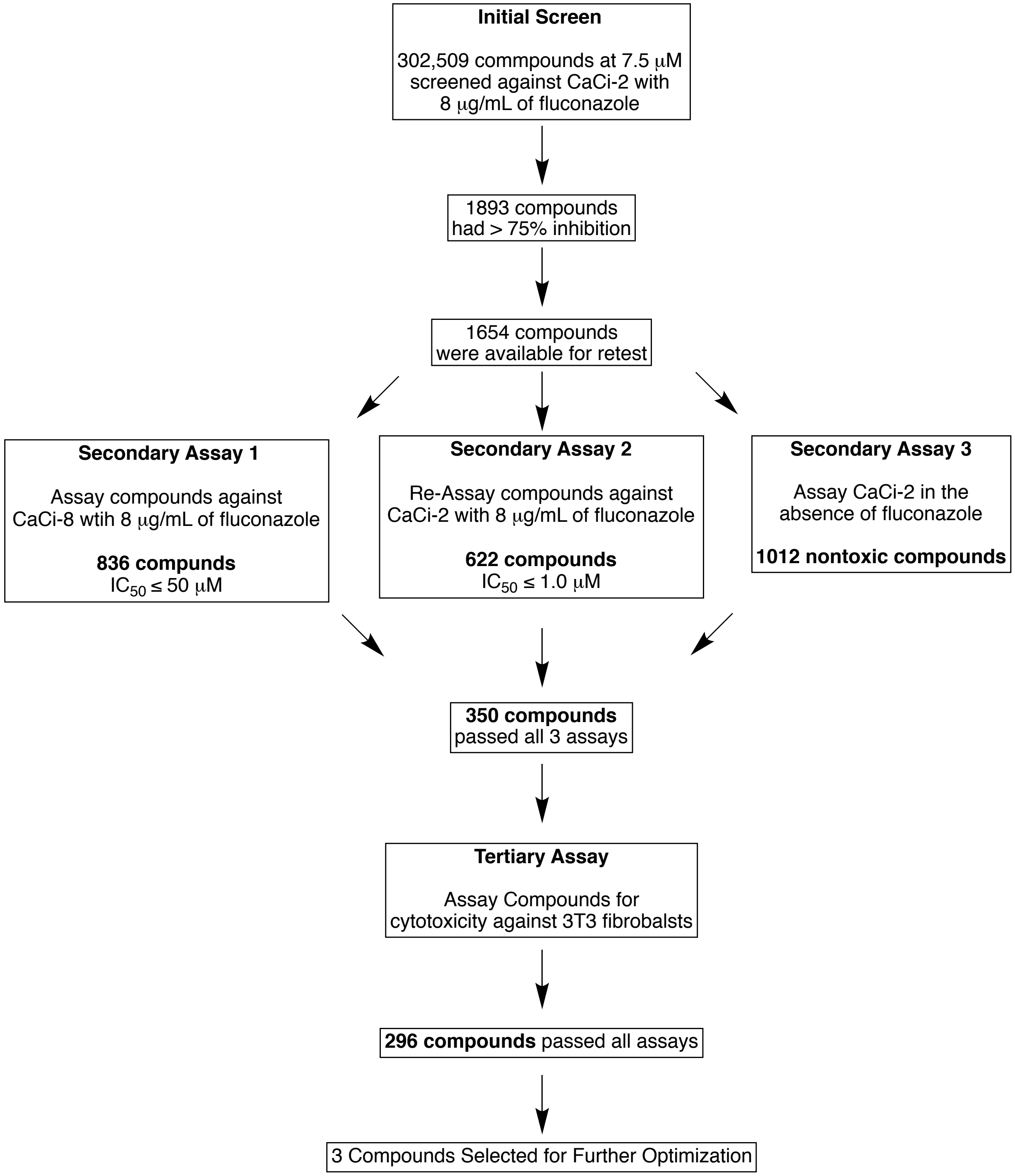


$IC_{50}$ 20 μM  $IC_{50}$ 3 μM  $IC_{50}$ 140 μM  $IC_{50}$ 10 μM

Spitzer and coworkers screened 1,120 off-patent drugs compounds that could enhance the activity of fluconazole against *C. albicans*. They identified 30 hits including sertraline, thiethylperazine maleate, pirlindole mesylate, and flufenamic acid. None of these compounds had activity below 1 μM.

The most extensive screen of potential antifungal synergizers was initiated by Lindquist and Schreiber at the Broad Institute.[85,86] They screened a total of 302,509 compounds from the NIH's Molecular Libraries Small Molecule Repository (MLSMR) against *C. albicans* as depicted in Figure 1-6a. Lindquist and Schreiber began by running an initial screen against all 302,509 compounds at a single dose (7.5 μM) in conjunction with fluconazole (8 μg/mL) against the *C. albicans* strain CaCi-2. They found 1,893 compounds reduced growth below 25% of the control. 1,654 of these compounds were subjected to further testing in 3 subsequent assays.

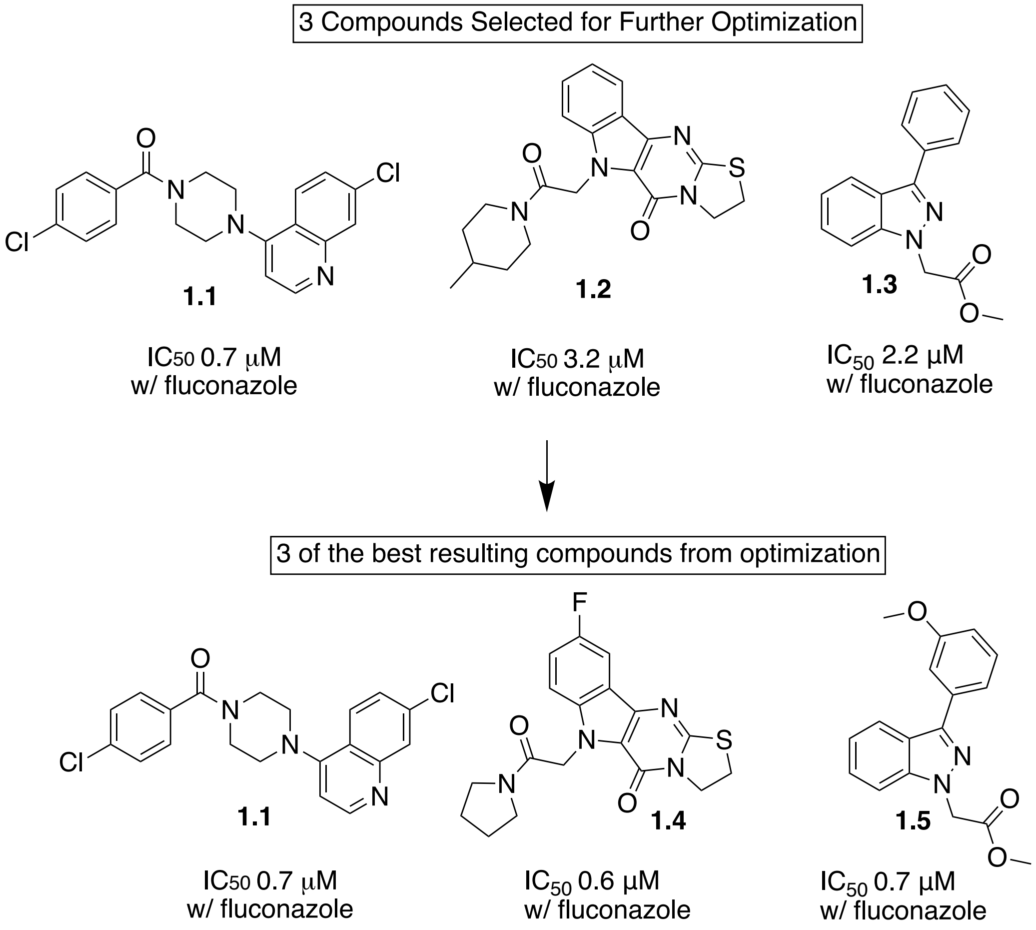
**Figure 1-6a**: Lindquist and Schreiber Screen



The first assay tested each compound in a dose-response fashion together with fluconazole (8 μg/mL) against the partially resistant *C. albicans* strain CaCi-8. 836 compounds were found to have $IC_{50}$ values at or below 50 μM. The 1,654 compounds were also retested against CaCi-2 in a dose-response fashion with a fixed concentration of fluconazole; 622 compounds had $IC_{50}$ values at or below 1 μM. The last assay identified 1012 compounds that exhibited no antifungal activity without fluconazole. 350 compounds passed all 3 criteria mentioned above. Those 350 compounds were tested against mammalian fibroblasts (NIH 3T3 cells); 296 compounds exhibited no cytotoxicity.

Lindquist and Schreiber decided to further optimize three of the compounds (figure 1-6b) found in their massive screen, quinoline **1.1**, indole **1.2**, and indazole **1.3**. [87,88,89] In addition to quinoline **1.1**, none of the resulting compounds they synthesized, including compounds **1.2** and **1.3** had activities below 0.7 μM against CaCi-2 in conjugation with fluconazole. There were still 293 other compounds that were ripe for further optimization and testing.

**Figure 1-6b**: Lindquist and Schreiber Follow-up Summary



## Further Testing of Selected Lindquist and Schreiber Compounds

Following up on the work from the Lindquist and Schreiber screen, the Van Vranken and Liu labs further investigated and test other compounds identified in their massive screen.[90] The Van Vranken/Liu team was hoping to identify azole synergizers that might be acting on the transcription factor UPC2 that drives overexpression of the ergosterol biosynthesis genes.

The Van Vranken and Liu labs ordered 51 compounds that were readily available from the 296 compounds that meet all the criteria from the Lindquist and Schreiber screen. The initial screen was carried out using a fungal strain of *C. albicans* engineered (HLY4123) with a GFP reporter to monitor *ERG3* and *ERG11* expression. HLY4123 was engineered from the susceptible common laboratory strain CAI4.[91] FACS (fluorescence activated cell sorting) was used to monitor the effects of compounds on *ERG* transcription.

Dr. Fu-Qiang Wang from the Liu lab tested all 51 compounds and found that 20 of compounds affected the transcription levels of HLY4123. After further testing Dr. Wang found that 5 of the compounds were potent down-regulators of *ERG3* and *ERG11* (Figure 1-7) and 6 of compounds were potent up-regulators (Figure 1-8). It was anticipated that down-regulation of *ERG* transcription would lead to antifungal synergy with fluconazole. The data showed the opposite trend. All 5 potent down-regulators displayed no activity against HLY4123 in the presence of fluconazole.

In contrast, the 6 potent up-regulators were found to enhance the activity of fluconazole against HLY4123. Their $IC_{50}$ values are given in Figure 1-8 at a fixed concentration of fluconazole (0.25 μg/mL). These 6 potent up-regulators are ripe targets for the design and testing of new synthetic compounds that could be potent enhancers of fluconazole.

**Figure 1-7**: Potent Down-Regulators

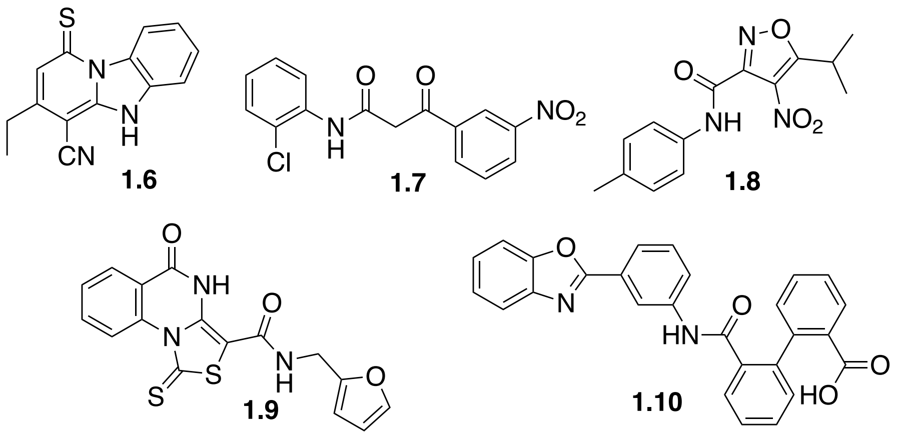
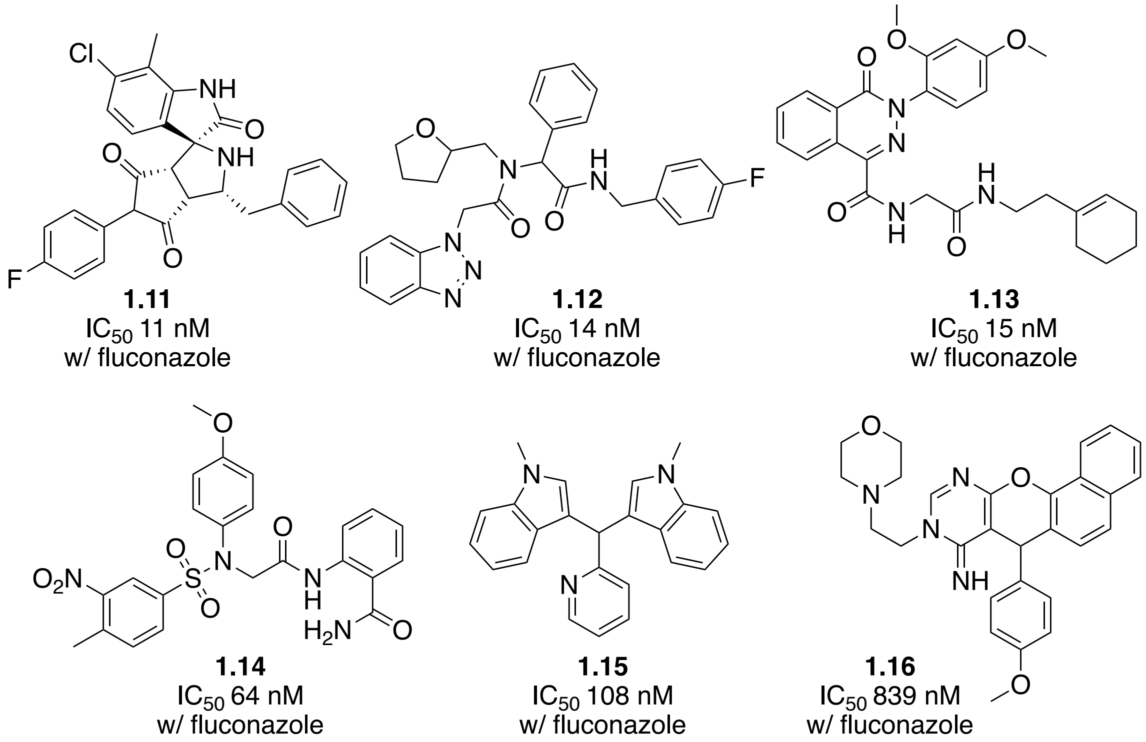


**Figure 1-8**: Potent Up-Regulators and Potent Enhancers



**1.11**
$IC_{50}$ 11 nM
w/ fluconazole

**1.12**
$IC_{50}$ 14 nM
w/ fluconazole

**1.13**
$IC_{50}$ 15 nM
w/ fluconazole

**1.14**
$IC_{50}$ 64 nM
w/ fluconazole

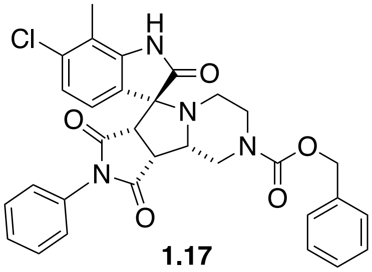
**1.15**
$IC_{50}$ 108 nM
w/ fluconazole

**1.16**
$IC_{50}$ 839 nM
w/ fluconazole

In the Van Vranken lab, Udara Premachandra led an effort to synthesize analogues of bis-indole **1.15** but the analogues proved to be readily oxidized in air and had very low solubility. Only one analogue was successfully purified and it was no more potent than the original bisindole **1.15**.

Because of that failure Premachandra and coworkers investigated another hit, spirocyclic indolone **1.11**. [92] The indolone analogues were more soluble, stable, and exhibited highly responsive structure-activity relationships. They ended up making over 25 new analogues and improved upon the activity of the lead compound. The best compound they made, termed synazo-1 (**1.17**) had activity down to 0.3 nM against HLY4123 and was also active against many resistant *C. albicans* strains. The background and further work on these compounds will be discussed in Chapter 3 of this dissertation. The successful optimization of compound **1.11** suggests that other compounds tested by Lindquist and Schreiber could be developed into potent azole antifungal synergizers.

**Figure 1-9**: Synazo-1



**1.17**
$IC_{50}$ 0.3 nM
w/ fluconazole

## Conclusion

In summary, over a million people will die from fungal infections each and every year. Immunocompromised patients are at the greatest risk of death from fungal infections. Azoles are still heavily prescribed as antifungal agents but the evolution of resistant strains is a major problem. There have been two main strategies to combat azole resistance: develop new azoles and develop small molecule synergizers that increase the efficacy of existing azoles. There has been success in the development of azoles but developing molecules that enhance azoles is ripe for development. Lindquist and Schreiber screened over 300,000 compounds in search of some that would increase the efficacy of fluconazole. They followed up on three of those compounds but had limited success. Premachandra and coworkers followed up on one compound, **1.11**, and was able to develop an analogue that had activity below 1 nM in conjugation with fluconazole. More compounds from the Lindquist and Schreiber screen that were active could lead to potential new drugs and could help in combating fungal infections. More investigation is needed to see if new potent enhancers could be developed.

# Chapter 2: Phthalazinone and Isoquinolone Azole Synergizers

## Introduction

As described in Chapter 1, over one million people die every year from fungal infections. Infections caused by *C. albicans* are the leading cause of death worldwide. *C. glabrata* is the second most invasive fungal species in the United States, UK, Northern Europe, and Australia.[93] One of the most common forms of treatment for fungal infections, especially systemic fungal infections, is the use of azoles but azole resistance is increasing. In this chapter, the design, synthesis, and testing of potent phthalazinone and isoquinolone azole synergizers is described. The work described in this chapter was completed with the assistance of Dr. Stan Hiew, Dr. Udara Premachandra, and Kevin Scott in the Van Vranken lab and Dr. Fuqiang Wang in the Liu lab. I did the bulk of the synthesis and testing on this project.

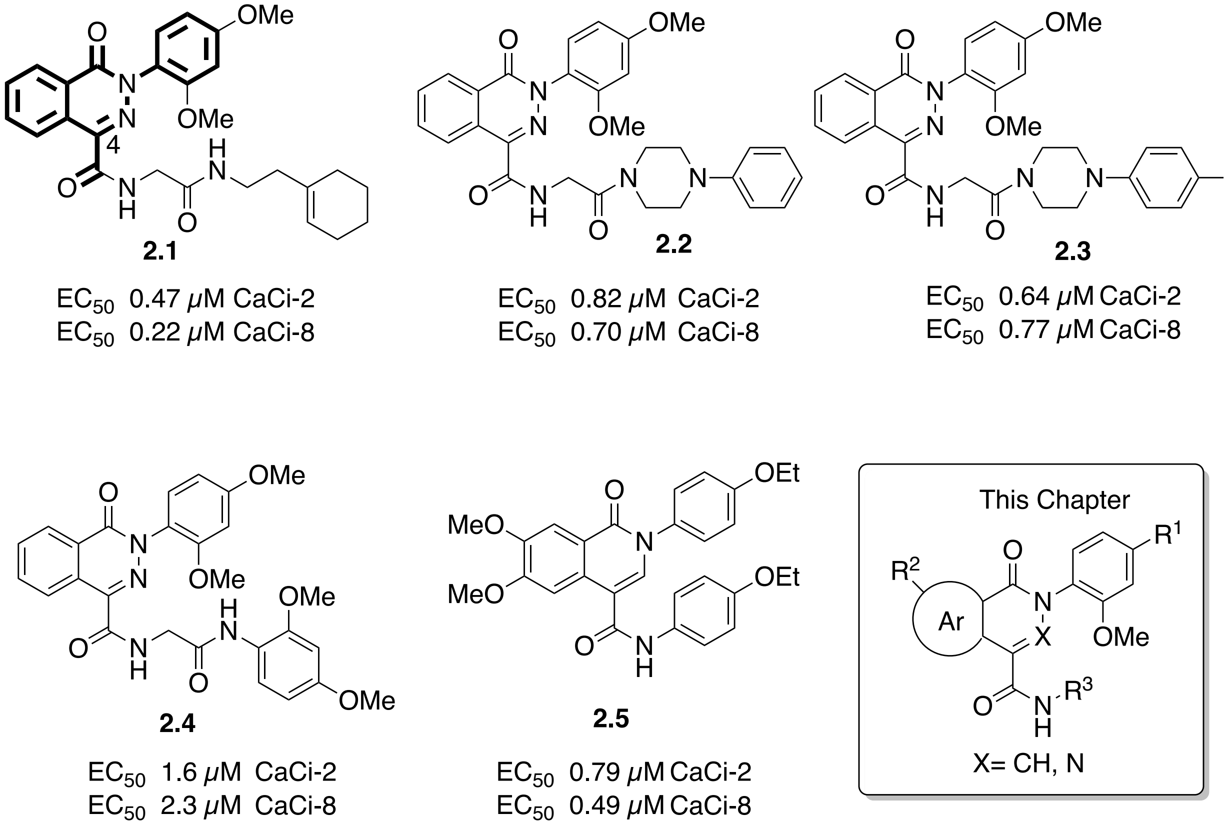
Lindquist, Schreiber, and coworkers carried out a screening campaign to identify small molecules that could enhance the antifungal effect of fluconazole against *C. albicans*.[94,95] After an initial screen of over 300,000 compounds and a subsequent rescreening, 296 compounds were found to enhance the antifungal effect of fluconazole against a partially resistant clinical strain CaCi-8 without cytotoxicity against mammalian cells. Three of those compounds[96,97,84] were selected for further optimization but none of the resulting compounds (ML189, ML212, and ML229) were active below 0.7 μM against CaCi-2. Following up on another hit from the Lindquist-Schreiber screen, Premachandra and coworkers recently reported an analogue called synazo-1 that could enhance the antifungal effect of fluconazole with an $EC_{50}$ of 300 pM.[98] Encouraged by the discovery of highly potent spiroindolinones we set out to optimize other lead compounds from the

Schreiber-Lindquist screen, study their synergy with other azoles, and assess their selectivity for *C. albicans*.

## Previous Phthalazinone and Isoquinolone Azole Synergizers

Among the compounds initially screened by Lindquist and coworkers in conjugation with fluconazole were 233 structurally related *N*-arylphthalazinones (X=N, Figure 2-1) and *N*-arylisoquinolones (X=CH). Four phthalazinones (**2.1**, **2.2**, **2.3** and **2.4**) and one isoquinolone (**2.5**) were active in the initial screen. The most active compound of the five was phthalazinone **2.1** (CID 22334057), which showed an $EC_{50}$ below 0.5 μM for *C. albicans* clinical isolates CaCi-8 and CaCi-2 in conjugation with fluconazole.

**Figure 2-1**: Structures of Active Compounds, Lead Phthalazinone **2.1** (CID 22334057) and Representative Structure of Analogues Synthesized in this Study



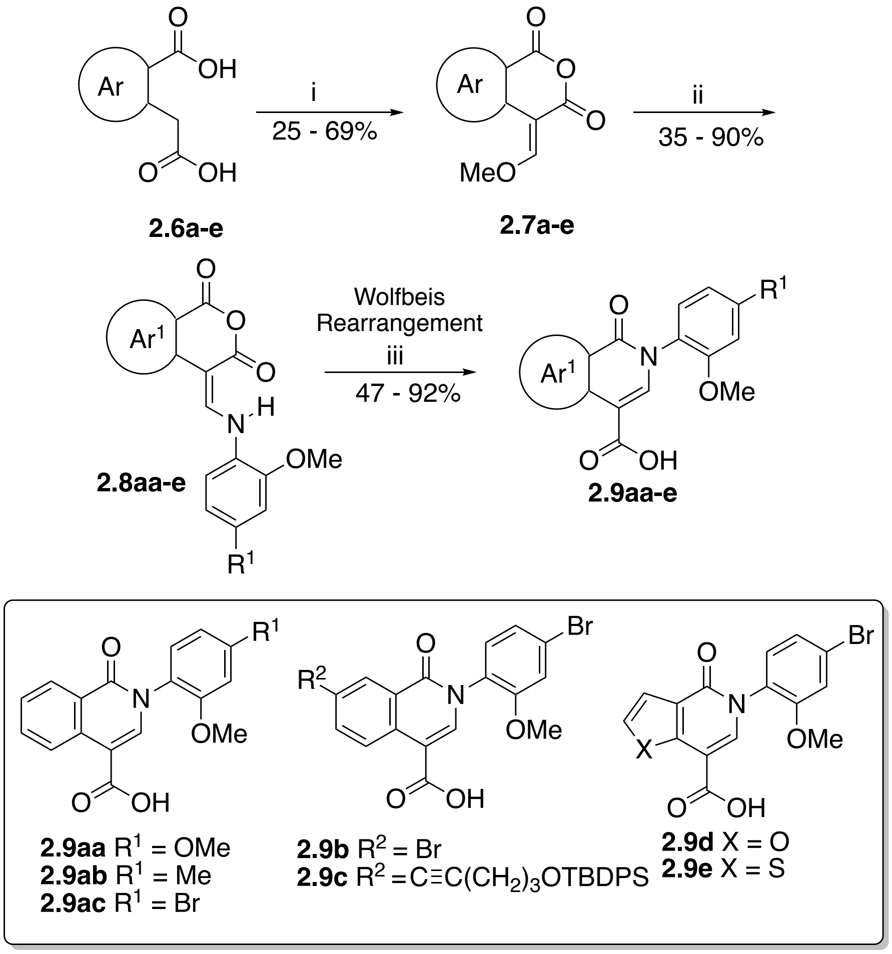
An initial analysis of the Lindquist data suggested that the biological activity of the phthalazinones was sensitive to substituents on the *N*-phenyl ring and the C4 carboxamide side chain (Figure 2-1). In particular, a *para* substituent on the *N*-phenyl ring was favorable for activity, and an *ortho* substituent seemed essential. Additionally, the glycine linker was present in all of the active phthalazinones. The effect of modifications within the bicyclic core—at the atom X within the heterocycle or the fused benzo ring—were unclear. Analogues of the isoquinolone and phthalazinone compounds were therefore synthesized to explore chemical modification at three sites: a) modification of the bicyclic core, including substitution of X (N versus CH), substitution of the fused benzo ring, or replacement of the benzo ring with a heterocycle; b) substitution at the *para* position of the *N*-phenyl ring; c) variation of the C4 carboxamide side chain.

## Results and Discussion

### Chemistry

All analogues were synthesized by coupling heterocyclic carboxylic acids with amines. Isoquinolone analogues were synthesized from the corresponding dicarboxylic acids **2.6a-e** following a route developed by Wolfbeis (Scheme 2-1).[99] A one-step anhydride formation and formylation generated enol ethers **2.7a-e**. Conjugate substitution of the methoxy group with various anilines generated the corresponding enamines **2.8aa-e**. Ethoxide catalyzed the Wolfbeis rearrangement of anhydrides **2.8aa-e** to isoquinolones **2.9aa-e**.[100]

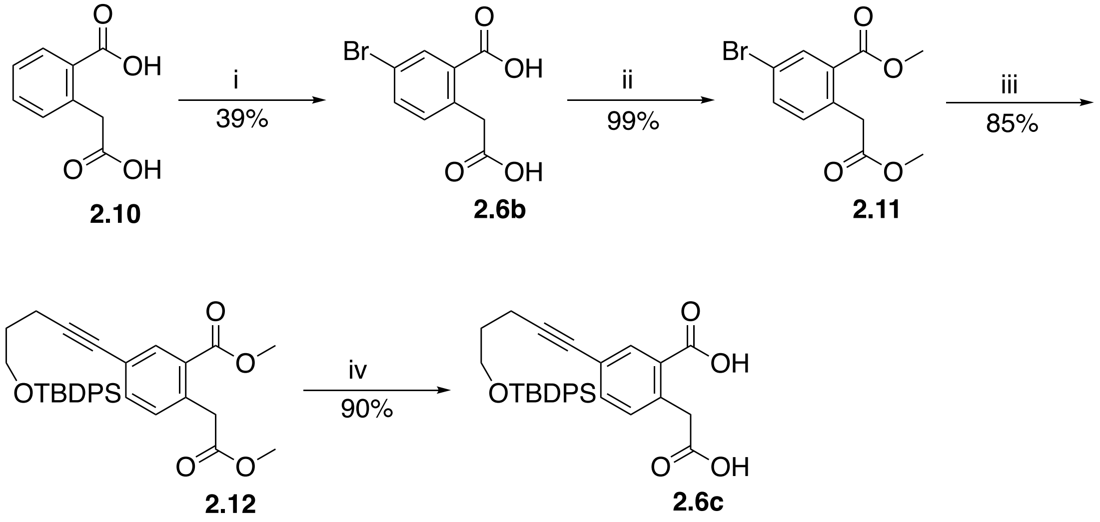
**Scheme 2-1:** Synthesis of Isoquinolone Carboxylic Acids[a]



*[a]Reagents and conditions:* (i) 1.0 mol-equiv $CH(OCH_3)_3$, $Ac_2O$, 140 °C, 5 min-2.5 h (ii) 1.0 mol-equiv $ArNH_2$, 1,4-dioxane, 23 °C, 1-4 h (iii) 5.0 mol-equiv NaOH, EtOH, 80 °C, 1-4 h.

The synthesis of homophthalic acid starting materials **2.6b** and **2.6c** is outlined in Scheme 2-2. Homophthalic acid (**2.10**) was brominated with $KBrO_3$ to yield bromoacid **2.6b**. Bromoacid **2.6b** was subjected to Presser esterification with $TMSCHN_2$ to make ester **2.11**. A Sonogashira coupling of aryl bromide **2.11** with 4-pentyn-1-ol generated alkyne **2.12**. **2.12** was saponified to afford acid **2.6c**. Originally we planned to avoid protection of the primary alcohol but the formylation/cyclization step in Scheme 2-1 failed with the ω-hydroxyalkyne moiety.

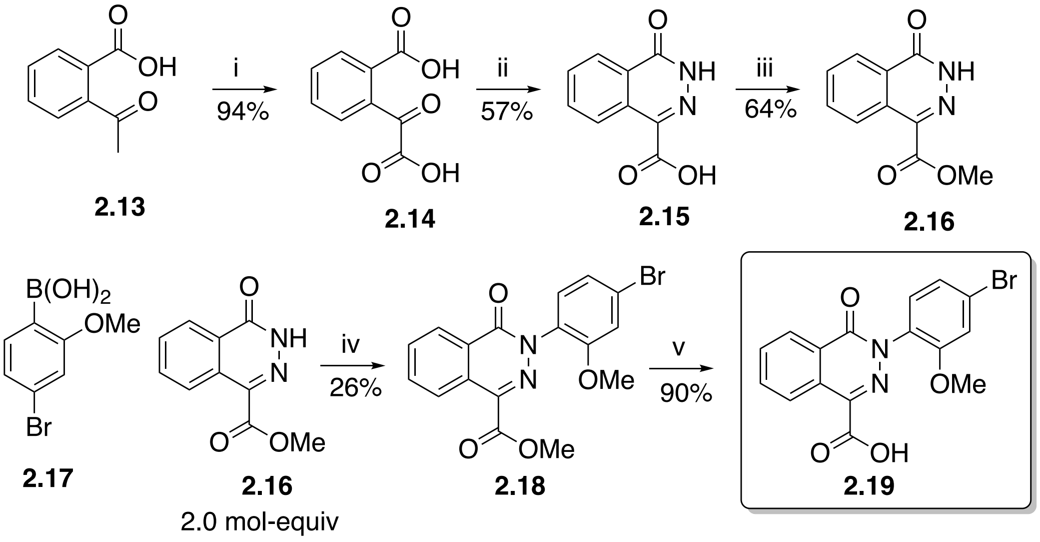
**Scheme 2-2**: Synthesis of Homophthalic Acid Derivatives[a]



[a]*Reagents and conditions:* (i) 150 mol% $KBrO_3$, $H_2O/H_2SO_4$, 90 °C, 4 h (ii) 2.8 mol-equiv $TMSCHN_2$, 2:1 benzene/MeOH, 23 °C, 2 h (iii) 1.7 mol-equiv 4-pentyn-1-ol, 5 mol% $Pd_2Cl_2(PPh_3)_2$, 5 mol% CuI, 3:2 DMF/$Et_3N$, 100 °C, 0.75 h (iv) 3.8 equiv LiOH, 3:1 THF/H2O, 23 °C, 16 h

The original Dieckmann synthesis[101] of *N*-arylphthalazinones was problematic due to the capricious reactivity of electron-rich arylhydrazines. The synthesis of phthalazinones, such as lead compound **2.1**, with electron-rich *N*-aryl groups has never been reported and the only known synthetic approach involves electron-rich arylhydrazines, which are known to be highly sensitive.[102,103] A new route, absent of phenylhydrazines, was used to successfully synthesize *N*-arylphthalazinone **2.18** (Scheme 2-3). Carboxylic acid **2.13** was oxidized to diacid **2.14**[104], which was then converted into carboxylic acid **2.15**[105] through a condensation with hydrazine. Carboxylic acid **2.15** was converted to the methyl ester[106] **2.16**, which was then coupled with an arylboronic acid through a Chan-Lam coupling[107] to give phthalazinone **2.18**. Ester **2.18** was saponified to afford carboxylic acid **2.19.**

**Scheme 2-3**: Synthesis of Phthalazinone Carboxylic Acid[a]



2.13 2.14 2.15 2.16

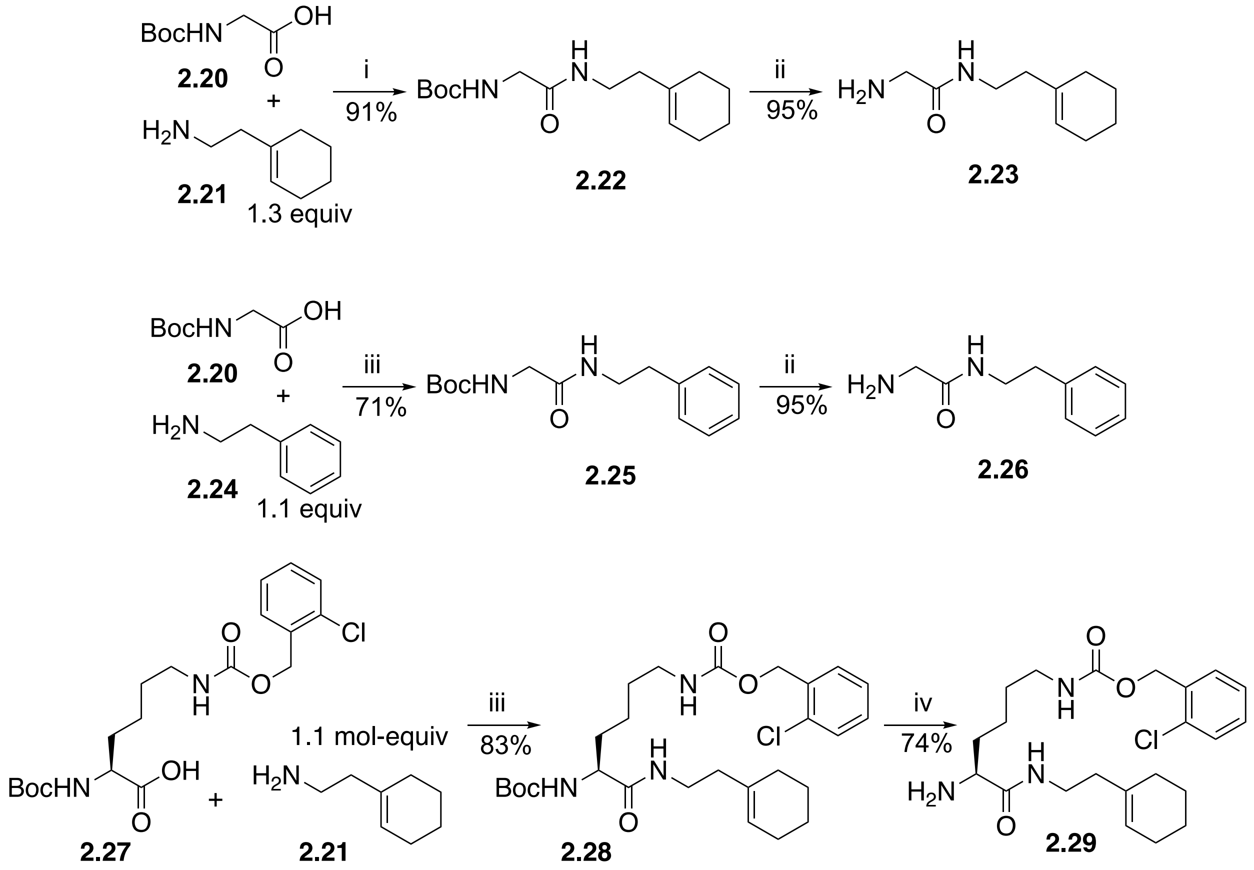
2.17 2.16 2.18 2.19

2.0 mol-equiv

[a]*Reagents and conditions*: (i) 1.7 mol-equiv $SeO_2$, pyridine, 115 °C, 3 h (ii) 1.1 mol-equiv $H_2NNH_2$, EtOH, 78 °C, 4 h (iii) 5.3 mol-equiv MeI, 3.9 mol-equiv $NaHCO_3$, DMF, 23 °C, 16 h (iv) 2 mol-equiv $Cu(OAc)_2$, 5 mol-equiv pyridine, $CH_2Cl_2$, 23 °C, 24 h (v) 3.8 mol-equiv LiOH, 3:1 THF/$H_2O$, 23 °C, 16 h.

The most potent phthalazinone analogues identified in the Schreiber-Lindquist screen included glycine linkers. Several glycine derivatives (compounds **2.23**, **2.26**, and **2.29**) were synthesized in order to couple with carboxylic acids **2.9aa-e** and **2.19** (Scheme 2-4). *N*-Boc-glycine **2.20** was coupled with 2-(1-cyclohexenyl)ethylamine **2.21** or amine **2.24** through a carbodiimide coupling reaction to afford amides **2.22** or **2.25** in good yields.[108] A protected lysine derivative **2.27** was also coupled with amine **2.21** through a carbodiimide coupling. Deprotection of the Boc group in the presence of the cyclohexenyl group, however, was found to be challenging. Common methods of deprotection such as treatment with trifluoroacetic acid resulted in complete degradation of the starting material due to protonation of the alkene. Consequently, a thermal deprotection was employed to generate amine **2.23**. Compounds **2.22** and **2.25** were deprotected by heating at reflux in water to remove the Boc group.[109] However, compound **2.28** with limited solubility in water was instead heated under reflux in ethylene glycol.[110]

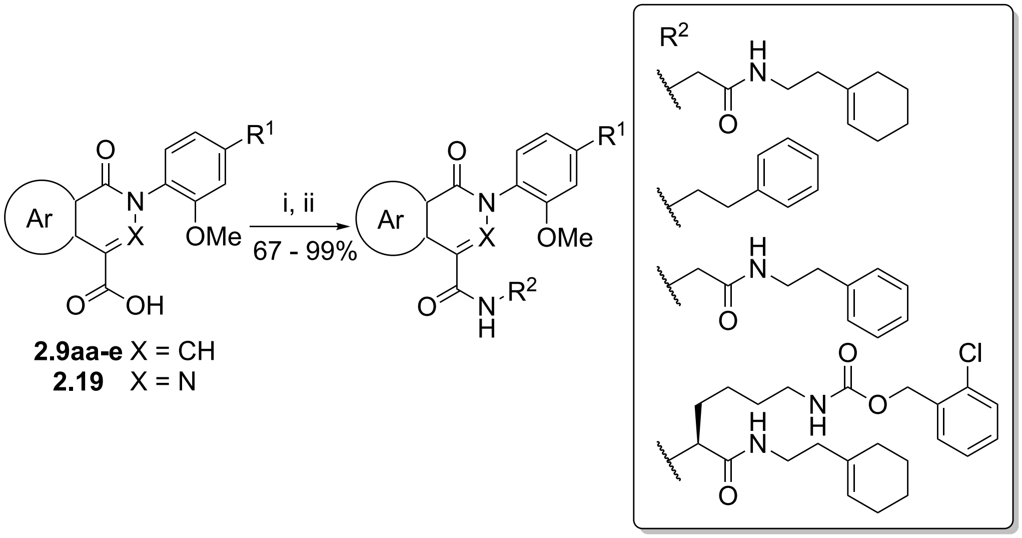
**Scheme 2-4**: Synthesis of 2-Amino Acetamide Analogues[a]



[a]*Reagents and conditions:* (i) 1.3 mol-equiv EDC, 1.7 mol-equiv HOBT, 5.5 mol-equiv DIPEA, THF, 23 °C, 16 h (ii) $H_2O$, 100 °C, 16 h (iii) 1.2 mol-equiv EDC, 1.2 mol-equiv HOBT, 1.5 mol-equiv DIPEA, $CH_2Cl_2$, 0 - 23 °C, 16 h (iv) ethylene glycol, 200 °C, 20 min.

Carboxylic acids **2.9aa-e** and **2.19** were converted to the corresponding acid chlorides under Vilsmeier conditions and then directly coupled with amines in the presence of triethylamine to afford analogues **2.30-2.32, 2.34**, and **2.36-2.42** in good yields (Scheme 2-5).[111] Analogue **2.42** was deprotected with TBAF to afforded analogue **2.35**.

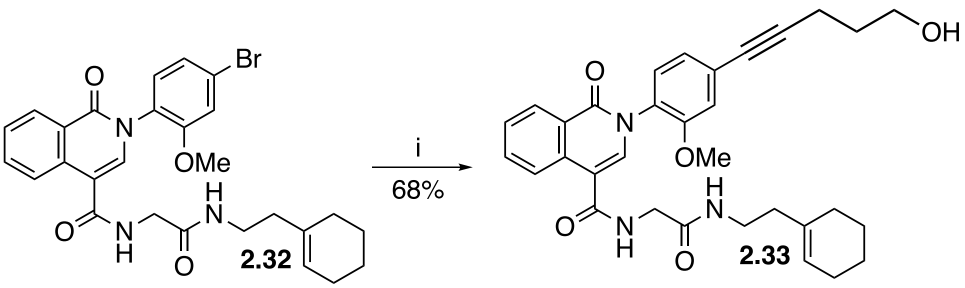
**Scheme 2-5**: Coupling of Carboxylic Acid and Amine Fragments[a]



[a]*Reagents and conditions:* (i) 1.5 mol-equiv oxalyl chloride, 10 mol % DMF, $CH_2Cl_2$, 0 °C, 2 h (ii) 1.2 mol-equiv $Et_3N$, CH2Cl2, 0-23 °C, 30 min.

To test the steric demands around the *N*-phenyl group the bromine substituent of isoquinolone **2.32** was converted to the corresponding ω-hydroxyalkyne using a palladium-catalyzed Sonogashira coupling (Scheme 2-6).

**Scheme 2-6**: Derivatization of Analogue **2.32** via Sonogashira Coupling[a]

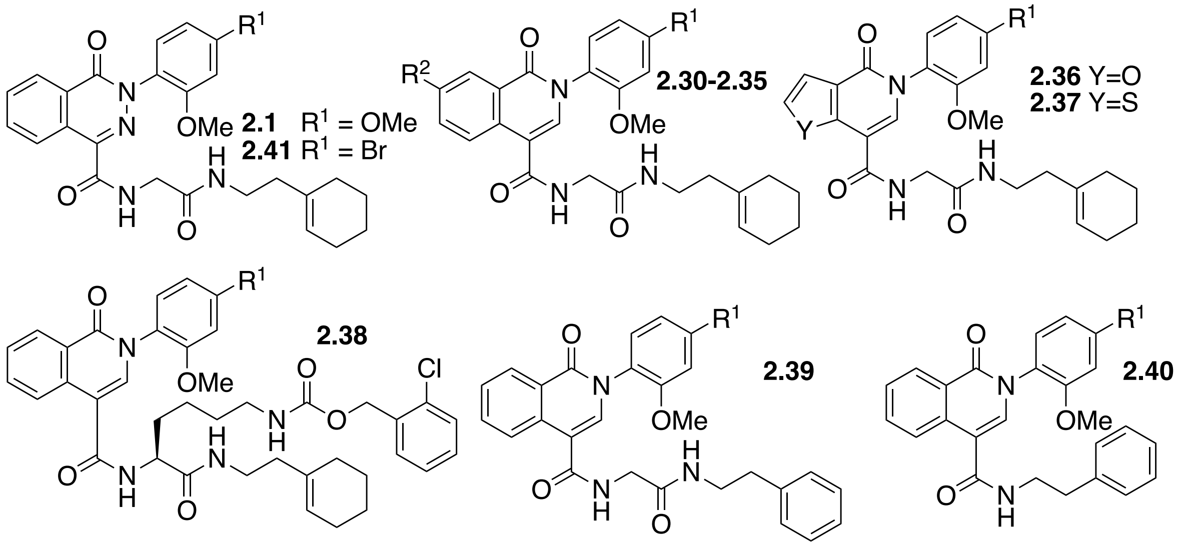


[a]*Reagents and conditions:* (i) 1.2 mol-equiv 4-pentyn-1-ol, 5 mol% $Pd(Cl)_2(PPh3)_2$, 5 mol% CuI, 3:2 DMF/$Et_3N$, 100 °C, 45 min.

## Structure Activity Relationships and Biological Evaluations

We determined the enhancement of antifungal activity for all of the new analogues against a susceptible strain of *C. albicans*, HLY4123, derived from the common laboratory strain CAI4. In the presence of a constant, non-lethal concentration of fluconazole (0.25 μg/mL), the analogues inhibited fungal cell growth in a dose-dependent fashion, from which $EC_{50}$ values were determined (Table 2-1).

**Table 2-1**: Antifungal Activities for Phthalazinone and Isoquinolone Analogues Against *C. albicans* in the Presence of Fluconazole[a]



| Compound | $R^1$ | $R^2$ | $EC_{50}$ (mM) |
|---|---|---|---|
| **2.1** | OMe | - | 0.015 ± 0.002 |
| **2.30** | OMe | H | 0.033 ± 0.005 |
| **2.31** | Me | H | 0.065 ± 0.02 |
| **2.32** | Br | H | 0.003 ± 0.001 |
| **2.33** | $C{\equiv}C(CH_2)_3OH$ | H | >100 |
| **2.34** | Br | Br | 0.003 ± 0.001 |
| **2.35** | Br | $C{\equiv}C(CH_2)_3OH$ | >100 |
| **2.36** | Br | - | >10 |
| **2.37** | Br | - | 0.230 ± 0.01 |
| **2.38** | Br | - | 0.023 ± 0.008 |
| **2.39** | Br | - | 0.020 ± 0.006 |
| **2.40** | Br | - | 0.220 ± 0.05 |
| **2.41** | Br | - | 0.001 ± 0.0003 |

[a] Cells incubated with 0.25 μg/mL fluconazole

Against HLY4123, phthalazinone **2.1** demonstrated promising activity ($EC_{50}$ 0.015 μM) in the presence of 0.25 μg/mL fluconazole. The isostere, isoquinolone **2.30**, exhibited a similar $EC_{50}$ of 0.033 μM suggesting that both the isoquinolone and phthalazinone cores are competent scaffolds for eliciting antifungal activity. Only one of five active compounds in the initial Lindquist-Schreiber screen possessed an isoquinolone core, so it was unclear which structural features most influenced antifungal activity. We set out to examine the isoquinolone core further by making modifications to the *N*-phenyl ring and benzo ring of the core, as well as the C4 carboxamide side chain.

First, we explored the effect of substitution at the *para* position of the *N*-phenyl ring ($R^1$). A decrease in activity was observed when methoxy (isoquinolone **2.30**) was replaced by a methyl group (isoquinolone **2.31**) at this position.

A bromine atom at the *para* position led to a surprising improvement in activity, with bromo-analogue **2.32** exhibiting ten-fold better activity than methoxy-analogue **2.30**, and also better activity than phthalazinone **2.1**. Substitution at $R^1$ with an alcohol-terminated alkyne abolishes activity, suggesting that larger or more rigid substituents are detrimental at this position.

After establishing the importance of the bromine substituent in isoquinolone **2.32**, we proceeded to evaluate the arene ring fused to the central heterocycle. Substitution with bromine at the C7 position of the benzo ring ($R^2$) resulted in activity of analogue **2.34** comparable to that of **2.32**. As with $R^1$, substitution at $R^2$ with an alcohol-terminated alkyne abolished activity. The sensitivity to substituents at $R^1$ and $R^2$ suggests that both positions play an important role in binding to the biological target.

Attempts to replace the benzo group with a smaller furano (analogue **2.36**) or thiopheno (analogue **2.37**) group resulted in a significant loss of potency. Even so, the thiophene analogue **2.37** showed significantly better activity than its electron-rich furan isostere **2.36**.

Neither contraction of the benzo ring, nor substitution improved activity. Therefore, we directed our attention to the C4 carboxamide side chain. Using analogue **2.32** again as a reference point, we evaluated the effect of substitution at the glycine α-carbon. The activity of ClCbz-lysine analogue **2.38** was only slightly attenuated relative to glycine analogue **2.32**, revealing some tolerance for bulky substituents at this position of the side chain. We then prepared phenethyl amide **2.39** to test the importance of the cyclohexenylethyl group. The activity of cyclohexenylethyl analogue **2.32** was superior to that of the aromatic phenethyl analogue **2.39**. Shortened analogue **2.40**, missing the glycine linker, was 70-fold less active than full-length analogue **2.32**.

Phthalazinone **2.41** was slightly more active than the isosteric bromophenyl isoquinolone **2.32**. With an $EC_{50}$ of 1 nM, bromophenyl phthalazinone **2.41** was the most active of all compounds tested.

Lead compound **2.1**, isoquinolone **2.32**, and phthalazinone **2.41** showed potent activity even at fluconazole concentrations of 0.05 μg/mL, five-fold lower than that used in Table 1. The $EC_{50}$ values were measured as 49, 24, and 7 nM, respectively.

Next, highly active bromophenyl analogues **2.32** and **2.41** were tested against five fluconazole-resistant clinical isolates of *C. albicans* (Table 2-2). Resistance in these isolates has been linked to multiple factors, including overexpression and point mutations in *ERG11*,[112] the gene encoding sterol 14α-demethylase. Point mutations in *ERG11* may contribute to fluconazole resistance by reducing binding affinity to the enzyme active site.[113] In some cases, the isolates also exhibit gain-of-function mutations in *UPC2*, a transcription factor regulating *ERG11* expression. The isolates also show varying levels of *CDR1*, *CDR2*, and *MDR1* expression, implicating efflux pumps as an important source of fluconazole resistance.

**Table 2-2**: Strains Used in this Chapter [a]

| Species | Strain | Relevant Characteristics or Genotype | | | | | Reference |
|---|---|---|---|---|---|---|---|
| *Candida albicans* | HLY4123 | *ERG3-GFP* | | | | | Premachandra[29] |
| *Candida glabrata* | BG2 | WT | | | | | Fidel[39,40] |
| *Cryptococcus neoformans var. grubii* | H99 | WT | | | | | Broad Institute[41] |
| | | | Expression (fold)[a] | | | | |
| *Candida albicans* | clinical isolate | Mutations | *ERG11* | *CDR1* | *CDR2* | *MDR1* | Flowers[37] |
| | 17 | *ERG11A114S,Y257H* | 1.6 | 2.7 | 23.9 | 0.8 | |
| | 26 | *ERG11G307S,G448R* | 1.0 | 0.9 | 0.5 | 2.6 | |
| | 33 | *ERG11F145L,E266D* | 1.7 | 16.2 | 1466 | 4.1 | |
| | 36 | *UPC2Y642F* | 12.6 | 6.8 | 201.5 | 1.5 | |
| | 45 | *ERG11E266D,G464S, UPC2A646V* | 3.5 | 4.8 | 147.8 | 15.5 | |

[a] Fold increase relative to expression levels averaged across three unrelated fluconazole-susceptible strains.

In dose-dependent broth microdilution assays, analogues **2.32** and **2.41** showed potent activities ($EC_{50}$ < 1 μM) against all resistant isolates. The $EC_{50}$ values were determined by varying the analogue concentration while keeping the fluconazole concentration fixed. The fluconazole $MIC_{50}$ was used, and was determined for each isolate individually. Compound **2.41** exhibited comparable or better activity than compound **2.32** against the isolates tested (Table 2-3). At present, the origin of fluconazole synergy is uncertain. Many factors contribute to fluconazole resistance in these isolates and we did not observe a correlation of compound activity with one specific resistance mechanism, such as levels of *CDR1* expression, among the isolates we tested here. Therefore, we are unable to attribute the synergistic effect of compounds **2.32** and **2.41** with fluconazole to any single variable. Investigation into the possible causes of fluconazole synergy is ongoing.

**Table 2-3**: Antifungal Activities of Analogues **2.32** and **2.41** against Resistant Isolates of *C. albicans* in the Presence of Fluconazole

| | | $EC_{50}$[a] | |
|---|---|---|---|
| Isolate | [Flu][b] | Cpd **2.32** | Cpd **2.41** |
| 17 | 12 | 74 ± 10 | 39 ± 3 |
| 26 | 32 | 11 ± 1 | 17 ± 2 |
| 33 | 64 | 371 ± 23 | 72 ± 6 |
| 36 | 64 | 32 ± 4 | 20 ± 2 |
| 45 | 96 | 170 ± 20 | 65 ± 15 |

[a] $EC_{50}$ (nM) expressed as arithmetic mean ± S.D. of three independent experiments. [b] Measured $MIC_{50}$ values for fluconazole alone; $EC_{50}$ values were deteremined at the fluconazole concentrations listed.

Compounds **2.1**, **2.32**, and **2.41** were also tested against *Candida. glabrata* BG2[114,115] and *C. neoformans var. grubii* H99[116] and showed no activity up to 30 mM at their $MIC_{50}$ values (128 and 4.0 mg/mL respectively). It is not clear why analogues **2.32** and **2.41** are active against *C. albicans* but not *C. glabrata* or *Cryptococcus neoformans*.

Isavuconazole is one of the newest azole drugs—approved by FDA in 2015. We tested the potency of compounds **2.32** and **2.41** against HLY4123 and the highly resistant CaCi-45 in the presence of isavuconazole (Table 2-4). Compounds **2.32** and **2.41** showed potent antifungal activity with isavuconazole at much lower concentrations than was required for fluconazole.

**Table 2-4:** Antifungal Activities[a] of Analogues **2.32** and **2.41** against *C. albicans* in the Presence of Isavuconazole

| Compound | Isolate<br>HLY4123<br>([isa] = 0.001 μg/mL)[b] | <br>CaCi-45<br>([isa] = 0.5 μg/mL isa.)[b] |
|---|---|---|
| **2.32** | 6 ± 0.2 | 110 ± 20 |
| **2.41** | 4 ± 0.2 | 13 ± 4 |

[a]$EC_{50}$ (nM) expressed as arithmetic mean ± S.D. of three independent experiments. [b]MIC values

At 30 μM or below, the analogues do not significantly affect fungal growth in the absence of azoles. Checkerboard assays revealed that compounds **2.32** and **2.41** are true synergizers with fluconazole, exhibiting fractional inhibitory concentration indices of less than 0.17 and 0.12, respectively. These indices are well below the upper-limit of 0.5 for pharmacological synergy.

All analogues were also tested for cytotoxicity against 3T3 mammalian fibroblasts. No cytotoxicity was observed up to 10 μM, indicating high selectivity for inhibiting *C. albicans* cell growth over that of mammalian fibroblasts.

In order to assess the potential for compounds **2.32** and **2.41** as drug leads, the physicochemical properties were calculated using FAF-Drugs3. The bromine atom is beneficial for activity but puts the molecular weight over 500. Both compounds exhibit favorable characteristics according to other criteria including tPSA, predicted bioavailability, predicted induction of phospholipidosis but were slightly lipophilic based on logD (Table 2-5)

**Table 2-5:** Calculated Physiochemical Properties of Analogues **2.32** and **2.41**

| Ligand | Desirable | **2.32** | **2.41** |
|---|---|---|---|
| MW | ≤460 | 538.4 | 539.4 |
| logP | -4 to 4.2 | 4.13 | 4.2 |
| logD | 0 to 3 | 3.69 | 3.67 |
| tPSA | ≤120 | 89.4 | 102.3 |
| Fraction $sp^3$ | 0.15-0.80 | 0.30 | 0.31 |
| Rotatable bonds | ≤10 | 8 | 8 |
| HBD | ≤5 | 2 | 2 |
| HBA | ≤9 | 7 | 8 |
| Oral Bioavail. |  | Good | Good |
| Phospholipidosis |  | NonInducer | NonInducer |

## Conclusion

In conclusion we have designed, synthesized, and tested phthalazinone and isoquinolone analogues of lead compound **2.1** (CID 22334057), which was previously shown to be active against *C. albicans* in the presence of fluconazole. Most of the analogues synthesized showed highly potent activities against a susceptible strain of *C. albicans*, HLY4123. Two compounds, isoquinolone analogue **2.32** and the other a phthalazinone analogue **2.41** were selected for further studies and shown to be active against clinical isolates with high resistance to fluconazole. Checkerboard assays confirmed compounds **2.32** and **2.41** as true synergizers of fluconazole. Also, compounds **2.32** and **2.41** were shown to increase the efficacy of the new azole drug, isavuconazole.

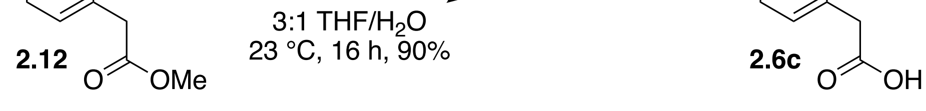
## Experimental Section

### General Experiment Procedure:

NMR spectral data were recorded at 25 °C using a Bruker 500 MHz spectrometer. The NMR data are reported as follows: chemical shifts in ppm are calibrated to tetramethylsilane (0 ppm), or residual solvents signals of $CDCl_3$ (7.26 ppm) or DMSO-*d*$_6$ (2.50 ppm), multiplicity (br = broad, app = apparent, s = singlet, d = doublet, t = triplet, q = quartet and m = multiplet), coupling constants (Hz), and integration. Analytical thin layer chromatography (TLC) was performed using EMD Reagents 0.25 mm silica gel 60–F plates. Silica gel chromatography was performed using Silicycle silica gel (40–63 µm). All reactions were carried out under an atmosphere of nitrogen. Reactions were carried out at ambient temperature unless otherwise indicated. Unless otherwise noted, all reagents were commercially obtained and, where appropriate, purified prior to use. Amines were distilled from calcium hydride. THF and $CH_2Cl_2$ were dried by filtration through alumina according to the procedure of Grubbs and coworkers.[117] The purity of compounds tested for antifungal activity was determined by reversed-phase high-performance liquid chromatography using a Waters Symmetry C8 column (4.6 x 5.50 mm). A mixture of $H_2O$ (with 0.1% TFA) and MeOH (50-85% MeOH) was used as eluent.

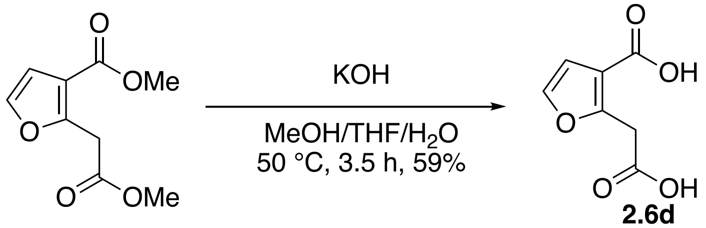
### Synthetic Procedures and Characterization:

5-(5-((*tert*-Butyldimethylsilyl)oxy)pent-1-yn-1-yl)-2-(carboxymethyl)benzoic acid (**2.6c**):



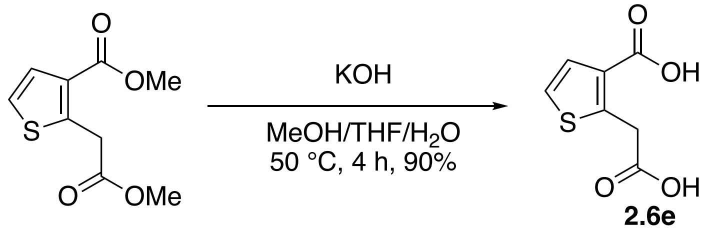
Carboxylic acid **2.6c** was synthesized from bis(methylester) **2.12** according to a procedure developed by Selwood.[118] A round bottom flask equipped with stir bar was charged with alkyne **2.12** (0.73 g, 1.4 mmol, 1.0 mol-equiv). THF (13 mL) and 3.9 mL of aqueous LiOH (1.4 M, 5.3 mmol, 3.8 mol-equiv) were added to the flask via syringe. The reaction progress was monitored by TLC, which indicated complete consumption of **2.12** after 16 h. Next, 40 mL of 1 N HCl and 65 mL of EtOAc were added to the reaction mixture. The mixture was extracted with EtOAc (3 x 100 mL). The combined organic layers were washed with brine, dried with $Na_2SO_4$, and concentrated *in vacuo* to yield dicarboxylic acid **2.6c** (0.62 g, 1.2 mmol, 90%) as a brown solid. $R_f$ = 0.5 (17:3 $CH_2Cl_2$/MeOH). $^1$H NMR (500 MHz, DMSO-$d_6$) δ 13.2–12.0 (br s, 2H), 7.82 (s, 1H), 7.66–7.61 (m, 4H), 7.46–7.36 (m, 7H), 7.30 (d, *J* = 7.8 Hz, 1H), 3.93 (s, 2H), 3.79 (t, *J* = 6.0 Hz, 2H), 2.57 (t, *J* = 7.0 Hz, 2H), 1.81 (quin, *J* = 6.6 Hz, 2H), 1.01 (s, 9H); $^{13}$C NMR (125 MHz, DMSO-$d_6$) δ 172.2, 167.6, 136.3, 135.0, 134.5, 134.1, 133.1, 133.0, 132.8, 129.9, 127.9, 121.9, 90.7, 79.7, 62.0, 30.9, 26.7, 18.8, 15.2; HRMS (ESI): *m/z* calculated for $C_{30}H_{31}O_5Si$ $[M-H]^-$ 499.1941, found 499.1953.

2-(Carboxymethyl)furan-3-carboxylic acid (**2.6d**):



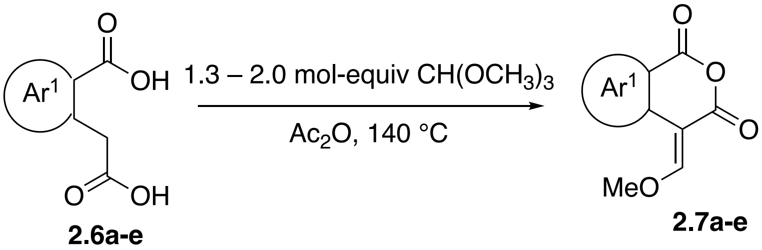
Dicarboxylic acid **2.6d** was synthesized as previously reported by Ozer *et. al.* with minor modification.[119] A 50 mL round bottom flask equipped with stir bar was charged with methanol (15 mL), THF (15 mL), $H_2O$ (1 mL), and KOH (0.80 g, 14 mmol, 2.8 mol-equiv), then stirred until the KOH was dissolved. To the solution was added the bis(methylester) starting material (1.0 g, 5.0 mmol, 1.0 mol-equiv), which was synthesized as previously reported.[120] The flask was sealed with a rubber septum and submerged in a 50 °C oil bath. After 2 h, a white precipitate was observed, and the reaction was allowed to stir for an additional 1.5 h. The flask was removed from the oil bath and cooled in an ice-water bath for 15 min. The precipitate was collected by filtration and washed with ethyl acetate (5 mL). The precipitate was dissolved in $H_2O$ (10 mL) and acidified to pH = 2 with 1 N HCl (aq). The mixture was extracted with ethyl acetate (2 x 50 mL). The combined organic layers were washed with brine (50 mL), dried over $Na_2SO_4$, and concentrated *in vacuo*. The product was further dried under high vacuum to obtain dicarboxylic acid **2.6d** as a white solid (0.50 g, 3.0 mmol, 59%). $^1H$ NMR (500 MHz, DMSO-$d_6$) δ 12.67 (br, 2H), 7.65 (d, $J$ = 2.0 Hz, 1H), 6.67 (d, $J$ = 2.0 Hz, 1H), 3.98 (s, 2H); $^{13}C$ NMR (125 MHz, DMSO-$d_6$) δ 169.9, 164.4, 154.8, 142.3, 115.5, 110.8, 33.3; HRMS (ESI): m/z calculated for $C_7H_6O_5Na$ $[M+Na]^+$ 193.0113, found 193.0111.

2-(Carboxymethyl)thiophene-3-carboxylic acid (**2.6e**):



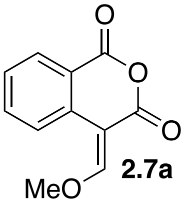
Dicarboxylic acid **2.6e** was synthesized by adapting a previously reported procedure by Ozer *et. al*. which obtained **2.6e** as a minor product. A 50 mL round bottom flask equipped with stir bar was charged with methanol (15 mL), THF (15 mL), $H_2O$ (1 mL), and KOH (0.80 g, 14 mmol, 2.8 mol-equiv), then stirred until the KOH dissolved. To the solution was added the bis(methylester) starting material (1.1 g, 5.0 mmol, 1.0 mol-equiv), which was synthesized as previously reported. The flask was sealed with a rubber septum and submerged in a 50 °C oil bath. After 4 h, the flask was cooled to room temperature. The reaction mixture was diluted with 50 mL $H_2O$ and acidified to pH = 2 with 1 N HCl (aq). The mixture was extracted with ethyl acetate (2 x 50 mL). The combined organic layers were washed with brine (50 mL), dried over $Na_2SO_4$, and concentrated *in vacuo*. The product was further dried under high vacuum to obtain dicarboxylic acid **2.6e** as a pale-yellow solid (0.84 g, 4.51 mmol, 90%). $^1$H NMR (500 MHz, DMSO-*d₆*) δ 12.57 (br, 2H), 7.41(d, *J* = 5.4 Hz, 1H), 7.34 (d, *J* = 5.4 Hz, 1H), 4.14 (s, 2H); $^{13}$C NMR (125 MHz, DMSO-$d_6$) δ 171.2, 164.3, 144.4, 130.2, 128.9, 123.9, 34.1; HRMS (ESI): m/z calculated for $C_7H_6O_4SNa$ $[M+Na]^+$ 208.9884, found 208.9882.

General procedure for the synthesis of enol ethers (**2.7a-e**):



Enol ethers **2.7a-e** were synthesized according to a procedure developed by Wolfbeis.[121] An oven–dried round bottom flask equipped with stir bar was charged with dicarboxylic acid (1.0 mol-equiv), trimethyl orthoformate (1.3 mol-equiv), and acetic anhydride (to obtain a 2.2 M solution of the dicarboxylic acid). The flask was fitted with a reflux condenser. The reaction mixture was heated at reflux and monitored by TLC for disappearance of the dicarboxylic acid. Upon consumption of the dicarboxylic acid, the reaction mixture was cooled to room temperature. The resulting solid was filtered using a Büchner funnel, washed with cold carbon tetrachloride and dried under vacuum to obtain the enol ether as a solid, which was used without further purification. The stereochemistry of the alkene in **2.7a** was determined by NOESY. No NOE signal was detected between the alkene proton and the proximal proton of the benzo ring. The stereochemistry of all other enol ethers was assigned by analogy to **2.7a**.

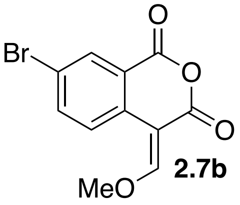
Example: (*E*)-4-(Methoxymethylene)isochromane-1,3-dione (**2.7a**):



**2.7a**

An oven–dried round bottom flask equipped with stir bar was charged with homophthalic acid (15 g, 83 mmol, 1.0 mol-equiv), trimethyl orthoformate (11 mL, 108 mmol, 1.3 mol-equiv), and acetic anhydride (38 mL). The flask was fitted with a reflux condenser. The reaction mixture was heated at reflux for 1.5 h and monitored by TLC for disappearance of homophthalic acid. Upon consumption of homophthalic acid, the reaction mixture was cooled to room temperature. The resulting solid was filtered with cold carbon tetrachloride (3 x 20 mL) in a Büchner funnel and dried under vacuum to obtain enol ether **2.7a** (11 g, 53 mmol, 64%) as a white solid. R$_f$ = 0.9 (1:9 MeOH/CH$_2$Cl$_2$). $^1$H NMR (500 MHz, CDCl$_3$) δ 8.23 – 8.21 (m, 2H), 8.05 (s, 1H), 7.67 (t, *J* = 7.9 Hz, 1H), 7.41 (t, *J* = 7.5, 1H), 4.26 (s, 1H).

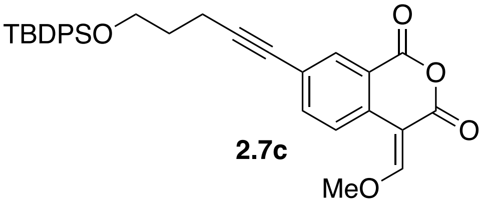
(*E*)-7-Bromo-4-(methoxymethylene)isochromane-1,3-dione (**2.7b**):



**2.7b**

Using the general procedure for enol ether synthesis outlined above, 5-Bromo-homophthalic acid (1.5 g, 5.8 mmol, 1.0 mol-equiv) was used to give enol ether **2.7b** (0.94 g, 3.3 mmol, 58%) as a white solid. R$_f$ = 0.2 (1:1 EtOAc/Hex). ($^1$H NMR (500 MHz, CDCl$_3$) δ 8.23 (s, 1H), 8.15 – 8.13 (m, 2H), 7.95 (dd, *J* = 8.7, 2.3 Hz, 1H), 4.30 (s, 3H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 169.5, 161.8, 160.2, 137.9, 132.8, 131.7, 127.5, 121.2, 119.5, 99.4, 65.4; HRMS (ESI): *m/z* calculated for $C_{11}H_7BrO_4Na$ [M+Na]$^+$ 304.9425, found 304.9418.

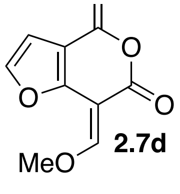
(*E*)-7-(5-((*tert*-Butyldiphenylsilyl)oxy)pent-1-yn-1-yl)-4(methoxymethylene)isochromane-1,3-dione (**2.7c**):



**2.7c**

Using the general procedure for enol ether synthesis outlined above, dicarboxylic acid **2.6c** (0.48 g, 0.95 mmol, 1.0 mol-equiv) was used to give enol ether **2.7c** (0.13 g, 0.24 mmol, 25%) as a white solid. R$_f$ = 0.9 (8.5:1.5 $CH_2Cl_2$/MeOH). $^1$H NMR (600 MHz, CDCl$_3$) δ 8.21 (s, 1H), 8.14 (d, *J* = 8.4 Hz, 1H), 8.04 (s, 1H), 7.69-7.67 (m, 4H), 7.59 (dd, *J* = 8.4, 1.8 Hz, 1H), 7.41-7.40 (m, 2H), 7.38-7.36 (m, 4H), 4.26 (s, 3H), 3.81 (t, *J* = 5.7 Hz, 2H), 2.59 (d, *J* = 7.2 Hz, 2H), 1.86 (d, *J* = 6.3 Hz, 2H), 1.07 (s, 9H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 167.1, 137.9, 135.6, 133.8, 133.6, 129.7, 127.7, 125.9, 123.8, 64.9, 62.3, 31.4, 26.9, 19.3, 16.1; HRMS (ESI): *m/z* calculated for $C_{32}H_{32}NaO_5SiNa$ [M+Na]$^+$ 547.1917, found 547.1911.

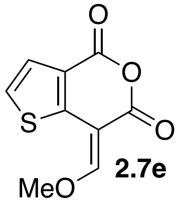
(*E*)-7-(Methoxymethylene)-4*H*-furo[3,2-*c*]pyran-4,6(7*H*)-dione (**2.7d**):



**2.7d**

An oven dried 5 mL round bottom flask equipped with a stir bar was charged with dicarboxylic acid **2.6d** (500 mg, 3.0 mmol, 1 mol-equiv), acetic anhydride (1.3 mL, 14.2 mmol, 5 mol-equiv), and trimethyl orthoformate (0.40 mL, 3.6 mmol, 1.2 mol-equiv). The flask was equipped with a reflux condenser, and submerged in a 110 °C oil bath. The reaction was monitored by TLC (95:5 $CH_2Cl_2$/MeOH). After 2 h, additional trimethyl orthoformate (0.3 mL) was added. After 2.5 h total of heating, the reaction was complete by TLC. The flask was removed from the oil bath and cooled to room temperature. The resulting precipitate was collected by filtration and washed with the cold carbon tetrachloride (20 mL). The precipitate was dried under high vacuum to obtain enol ether **2.7d** as a light brown solid (400 mg, 2.1 mmol, 69%). $^1$H NMR (500 MHz, $CDCl_3$) δ 7.86 (s, 1H), 7.51 (d, *J* = 2.0, 1H), 6.86 (d, *J* = 2.0, 1H), 4.25 (s, 3H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 165.0, 161.6, 156.8, 156.1, 144.8, 109.0, 108.3, 97.8, 65.1; HRMS (ESI): *m/z* calculated for $C_9H_6O_5Na$ $[M+Na]^+$ 217.0113, found 217.011.

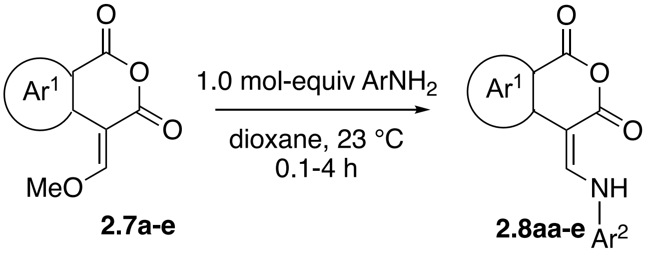
(*E*)-7-(Methoxymethylene)-4*H*-thieno[3,2-*c*]pyran-4,6(7*H*)-dione (**2.7e**):



**2.7e**

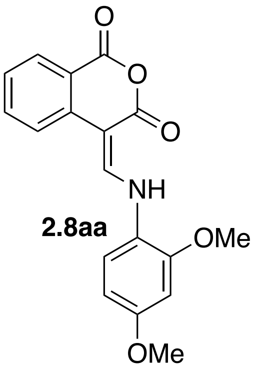
An oven dried 5 mL round bottom flask equipped with stir bar was charged with dicarboxylic acid **2.6e** (750 mg, 4.0 mmol, 1 mol-equiv), acetic anhydride (1.9 mL, 20 mmol, 5 mol-equiv), and trimethyl orthoformate (0.90 mL, 8.1 mmol, 2 mol-equiv). The flask was equipped with a reflux condenser, and the flask submerged in a 110 °C oil bath. After 2 h, the flask was removed from the oil bath and cooled to room temperature. The resulting precipitate was collected by filtration. The precipitate was dried under high vacuum to obtain enol ether **2.7e** as a purple solid (415 mg, 2.0 mmol, 49%) and used without further purification. $^1$H NMR (500 MHz, CDCl$_3$) δ 7.92 (s, 1H), 7.54 (d, *J* = 5.3, 1H), 7.33 (d, *J* = 5.4, 1H), 4.29 (s, 3H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 163.6, 161.9, 156.4, 144.3, 126.5, 125.7, 122.6, 102.1, 64.5; HRMS (ESI): *m/z* calculated for $C_9H_6O_4SNa$ [M+Na]$^+$ 232.9884, found 232.9879.

General procedure for the synthesis of enamines (**2.8aa-e**):



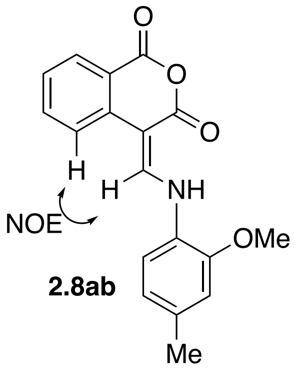
Enamines **2.8aa-e** were synthesized according to a procedure developed by Wolfbeis.[122] An oven–dried round bottom flask equipped with stir bar was charged with the enol ether starting material (1.0 mol-equiv). Next, dioxane was added to the reaction flask to obtain an enol ether concentration of 0.5 M. A separate oven–dried round bottom flask equipped with stir bar was charged with the substituted aniline (1.0 mol-equiv). Dioxane was added to the flask to obtain a 0.5 M solution of the aniline. The aniline solution was transferred via syringe to the flask containing the enol ether solution. The reaction was monitored until enol ether was no longer detected by TLC. The resulting solid was filtered in a Büchner funnel. The solid was washed with cold dioxane and dried under vacuum to obtain the enamine, which was used without further purification. The stereochemistry of the alkene in **2.8ab** was determined by NOESY, which indicated an NOE signal between the alkene proton and the proximal proton of the benzo ring. The stereochemistry of all other enamines was assigned by analogy to **2.8ab**.

Example: (*Z*)-4-(((2,4-Dimethoxyphenyl)amino)methylene)isochromane-1,3-dione (**2.8aa**):


**2.8aa**

An oven–dried round bottom flask equipped with stir bar was charged with enol ether **2.7a** (0.50 g, 2.5 mmol, 1.0 mol-equiv). Next, dioxane (5.0 mL) was added to the reaction flask. A separate oven–dried round bottom flask equipped with stir bar was charged with 2,4-dimethoxyaniline (0.38 g, 2.5 mmol, 1.0 mol-equiv) and dioxane (5.0 mL) to obtain a homogeneous solution. The solution was transferred to the flask containing **2.7a** via syringe. The reaction was monitored until **2.7a** was no longer detected by TLC (10 min). Over this period, a green precipitate formed, which was collected by filtration using a Büchner funnel. The solid was washed with cold dioxane (45 mL) to give enamine **2.8aa** (0.53 g, 1.6 mmol, 70%). $R_f$ = 0.4 (1:1:0.05 EtOAc/Hex/$Et_3N$). $^1$H NMR (500 MHz, $CDCl_3$) δ 11.64 (d, *J* = 13.2 Hz, 1H), 8.41 (d, J = 13.8 Hz, 1H), 8.20 (d, *J* = 8.1 Hz, 1H), 7.61 (t, *J* = 7.3 Hz, 1H), 7.55 (d, *J* = 8.1 Hz, 1H), 7.27–7.21 (m, 2H), 6.56–6.54 (m, 2H), 3.94 (s, 3H), 3.84 (s, 3H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 163.5, 161.9, 158.6, 150.7, 144.2, 137.5, 135.0, 131.0, 124.9, 121.9, 117.7, 117.3, 116.3, 104.8, 99.5, 91.1, 56.1, 55.7; HRMS (ESI): *m/z* calculated for $C_{18}H_{15}NO_5Na$ $[M+Na]^+$ 348.0848, found 348.0854.

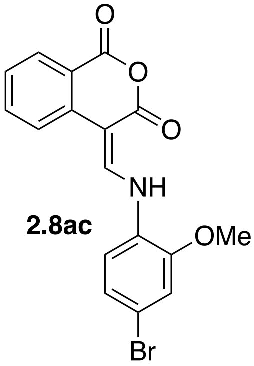
(*Z*)-4-(((2-Methoxy-4-methylphenyl)amino)methylene)isochromane-1,3-dione (**2.8ab**):



**2.8ab**

Using the general procedure for enamine formation outlined above, enol ether **2.7a** (0.50 g, 2.5 mmol, 1.0 mol-equiv) was used to give enamine **2.8ab** (0.27 g, 0.86 mmol, 35%) as a green solid. R$_f$ = 0.5 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$) δ 11.68 (d, *J* = 13.5 Hz, 1H), 8.46 (d, *J* = 13.6, 1H), 8.20 (d, *J* = 8.0 Hz, 1H), 7.62 (t, *J* = 8.1 Hz, 1H), 7.57 (d, *J* = 8.2 Hz, 1H), 7.26 (t, *J* = 7.6 Hz, 1H), 7.19 (d, *J* = 8.0 Hz, 1H), 6.84 (d, *J* = 8.3 Hz, 1H), 6.80 (s, 1H), 3.95 (s, 3H), 2.38 (s, 3H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 163.5, 161.8, 149.3, 143.9, 137.4, 136.5, 135.0, 131.1, 125.7, 125.0, 121.7, 117.8, 117.4, 114.9, 112.5, 91.5, 56.0, 21.5; HRMS (ESI): *m/z* calculated for $C_{18}H_{15}NO_4Na$ [M+Na]$^+$ 332.0899, found 348.0907.

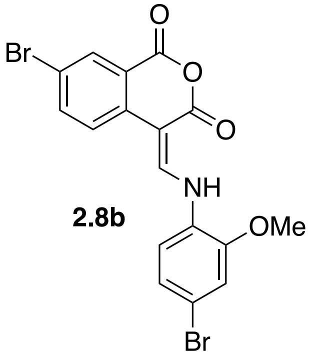
(*Z*)-4-(((4-Bromo-2-methoxyphenyl)amino)methylene)isochromane-1,3-dione (**2.8ac**):



**2.8ac**

Using the general procedure for enamine formation outlined above, enol ether **2.7a** (0.50 g, 2.5 mmol, 1.0 mol-equiv) was used to give enamine **2.8ac** (0.97 g, 2.6 mmol, 70%) as a green solid. R$_f$ = 0.5 (1:1:0.05 EtOAc/Hex/Et$_3$N). $^1$H NMR (500 MHz, CDCl$_3$) δ 11.65 (d, *J* = 13.3 Hz, 1H), 8.43 (d, *J* = 13.5 Hz, 1H), 8.21 (d, *J* = 8.4 Hz, 1H), 7.64 (td, *J* = 7.5 Hz, 1.3, 1H), 7.58 (d, *J* = 8.0 Hz, 1H) 7.30 (t, *J* = 7.8 Hz, 1H), 7.18 (br s, 2H), 7.11 (s, 1H), 3.98 (s, 3H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 163.5, 161.5, 149.8, 143.1, 136.9, 135.2, 131.2, 127.5, 125.5, 124.2, 118.4, 118.0, 117.6, 115.8, 115.2, 92.7, 56.4; HRMS (ESI): *m/z* calculated for $C_{17}H_{12}BrNO_4Na$ $[M+Na]^+$ 395.9847, found 395.9850.

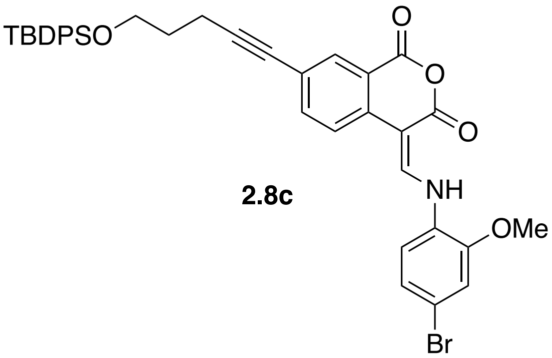
(*Z*)-7-Bromo-4-(((4-bromo-2-methoxyphenyl)amino)methylene)isochromane-1,3-dione (**2.8b**):



**2.8b**

Using the general procedure for enamine formation outlined above, enol ether **2.7b** (0.75 g, 2.6 mmol, 1.0 mol-equiv) was used to give enamine **2.8b** (1.1 g, 2.3 mmol, 90%) as an orange solid. $R_f$ = 0.5 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO-$d_6$) δ 11.70 (d, *J* = 13.2, 1H), 9.06 (d, *J* = 9.9, 1H), 8.17 – 7.88 (m, 4H), 7.37 – 7.27 (m, 2H), 3.97 (s, 3H); $^{13}$C NMR (125 MHz, DMSO-$d_6$) δ 162.8, 160.3, 149.1, 145.9, 137.4, 136.7, 131.3, 127.0, 123.8, 122.8, 118.7, 117.6, 117.4, 117.2, 115.1, 91.7, 56.9; HRMS (ESI): *m/z* calculated for $C_{17}H_{11}Br_2NO_4Na$ $[M+Na]^+$ 473.8953, found 473.8943.

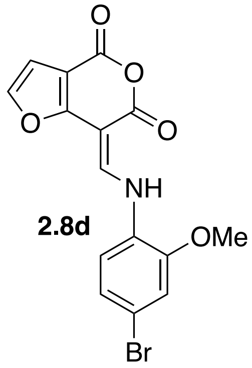
(*Z*)-4-(((4-Bromo-2-methoxyphenyl)amino)methylene)-7-(5-((*tert*-butyldiphenylsilyl)-oxy)pent-1-yn-1-yl)isochromane-1,3-dione (**4c**):



**2.8c**

Using the general procedure for enamine formation outlined above, enol ether **2.7c** (0.11 g, 0.20 mmol, 1.0 mol-equiv) was used to give enamine **2.8c** (0.08 g, 0.11 mmol, 57%) as a green solid. $R_f$ = 0.8 (3:7 EtOAc/Hex). $^1$H NMR (600 MHz, CDCl$_3$) δ 8.39 (d, *J* = 13.8, 1H), 8.19 (d, *J* = 1.2, 1H), 7.69 (d, *J* = 6.6, 4H), 7.56 (dd, *J* = 8.4, 1.8, 1H), 7.48–7.47 (m, 1H), 7.42–7.36 (m, 6H), 7.18 (s, 2H), 7.12 (s, 1H), 3.98 (s, 3H), 3.81 (t, *J* = 6.0, 2H), 2.59 (t, *J* = 7.2, 2H), 1.86 (t, *J* = 6.6, 2H), 1.07 (s, 9H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 160.9, 143.2, 137.8, 135.6, 134.1, 133.8, 129.7, 127.7, 127.4, 124.2, 121.5, 118.6, 118.0, 115.9, 115.3, 67.2, 62.4, 56.5, 31.5, 26.9, 19.3, 16.0; HRMS (ESI): *m/z* calculated for $C_{38}H_{36}BrNO_5SiNa$ [M+Na]$^+$ 716.1444, found 716.1458.

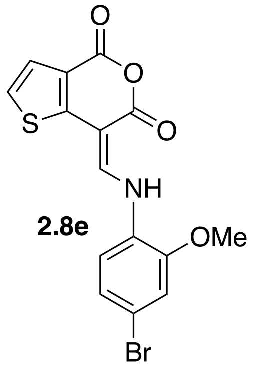
(*Z*)-7-(((4-Bromo-2-methoxyphenyl)amino)methylene)-4*H*-furo[3,2-*c*]pyran-4,6(7*H*)-dione (**2.8d**):



**2.8d**

An oven dried 5 mL round bottom flask equipped with stir bar was charged with enol ether **2.7d**, (200 mg, 1.0 mmol, 1 mol-equiv), 4-bromo-2-methoxyaniline (230 mg, 1.1 mmol, 1.1 mol-equiv), and dioxanes (4 mL). The reaction was stirred for 2 h at room temperature. The resulting yellow-brown precipitate was collected by filtration and washed with cold dioxanes (10 mL). The precipitate was further purified by silica gel chromatography using chloroform as eluent. Combined fractions were concentrated *in vacuo* and dried under high vacuum to obtain enamine **2.8d** as a bright yellow solid (290 mg, 0.80 mmol, 80%). $^1$H NMR (500 MHz, $CDCl_3$) δ 11.36 (d, *J* =13.7, 1H), 8.25 (d, *J* =13.8, 1H), 7.35 (d, *J* =7.4, 1H), 7.20 – 7.15 (m, 2H), 7.13 (s, 1H), 6.82 (d, *J* =2.1, 1H), 3.99 (s, 3H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 163.6, 160.8, 156.5, 149.8, 142.6, 141.3, 126.8, 124.3, 119.0, 115.8, 115.2, 108.4, 104.4, 89.8, 56.5; HRMS (ESI): *m/z* calculated for $C_{15}H_{10}BrNO_5Na$ $[M+Na]^+$ 385.9640, found 385.9646.

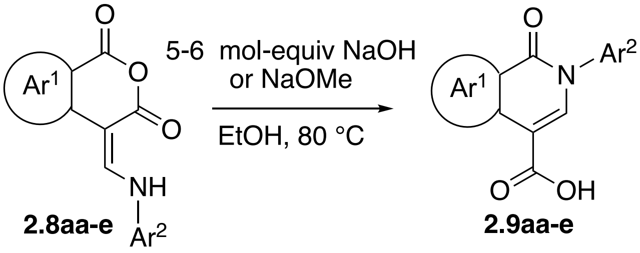
(*Z*)-7-(((4-Bromo-2-methoxyphenyl)amino)methylene)-4*H*-thieno[3,2-*c*]pyran-4,6(7*H*)-dione (**2.8e**):



**2.8e**

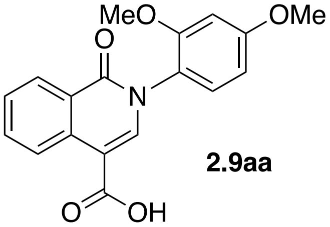
An oven dried 5 mL round bottom flask equipped with stir bar was charged with enol ether **2.7e**, (230 mg, 1.1 mmol, 1 mol-equiv), 4-bromo-2-methoxyaniline (245 mg, 1.2 mmol, 1.1 mol-equiv), and dioxanes (4.5 mL). The reaction was stirred for 2 h at room temperature. The resulting yellow-brown precipitate was collected by filtration, then purified by silica gel chromatography using chloroform as eluent. Combined column fractions were concentrated *in vacuo* and dried under high vacuum to obtain enamine **2.8e** as a bright yellow solid (250 mg, 0.65 mmol, 60%). $^1$H NMR (500 MHz, CDCl$_3$) δ 11.46 (d, *J* =13.3, 1 H), 8.07 (d , *J* =13.4, 1 H), 7.43 (d, *J* =5.3, 1H), 7.18 (dd, *J* =8.5, 1.7, 1H), 7.15 (d, *J* =8.5, 1H), 7.12 (d, *J* =1.7, 1H), 7.03 (d, *J* =5.3, 1H), 3.98 (s, 3H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ163.3, 156.5, 151.6, 149.8, 142.6, 126.9, 126.4, 124.2, 120.9, 120.1, 118.8, 115.8, 115.2, 93.9, 56.5; HRMS (ESI): *m/z* calculated for $C_{15}H_{10}BrNO_4SNa$ [M+Na]$^+$ 401.9412, found 401.9407.

General procedure for the synthesis of isoquinolone carboxylic acids (**2.9aa-e**):



Isoquinolone carboxylic acids **2.9aa-e** were synthesized according to a procedure developed by Patil *et. al.*[123] An oven–dried round bottom flask equipped with stir bar was charged with the corresponding enamine **2.8aa-e** (1.0 mol-equiv) and anhydrous NaOH (5.0 mol-equiv). Next, EtOH was added to the flask and the flask was fitted with a reflux condenser. The reaction mixture was heated at reflux for 1.5 h. The reaction was monitored by TLC for disappearance of the enamine. Upon consumption of the enamine, the reaction mixture was cooled to room temperature. Then, the resulting mixture was adjusted to a pH of 1-2 with 3 M HCl. The resulting solid was filtered with cold water in a Büchner funnel and dried under vacuum to obtain the isoquinolone carboxylic acids **2.9aa-e**.

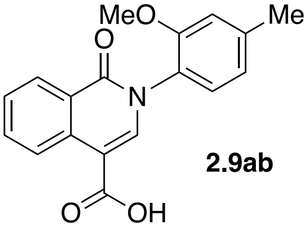
Example: 2-(2,4-Dimethoxyphenyl)-1-oxo-1,2-dihydroisoquinoline-4-carboxylic acid (**2.9aa**):



**2.9aa**

An oven–dried round bottom flask equipped with stir bar was charged with enamine **2.8aa** (1.5 g, 4.6 mmol, 1.0 mol-equiv) and anhydrous NaOH (0.91 g, 23 mmol, 5.0 mol-equiv). Next, EtOH (18 mL) was added to the flask and the flask was fitted with a reflux condenser. The reaction mixture was heated at reflux for 1.5 h. The reaction was monitored by TLC for disappearance of the enamine. Upon consumption of the enamine, the reaction mixture was cooled to room temperature. Then, the resulting mixture was adjusted to a pH of 1-2 with 3 M HCl. The resulting solid was filtered with cold water (3 x 20 mL) using a Büchner funnel to give isoquinolone carboxylic acid **2.9aa** (1.1 g, 3.5 mmol, 75%) as a purple solid. $R_f$ = 0.6 (4:1 $CH_2Cl_2$/MeOH). $^1$H NMR (125 MHz, DMSO-$d_6$) δ 12.86 (s, 1H), 8.86 (d, *J* = 8.4 Hz, 1H), 8.28 (d, *J* = 7.2 Hz, 1H), 8.02 (s, 1H), 7.85 (td, *J* = 7.7 Hz, 1.3, 1H), 7.60 (t, *J* = 7.7 Hz, 1H), 7.35 (d, *J* = 8.7 Hz, 1H), 6.78 (d, *J* = 2.6 Hz, 1H) 6.66 (d, *J* = 2.6 Hz, 1H), 6.64 (d, *J* = 2.7 Hz, 1H), 3.84 (s, 3H) 3.75 (s, 3H); $^{13}$C NMR (500 MHz, DMSO-$d_6$) δ 166.3, 161.0, 160.9, 155.1, 142.0, 134.5, 133.2, 129.3, 127.7, 127.2, 125.2, 125.2, 122.0, 105.7, 105.1, 99.4, 56.0, 55.6; HRMS (ESI): *m/z* calculated for $C_{18}H_{15}NO_5Na$ [M+Na]$^+$ 348.0848, found 348.0858.

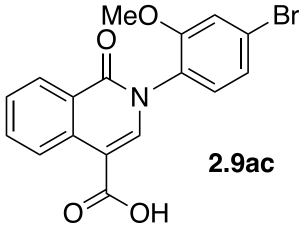
2-(2-Methoxy-4–methylphenyl)-1-oxo-1,2-dihydroisoquinoline-4-carboxylic acid (**2.9ab**):



**2.9ab**

Using the general procedure for the synthesis of isoquinolone carboxylic acids outlined above, enamine **2.8ab** (0.20 g, 0.81 mmol, 1.0 mol-equiv) was used to give isoquinolone carboxylic acid **2.9ab** (0.12 g, 0.38 mmol, 47%) as a brown solid. R*f* = 0.6 (9:1 $CH_2Cl_2$/MeOH). $^1H$ NMR (500 MHz, DMSO-*d*6) δ 12.86 (br s, 1H), 8.86 (d, *J* = 8.3 Hz, 1H), 8.29 (d, *J* = 8.0 Hz, 1H), 8.02 (s, 1H), 7.85 (t, *J* = 7.8 Hz, 1H), 7.61 (t, *J* = 7.6 Hz, 1H), 7.31 (d, *J* = 7.8 Hz, 1H), 7.08 (s, 1H), 6.91 (d, *J* = 7.9 Hz, 1H), 3.75 (s, 3H), 2.41 (s, 3H); $^{13}C$ NMR (125 MHz, DMSO-*d*6) δ 166.3, 160.9, 153.8, 141.7, 140.5, 134.5, 133.3, 128.4, 127.7, 127.3, 126.4, 125.2, 125.16, 121.1, 113.2, 105.7, 55.8, 21.3; HRMS (ESI): *m/z* calculated for $C_{18}H_{15}NO_4Na$ $[M+Na]^+$ 332.0899, found 348.0904.

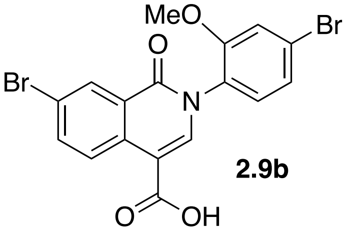
2-(4-Bromo-2-methoxyphenyl)-1-oxo-1,2-dihydroisoquinoline-4-carboxylic acid (**2.9ac**):



**2.9ac**

Using the general procedure for synthesis of isoquinolone carboxylic acids outlined above, enamine **2.8ac** (0.23 g, 0.61 mmol, 1.0 mol-equiv) was used to give isoquinolone carboxylic acid **2.9ac** (0.18 g, 0.47 mmol, 77% yield) as a brown solid. R*f* = 0.3 (9:1 $CH_2Cl_2$/MeOH). $^1H$ NMR (500 MHz, DMSO-*d*6) δ 12.90 (s, 1H), 8.85 (d, *J* = 8.4 Hz, 1H), 8.28 (d, *J* = 8.0 Hz, 1H), 8.06 (s, 1H), 7.86 (t, *J* = 7.7 Hz, 1H), 7.61 (t, *J* = 7.7 Hz, 1H), 7.47–7.43 (m, 2H), 7.31 (dd, *J* = 8.2, 1.6 Hz, 1H), 3.79 (s, 3H); $^{13}$C NMR (125 MHz, DMSO-*d*$_6$) δ 166.2, 160.7, 155.1, 141.1, 134.5, 133.4, 133.4, 130.6, 128.2, 127.7, 127.4, 125.3, 125.0, 123.6, 123.0, 116.0, 106.1, 56.6; HRMS (ESI): *m/z* calculated for $C_{17}H_{12}BrNO_4Na$ [M+Na]$^+$ 395.9847, found 395.9842.

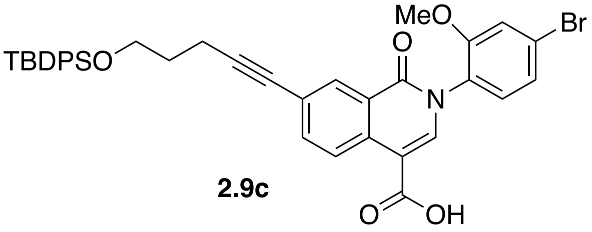
7-Bromo-2-(4-bromo-2-methoxyphenyl)-1-oxo-1,2-dihydroisoquinoline-4-carboxylic acid (**2.9b**):



**2.9b**

Using the general procedure for the synthesis of isoquinolone carboxylic acids outlined above, enamine **2.8b** (0.5 g, 1.1 mmol, 1.0 mol-equiv) was used to give isoquinolone carboxylic acid **2.9b** as a green solid. The crude material was purified by flash chromatography using $CH_2Cl_2$/MeOH to give **2.9b** (0.30 g, 0.38 mmol, 61%) as a green solid. R$_f$ = 0.1 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO-*d*$_6$) δ 8.87 (d, *J* = 8.5, 1H), 8.35 (s, 1H), 8.07 – 8.02 (m, 2H), 7.47 – 7.43 (m, 2H), 7.31 (d, *J* = 8.3, 1H) 3.79 (s, 3H); $^{13}$C NMR (125 MHz, DMSO-*d*$_6$) δ 166.5, 160.1, 155.5, 142.2, 136.8, 134.0, 131.0, 130.2, 128.33, 128.31, 127.2, 124.1, 123.7, 120.9, 116.5, 106.3, 57.0; HRMS (ESI): *m/z* calculated for $C_{17}H_{11}Br_2NO_4Na$ [M+Na]$^+$ 473.8953, found 473.8947.

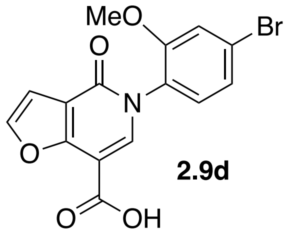
2-(4-Bromo-2-methoxyphenyl)-7-(5-((*tert*-butyldiphenylsilyl)oxy)pent-1-yn-1-yl)-1-oxo-1,2-dihydroisoquinoline-4-carboxylic acid (**2.9c**):



**2.9c**

Using the general procedure for the synthesis of isoquinolone carboxylic acids outlined above, enamine **2.8c** (57.5 mg, 0.08 mmol, 1.0 mol-equiv) was used to give isoquinolone carboxylic acid **2.9c** as a green solid. The crude material was purified by flash chromatography using $CH_2Cl_2$/MeOH to give **2.9c** (51.0 mg, 0.07 mmol, 92%) as a white solid. $R_f$ = 0.3 (3:7 EtOAc/Hex). $^1$H NMR (600 MHz, DMSO-*d*$_6$) δ 8.81 (d, *J* = 8.4, 1H), 8.18 (s, 1H), 8.06 (s, 1H), 7.77 (d, *J* = 8.4, 1H), 7.64–7.63 (m, 4H), 7.47–7.40 (m, 8H), 7.32 (d, *J* = 7.8, 1H), 3.82-3.80 (m, 5H), 2.61 (t, *J* = 6.6, 2H), 1.84 (t, *J* = 6.3, 2H), 1.01 (s, 9H); $^{13}$C NMR (125 MHz, DMSO-*d*$_6$) δ 166.6, 161.1, 155.5, 142.2, 135.5, 133.6, 131.0, 130.3, 128.4, 125.5, 124.1, 123.7, 116.5, 106.3, 62.5, 57.0, 31.3, 27.2, 19.3, 15.7; HRMS (ESI): *m/z* calculated for $C_{38}H_{36}BrNO_5SiNa$ [M+Na]$^+$ 716.1444, found 716.1438.

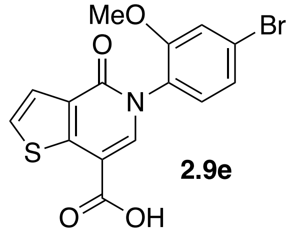
5-(4-Bromo-2-methoxyphenyl)-4-oxo-4,5-dihydrofuro[3,2-*c*]pyridine-7-carboxylic acid (**2.9d**):



**2.9d**

A 10 mL round bottom flask equipped with stir bar was charged with sodium methoxide (180 mg, 3.3 mmol, 6 mol-equiv), ethanol (6 mL) and enamine **2.8d** (200 mg, 0.55 mmol, 1 mol-equiv). The flask was equipped with a condenser and the mixture heated at refluxed for 21 h. The mixture was cooled to room temperature and dissolved in 10 mL $H_2O$. The mixture was adjusted to pH = 2 with 1 N HCl (aq). The resulting white precipitate was collected by filtration, washed with $H_2O$ (20 mL), and dried under high vacuum to obtain isoquinolone carboxylic acid **2.9d** as a white solid (160 mg, 0.44 mmol, 80%). $^1$H NMR (500 MHz, DMSO-$d_6$) δ 13.14 (br, 1H), 8.07 (d, *J* = 2.0, 1H), 8.01 (s, 1H), 7.46 (d, *J* =1.9, 1H), 7.39 (d, *J* =8.3, 1H), 7.30 (dd, *J* =8.3, 2.0, 1H), 7.06 (d, *J* =2.0, 1H), 3.79 (s, 3H); $^{13}$C NMR (125 MHz, DMSO-$d_6$) δ 163.2, 157.8, 156.1, 155.1, 145.5, 141.4, 130.6, 127.8, 123.4, 123.0, 115.8, 115.2, 107.1, 101.6, 56.4; HRMS (ESI): *m/z* calculated for $C_{15}H_{10}BrNO_5Na$ $[M+Na]^+$ 385.9640, found 385.9642.

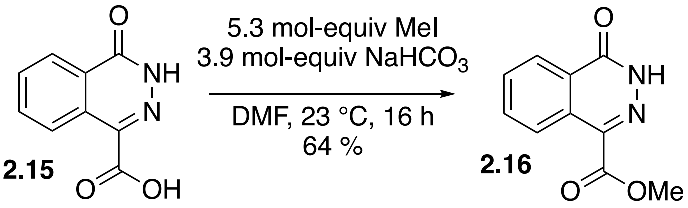
5-(4-Bromo-2-methoxyphenyl)-4-oxo-4,5-dihydrothieno[3,2-*c*]pyridine-7-carboxylic acid (**2.9e**):



**2.9e**

A 10 mL round bottom flask equipped with stir bar was charged with sodium methoxide (128 mg, 2.4 mmol, 6 mol-equiv), ethanol (5 mL) and enamine **2.8e** (150 mg, 0.39 mmol, 1 mol-equiv). The flask was equipped with a condenser and refluxed for 22 h. Then, an additional 3 mL of ethanol was added to replace ethanol lost to evaporation, and refluxed for an additional 6 h. The reaction mixture was cooled to room temperature and dissolved in 10 mL $H_2O$. The mixture was adjusted to pH = 2 with 1 N HCl (aq). The resulting light-brown precipitate was collected by filtration, washed with $H_2O$ (20 mL). The precipitate was purified by silica gel chromagraphy using EtOAc. Combined column fractions were concentrated *in vacuo* and dried under high vacuum to obtain isoquinolone carboxylic acid **2.9e** as a white solid (79 mg, 0.21 mmol, 54%). $^1$H NMR (500 MHz, DMSO-*d*$_6$) δ 13.35 (br, 1H), 8.06 (s, 1H), 7.78 (d, *J* = 5.4, 1H), 7.55 (d, *J* = 5.4, 1H), 7.46 (d, *J* = 1.9, 1H), 7.42 (d, *J* = 8.3, 1H), 7.31 (dd, *J* = 8.3, 1.9, 1H), 3.79 (s, 3H); $^{13}$C NMR (500 MHz, DMSO-*d*$_6$) δ 165.2, 157.3, 155.0, 145.0, 139.5, 130.5, 129.1, 128.8, 127.8, 123.9, 123.4, 123.0, 115.8, 106.0, 56.4; HRMS (ESI): *m/z* calculated for $C_{15}H_{10}BrNO_4SNa$ [M+Na]$^+$ 401.9412, found 401.9425.

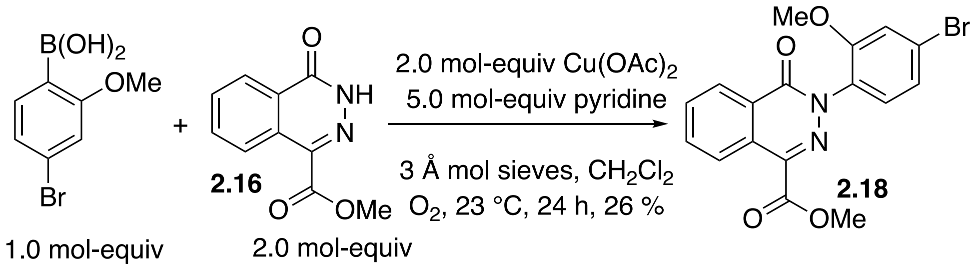
Methyl 4-oxo-3,4-dihydrophthalazine-1-carboxylate (**2.16**):



Phthalazinone methyl ester **2.16** was synthesized by adapting a procedure developed by Brittain and Wood.[124] An oven–dried round bottom flask equipped with stir bar was charged with pthalazinone carboxylic acid **2.15** (0.10 g, 0.53 mmol, 1.0 mol-equiv), $NaHCO_3$ (0.17 g, 2.1 mmol, 3.9 mol-equiv), DMF (2.3 mL), and methyl iodide (0.17 mL, 2.8 mmol, 5.3 mol-equiv). The reaction mixture was stirred for 16 h. Upon consumption of **2.15**, the reaction mixture was diluted with water (7 mL) and the resulting gray solid was collected by filtration using a Büchner funnel. The solid was washed with cold water (3 x 5 mL) to give phthalazinone methyl ester **2.16** (0.069 g, 0.34 mmol, 64%) as a gray solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.76 (d, *J* = 8.3 Hz, 1H), 8.47 (d, *J* = 7.9 Hz, 1H), 7.91 (t, *J* = 7.3 Hz, 1H), 7.83 (t, *J* = 7.6 Hz, 1H), 4.07 (s, 3H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ

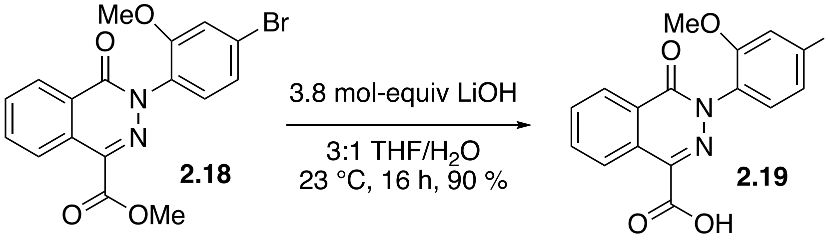
163.6, 160.4 136.3, 134.5, 132.2, 128.4, 128.0, 126.9, 126.8, 53.2; HRMS (ESI): *m/z* calculated for $C_{10}H_8N_2O_3Na$ [M+Na]$^+$ 227.0433, found 227.0440.

Methyl 3-(4-bromo-2-methoxyphenyl)-4-oxo-3,4-dihydrophthalazine-1-carboxylate (**2.18**):



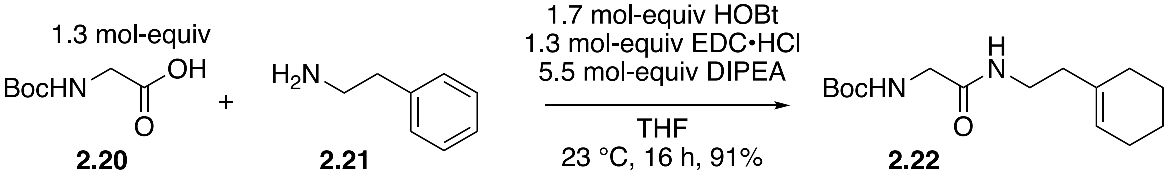
Phthalazinone methyl ester **2.18** was synthesized by adapting a procedure developed by Su and co-workers.[125] A flame-dried round bottom flask equipped stir bar was charged with amide **2.16** (0.050g, 0.24 mmol, 1.0 mol-equiv), 4-bromo-2-methoxyboronic acid (0.11 g, 0.49 mmol, 2.0 mol-equiv), $Cu(OAc)_2$ (0.089 g, 0.49 mmol, 2.0 mol-equiv), and 3 Å mol sieves (1.2 g). Next, $CH_2Cl_2$ (3.9 mL) and pyridine (0.10 mL, 1.2 mmol, 5.0 mol-equiv) were added to the reaction mixture. The flask was connected to a drying tube, which allowed atmospheric oxygen to enter the flask. After 24 h, the reaction mixture was filtered through celite and the filtrate concentrated *in vacuo*. The crude material was purified by flash chromatography (EtOAc/Hex) to afford phthalazinone methyl ester **2.18** (0.025 g, 0.064 mmol, 26%) as a white solid. $R_f$ = 0.6 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.66 (d, *J* = 8.3 Hz, 1H), 8.50 (d, *J* = 7.9 Hz, 1H), 7.91 (t, *J* = 7.9 Hz, 1H), 7.83 (t, *J* = 7.9, 1H), 7.28 – 7.22 (m, 2H) 7.19 (d, *J* = 1.6 Hz, 1H), 3.99 (s, 3H), 3.80 (s, 3H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 163.8, 159.1, 155.5, 136.4, 134.1, 132.2, 129.9, 129.6, 128.12, 128.06, 127.6, 126.6, 124.3, 124.1, 116.1, 56.5, 53.2; HRMS (ESI): *m/z* calculated for $C_{17}H_{13}BrN_2O_4$ [M]$^+$ 388.0059, found 388.0050.

3-(4-Bromo-2-methoxyphenyl)-4-oxo-3,4-dihydrophthalazine-1-carboxylic acid (**2.19**):



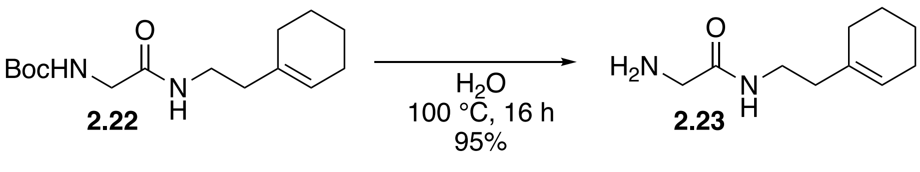
Carboxylic acid **2.19** was synthesized according to a procedure developed by Selwood.[126] A round bottom flask equipped with stir bar was charged with phthalazinone methyl ester **2.18** (0.024 g, 0.061 mmol, 1.0 mol-equiv). THF (0.60 mL) and 0.17 mL of aqueous LiOH (1.4 M. 0.23 mmol, 3.8 mol-equiv) was added to the flask via syringe. The reaction progress was monitored by TLC, which indicated complete consumption of **2.18** after stirring overnight. 1.7 mL of 1 N HCl and 2.8 mL of EtOAC were added to the reaction mixture. The mixture was extracted with EtOAc (3 x 7 mL). The combined organic layers were washed with brine and dried over $Na_2SO_4$. The solution was concentrated *in vacuo* to yield phthalazinone carboxylic acid **2.19** (0.021 g, 0.055 mmol, 90%) as a light yellow solid. $R_f$ = 0.3 (4:1 $CH_2Cl_2$/MeOH). $^1H$ NMR (500 MHz, DMSO-$d_6$) δ 8.55 (d, *J* = 8.2, 1H), 8.33 (d, *J* = 7.8, 1H), 8.03 (t, *J* = 8.1 Hz, 1H), 7.94 (t, *J* = 7.8, 1H), 7.46 – 7.43 (m, 2H), 7.31 (dd, *J* = 8.3,1.9, 1H), 3.78 (s, 3H); $^{13}C$ NMR (125 MHz, DMSO-$d_6$) δ 164.4, 158.1, 155.3, 137.4, 134.3, 132.4, 130.6, 129.6, 127.45, 127.39, 126.65, 126.58, 123.6, 123.0, 115.8, 56.4; HRMS (ESI): *m/z* calculated for $C_{16}H_{10}BrN_2O_4$ $[M-H]^-$ 372.9824, found 372.9834.

*tert*-Butyl (2-((2-(cyclohex-1-en-1-yl)ethyl)amino)-2-oxoethyl)carbamate (**2.22**):



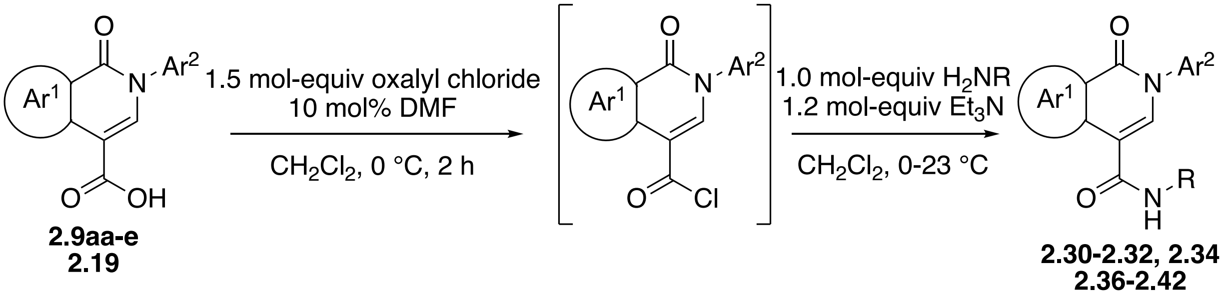
Amide **2.22** was synthesized according to a procedure developed by Awuah *et. al.*[127] An oven–dried round bottom flask equipped with stir bar was charged with Boc–glycine **2.20** (5.5 g, 31 mmol, 1.3 mol-equiv), HOBt (5.3 g, 40 mmol, 1.7 mol-equiv), and EDC•HCl (6.0 g, 31 mmol, 1.3 mol-equiv). THF (120 mL) was added to the reaction vessel followed by amine **2.21** (3.3 mL, 24 mmol, 1.0 mol-equiv). While stirring, DIPEA (23 mL, 130 mmol, 5.5 mol-equiv) was added to the reaction vessel via syringe. The reaction progress was monitored by TLC, which indicated complete consumption of **2.21** after 16 h. The reaction mixture was diluted with saturated $NH_4Cl$ and extracted with EtOAc (3 x 360 mL). The combined organic layers were washed with brine, dried with $Na_2SO_4$, and concentrated *in vacuo* to afford a white solid and purified with flash chromatography (EtOAc/Hex) to yield amide **2.22** (6.2 g, 22 mmol, 91%) as a white solid. $R_f$ = 0.8 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 6.18 (s, 1H), 5.44 (s, 1H), 5.25 (s, 1H), 3.74 (d, *J* = 5.7 Hz, 2H), 3.31 (q, *J* = 5.9 Hz, 2H), 2.10 (t, *J* = 6.8 Hz, 2H), 1.97 – 1.89 (m, 4H), 1.62 – 1.50 (m, 4H), 1.43 (s, 9H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 169.3, 156.1, 134.5, 123.8, 80.2, 44.4, 37.6, 37.2, 28.4, 28.0, 25.3, 22.9, 22.4; HRMS (ESI): *m/z* calculated for $C_{15}H_{26}N_2O_3Na$ $[M+Na]^+$ 305.1841, found 305.1833.

2-Amino-*N*-(2-(cyclohex-1-en-1-yl)ethyl)acetamide (**2.23**):



Amine **2.23** was synthesized by adapting a procedure developed by Zinelaabidine *et. al.*[128] A round bottom flask equipped with stir bar was charged with Boc–protected amine **2.22** (1.5 g, 5.3 mmol, 1.0 mol-equiv) and water (110 mL). The flask was fitted with a condenser and heated at reflux while monitoring for consumption of **2.22** by TLC. After 16 h, the reaction mixture was cooled to room temperature. The aqueous layer was extracted with $CH_2Cl_2$ (3 x 100 mL). The combined organic layers were concentrated *in vacuo* to give amine **2.23** (0.91 g, 5.0 mmol, 95%) as a yellow oil, which solidified upon storage at -20 °C. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.21 (br s, 1H), 5.48 (s, 1H), 3.38–3.34 (m, 4H), 2.15 (t, *J* = 6.7 Hz, 2H), 2.0–1.94 (m, 4H), 1.65–1.51 (m, 4H), 1.42 (br s, 2H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 172.5, 134.7, 123.4, 44.8, 37.7, 36.8, 28.0, 25.3, 22.9, 22.4; HRMS (ESI): *m/z* calculated for $C_{10}H_{18}N_2ONa$ $[M+Na]^+$ 205.1317, found 205.1312.

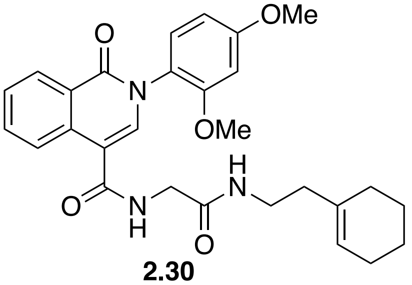
General procedure for synthesis of amides via acid chlorides (**2.30-2.32, 2.34, 2.36-2.42**):



Amides **2.30-2.32, 2.34** and **2.36-2.42** were synthesized by adapting procedures developed by Berghasuen *et. al.*[129] and Liu *et. al.*[130] A flame-dried round bottom flask equipped with stir bar was charged with the corresponding carboxylic acid **2.9aa-e** or **2.19** (1.0 mol-equiv). Next, $CH_2Cl_2$ was added to the flask and the reaction mixture was cooled to 0 °C in an ice-water bath. Oxalyl chloride (1.5 mol-equiv) and DMF (0.1 mol-equiv) were added sequentially. The reaction mixture was stirred at 0 °C for 2 h to obtain a clear solution. The solution was concentrated *in vacuo* to yield the corresponding acid chloride, which was used without purification.

A separate flame-dried round bottom flask equipped with stir bar was charged with the corresponding amine (1.0 mol-equiv), $CH_2Cl_2$, and $Et_3N$ (1.2 mol-equiv). The flask was cooled to 0 °C in an ice-water bath. Next, the acid chloride was dissolved in $CH_2Cl_2$ and transferred dropwise to the amine solution over 10 min. The reaction vessel was warmed to room temperature, and monitored by TLC for consumption of the acid chloride (0.5-2 h). The reaction mixture was washed with $K_2CO_3$ (aq, 10 wt%) and extracted with $CH_2Cl_2$. The combined organic layers were washed with brine, dried over $Na_2SO_4$, and concentrated *in vacuo.* The crude material was purified by flash chromatography to obtain the corresponding amide **2.30-2.32, 2.34** and **2.36-2.42**. Amide **2.35** was obtained by TBDPS-deprotection of the crude product, followed by purification using chromatography.

Example: *N*-(2-((2-(Cyclohex-1-en-1-yl)ethyl)amino)-2-oxoethyl)-2-(2,4-dimethoxy phenyl) -1-oxo-1,2-dihydroisoquinoline-4-carboxamide (**2.30**):

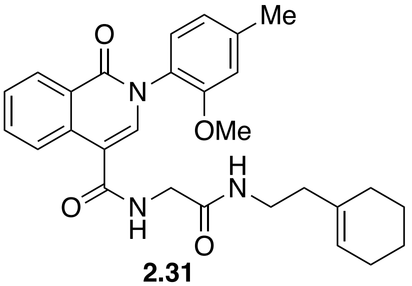


**2.30**

A flame-dried round bottom flask equipped with stir bar was charged with isoquinolone carboxylic acid **2.9aa** (0.050 g, 0.15 mmol, 1.0 mol-equiv) and $CH_2Cl_2$ (2.0 mL). The reaction mixture was cooled to 0 °C in an ice-water bath. Subsequently, oxalyl chloride (20 μL, 0.23 mmol, 1.5 mol-equiv) and DMF (1.2 μL, 0.015 mmol, 0.1 mol-equiv) were added sequentially. The reaction mixture was stirred at 0 °C for 2 h to obtain a clear solution. The solution was concentrated *in vacuo* to yield the acid chloride.

A separate flame-dried round bottom flask equipped with stir bar was charged with amine **2.23** (0.028 g, 0.15 mmol, 1.0 mol-equiv), $CH_2Cl_2$ (4.0 mL) and $Et_3N$ (0.025 mL, 0.18 mmol 1.2 mol-equiv). The flask was cooled to 0 °C in an ice-water bath. Next, the acid chloride was dissolved in $CH_2Cl_2$ (6.0 mL) and injected dropwise via syringe into the reaction mixture over 10 min. The reaction vessel was warmed to room temperature. The reaction mixture was stirred until the acid chloride was no longer detected by TLC (0.5 h). Upon consumption of the acid chloride, the reaction mixture was washed with $K_2CO_3$ (aq, 10 wt%) and extracted with $CH_2Cl_2$ (3 x 20 mL). The combined organic layers were washed with brine, dried over $Na_2SO_4$, and concentrated *in vacuo* to afford a purple solid. The solid was purified by flash chromatography ($CH_2Cl_2/Et_2O$) to afford amide **2.30** (0.074 g, 0.15 mmol, 98%) as a white solid. $R_f$ = 0.2 (6:4 EtOAc/Hex). $^1H$ NMR (500 MHz, $CDCl_3$) δ 8.47 (d, *J* = 7.9 Hz, 1H), 8.23 (d, *J* = 8.3 Hz, 1H), 7.72 (t, *J* = 7.5 Hz, 1H), 7.54 (t, *J* = 7.8 Hz, 1H), 7.51 (s, 1H), 7.17 (d, *J* = 8.7 Hz, 1H), 6.84 (t, *J* = 4.9 Hz, 1H), 6.57 (d, *J* = 2.6 Hz, 1H), 6.53 (dd, *J* = 9.6, 2.5 Hz, 1H), 6.06 (t, *J* = 5.3 Hz, 1H), 5.46 (s, 1H), 4.08 (d, *J* = 5.0 Hz, 2H), 3.85 (s, 3H), 3.75 (s, 3H), 3.56 (q, *J* = 5.6 Hz, 2H), 2.14 (t, *J* = 7.0 Hz, 2H), 1.96–1.90 (m, 4H), 1.62–1.50 (m, 4H); $^{13}C$ NMR (125 MHz, $CDCl_3$) δ 168.4, 168.8, 162.0, 161.4, 155.5, 135.7, 134.4, 134.2, 133.1, 129.3, 128.8, 127.6, 126.3, 124.8, 124.0, 122.4, 112.8, 104.7, 99.8, 56.0, 55.8, 43.6, 37.6, 37.5, 28.0, 25.3, 22.9, 22.4; HRMS (ESI): *m/z* calculated for $C_{28}H_{31}N_3O_5Na$ $[M+Na]^+$ 512.2161, found 512.2150; HPLC purity: 99.5%.

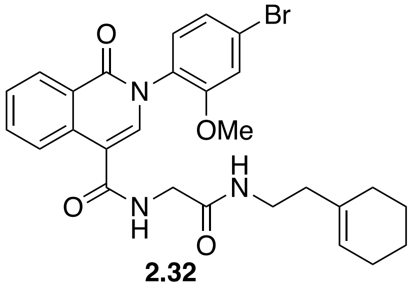
*N*-(2-((2-(Cyclohex-1-en-1-yl)ethyl)amino)-2-oxoethyl)-2-(2-methoxy-4-methylphenyl)-1-oxo-1,2-dihydroisoquinoline-4-carboxamide (**2.31**):



**2.31**

Isoquinolone carboxylic acid **2.9ab** (0.051 g, 0.17 mmol, 1.0 mol-equiv) and amine **2.23** (0.031 g, 0.17 mmol, 1.0 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material was purified by flash chromatography using $CH_2Cl_2/Et_2O$ to give amide **2.31** (0.075 g, 0.16 mmol, 96%) as a white solid. $R_f$ = 0.2 (6:4 EtOAc/Hex). $^1H$ NMR (500 MHz, $CDCl_3$) δ 8.47 (d, *J* = 8.0 Hz, 1H), 8.23 (d, *J* = 8.2 Hz, 1H), 7.72 (t, *J* = 7.1 Hz, 1H), 7.53 (t, *J* = 8.0 Hz, 1H), 7.51 (s, 1H), 7.13 (d, *J* = 8.3 Hz, 1H), 6.86 – 6.83 (m, 3H), 6.08 (br s, 1H), 5.45 (s, 1H), 4.07 (d, *J* =5.0 Hz, 2H), 3.77 (s, 3H), 3.35 (q, *J* = 6.7 Hz, 2H), 2.41 (s, 3H), 2.13 (t, *J* = 6.8 Hz, 2H), 1.97 – 1.86 (m, 4H), 1.62 – 1.49 (m, 4H); $^{13}C$ NMR (125 MHz, $CDCl_3$) δ 168.4, 166.8, 161.9, 154.3, 141.0, 135.5, 134.4, 134.2, 133.1, 128.8, 128.4, 127.6, 126.6, 126.3, 124.8, 124.0, 121.7, 113.1, 112.8, 55.9, 43.6, 37.6, 37.5, 28.0, 25.3, 22.9, 22.4, 21.9; HRMS (ESI): *m/z* calculated for $C_{28}H_{31}N_3O_4Na$ $[M+Na]^+$ 496.2212, found 496.2229; HPLC purity: 99.6%.

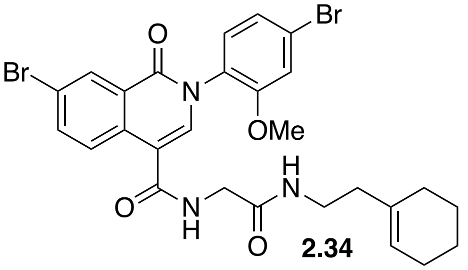
2-(4-Bromo-2-methoxyphenyl)-N-(2-((2-(cyclohex-1-en-1-yl)ethyl)amino)-2-oxoethyl)-1-oxo-1,2-dihydroisoquinoline-4-carboxamide (**2.32**):



**2.32**

Isoquinolone carboxylic acid **2.9ac** (0.059 g, 0.15 mmol, 1.0 mol-equiv) and amine **2.23** (0.029 g, 0.16 mmol, 1.0 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material was purified by flash chromatography using $CH_2Cl_2/Et_2O$ to give amide **2.32** (0.078 g, 0.14 mmol, 95%) as a white solid. R$_f$ = 0.2 (6:4 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$) δ 8.46 (d, *J* = 8.1 Hz, 1H), 8.22 (d, *J* = 8.1 Hz, 1H), 7.73 (t, *J* = 7.6 Hz, 1H), 7.55 (t, *J* = 7.5 Hz, 1H), 7.46 (s, 1H), 7.19–7.14 (m, 3H), 6.89 (br s, 1H), 6.05 (br s, 1H), 5.46 (s, 1H), 4.08 (d, *J* = 4.8 Hz, 2H), 3.79 (s, 3H), 3.35 (q, *J* = 6.2 Hz, 2H), 2.14 (t, *J* = 6.72 Hz, 2H), 1.97–1.90 (m, 4H), 1.62–1.50 (m, 4H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 168.4, 166.6, 161.6, 155.3, 134.7, 134.4, 134.2, 133.3, 130.1, 128.8, 128.3, 127.9, 126.2, 124.9, 124.2, 124.1, 123.9, 116.1, 113.3, 56.4, 43.5, 37.57, 37.56, 28.0, 25.3, 22.9, 22.4; HRMS (ESI): *m/z* calculated for $C_{27}H_{28}BrN_3O_4Na$ [M+Na]$^+$ 560.1161, found 560.1158; HPLC purity: 98.3%.

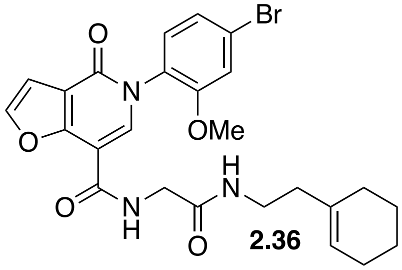
7-Bromo-2-(4-bromo-2-methoxyphenyl)-*N*-(2-((2-(cyclohex-1-en-1-yl)ethyl)amino)-2-oxoethyl)-1-oxo-1,2-dihydroisoquinoline-4-carboxamide (**2.34**):



**2.34**

Isoquinolone carboxylic acid **2.9b** (0.069 g, 0.15 mmol, 1.0 mol-equiv) and amine **2.23** (0.028 g, 0.15 mmol, 1.0 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material was purified by flash chromatography using CH$_2$Cl$_2$/MeOH to give amide **2.34** (0.092 g, 0.15 mmol, >99%) as a yellow solid. R$_f$ = 0.3 (6:4 EtOAc/Hex).$^1$H NMR (500 MHz, CDCl$_3$) δ 8.56 (d, *J* = 2.2 Hz, 1H), 8.15 (d, *J* = 8.8, 1H), 7.80 (dd, *J* = 8.8, 2.2 Hz, 1H), 7.48 (s, 1H), 7.21 – 7.14 (m, 3H), 6.93 (t, *J* = 4.5 Hz, 1H), 5.93 (br s, 1H), 5.46 (br s, 1H), 4.05 (d, *J* = 4.03 Hz, 2H), 3.79 (s, 3H), 3.35 (q, *J* = 5.5 Hz, 2H), 2.14 (t, *J* = 6.7 Hz, 2H) 1.98 – 1.90 (m, 4H) 1.64 – 1.52 (m, 4H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 168.2, 166.1, 160.3, 155.1, 136.3, 134.9, 134.2, 132.9, 131.2, 129.9, 127.9, 127.5, 126.8, 124.2, 124.10, 124.05, 122.9, 116.1, 112.6, 56.3, 43.3, 37.47, 37.46, 27.9, 25.3, 22.8, 22.3; HRMS (ESI): *m/z* calculated for $C_{27}H_{27}Br_2N_3O_4Na$ $[M+Na]^+$ 638.0266, found 638.0270; HPLC purity: 97.1%.

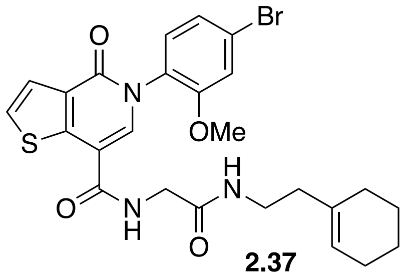
5-(4-Bromo-2-methoxyphenyl)-*N*-(2-((2-(cyclohex-1-en-1-yl)ethyl)amino)-2-oxoethyl)-4-oxo-4,5-dihydrofuro[3,2-*c*]pyridine-7-carboxamide (**2.36**):



**2.36**

Isoquinolone carboxylic acid **2.9d** (70 mg, 0.19 mmol, 1.0 mol-equiv) and amine **2.23** (83 mg, 0.45 mmol, 2.4 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material was purified by flash chromatography using ethyl acetate to obtain amide **2.36** (83 mg, 0.16 mmol, 82%) as a white solid. $^1H$ NMR (500 MHz, $CDCl_3$) δ 8.07 (s, 1H), 7.83 (t, *J* = 4.7 Hz, 1H), 7.68 (d, *J* = 1.8 Hz, 1H), 7.22 (dd, *J* = 8.3 Hz, 1.9 Hz, 1H), 7.20 (d, *J* = 2.0 Hz, 1H), 7.14 (d, *J* = 8.2 Hz, 1H), 6.06-5.90 (m, 1H), 5.44 (s, 1H), 4.16 (d, *J* = 5.1 Hz, 2H), 3.79 (s, 3H), 3.38 (q, *J* = 6.5 Hz, 2H), 2.15 (t, *J* = 6.7 Hz, 2H), 1.98-1.84 (m, 4H), 1.63-1.55 (m, 2H), 1.54-1.45 (m, 2H); $^{13}C$ NMR (125 MHz, $CDCl_3$) δ 168.3, 162.0, 158.7, 155.9, 155.2, 144.0, 140.7, 134.5, 130.0, 128.0, 124.3, 124.2, 124.1, 116.1, 115.6, 108.5, 103.5, 56.4, 43.8, 37.6, 37.5, 28.0, 25.3, 22.9, 22.4; HRMS (ESI): *m/z* calculated for $C_{25}H_{26}BrN_3O_5Na$ $[M+Na]^+$ 550.0953, found 550.0948; HPLC purity: 98.9%.

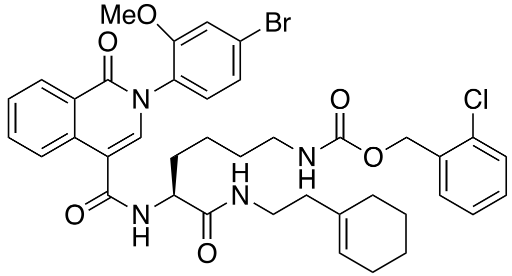
5-(4-Bromo-2-methoxyphenyl)-*N*-(2-((2-(cyclohex-1-en-1-yl)ethyl)amino)-2-oxoethyl)-4-oxo-4,5-dihydrothieno[3,2-*c*]pyridine-7-carboxamide (**2.37**):



**2.37**

Isoquinolone **2.9e** (70 mg, 0.19 mmol, 1.0 mol-equiv) and amine **2.23** (83 mg, 0.45 mmol, 2.4 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material was purified by flash chromatography using 50:50 EtOAc/Hex followed by 75:25 EtOAc/Hex to obtain amide **2.37** (83 mg, 0.16 mmol, 82%) as a white solid. $^1$H NMR (500 MHz, DMSO-*d*$_6$) δ 8.67 (t, *J* = 5.8 Hz, 1H), 8.33 (s, 1H), 7.84 (t, *J* = 5.6 Hz, 1H), 7.73 (d, *J* = 5.4 Hz, 1H), 7.51 (d, *J* = 5.5 Hz, 1H), 7.50 (d, *J* = 2.0 Hz, 1H), 7.42 (d, *J* = 8.3 Hz, 1H), 7.35 (dd, *J* = 8.3 Hz, 1.9 Hz, 1H), 5.42-5.31 (br, 1H), 3.86-3.74 (m, 5H), 3.12 (q, *J* = 6.8 Hz, 2H), 2.05-1.96 (t, *J* = 7.3 Hz , 2H), 1.93-1.83 (m, 4H), 1.56-1.49 (m, 2H), 1.49-1.42 (m, 2H); $^{13}$C NMR (125 MHz, DMSO-*d*$_6$) δ 168.5, 163.9, 157.2, 155.3, 145.2, 135.7, 134.8, 130.7, 129.4, 129.3, 128.5, 123.6, 123.5, 123.0, 122.0, 115.8, 108.7, 56.5, 42.4, 37.5, 37.2, 27.7, 24.6, 22.4, 21.9. HRMS (ESI): *m/z* calculated for $C_{25}H_{26}BrN_3O_4SNa$ [M+Na]$^+$ 566.0725, found 566.0711; HPLC purity: 99.3%.

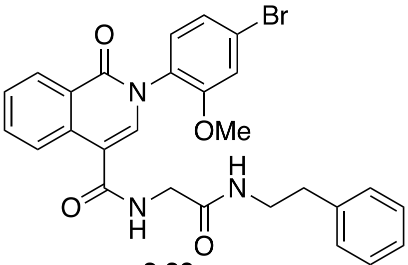
2-Chlorobenzyl (*S*)-(5-(2-(4-bromo-2-methoxyphenyl)-1-oxo-1,2-dihydroisoquinoline-4-carboxamido)-6–((2–(cyclohex-1–en-1-yl)ethyl)amino)-6-oxohexyl)carbamate (**2.38**):



**2.38**

Isoquinolone carboxylic acid **2.9ac** (0.058 g, 0.16 mmol, 1.0 mol-equiv) and amine **2.29** (0.068 g, 0.16 mmol, 1.0 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material was purified by flash chromatography using EtOAc/Hex to give amide **2.38** (0.097 g, 0.12 mmol, 80%) as a white solid. R$_f$ = 0.6 (6:4 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$) δ 8.44 (d, *J* = 7.9 Hz, 1H), 8.17 (d, *J* = 8.1 Hz, 1H), 7.72 (t, *J* = 7.3 Hz, 1H), 7.53 (t, *J* =7.7 Hz, 1H), 7.41 (s, 1H), 7.35–7.32 (m, 2H), 7.26–7.13 (m, 5H), 6.80 (d, *J* = 7.8 Hz, 1H), 6.15 (t, *J* = 5.6 Hz, 1H), 5.44 (s, 1H), 5.12 (q, *J* = 9.3 Hz, 2H), 4.95 (s, *J* = 5.1 Hz, 1H), 4.57 (q, *J* = 6.5 Hz, 1H), 3.78 (s, 3H), 3.42–3.34 (m, 1H), 3.31–3.25 (m, 1H), 3.20 (q, *J* = 6.5 Hz, 2H), 2.13 (t, *J* = 6.5 Hz, 2H), 1.98–1.86 (m, 5H), 1.88–1.70 (m, 1H), 1.62–1.39 (m, 8H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 171.3, 166.3, 161.5, 156.5, 155.3, 134.43, 134.37, 134.27, 134.17, 133.6, 133.3, 130.1, 129.8, 129.6, 129.5, 128.8, 128.3, 127.8, 127.0, 126.1, 124.8, 124.2, 124.0, 116.1, 113.6, 64.1, 56.3, 53.4, 40.5, 37.6, 37.5, 32.7, 29.7, 28.0, 25.4, 22.9, 22.7, 22.4; HRMS (ESI): *m/z* calculated for $C_{39}H_{42}BrClN_4O_6Na$ [M+Na]$^+$ 799.1874, found 799.1873; HPLC purity: 98.1%.

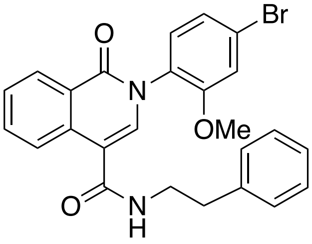
2-(4-Bromo-2-methoxyphenyl)-1-oxo-N-(2-oxo-2-(phenethylamino)ethyl)-1,2-dihydroisoquinoline-4-carboxamide (**2.39**):



**2.39**

Isoquinolone carboxylic acid **2.9ac** (0.059 g, 0.16 mmol, 1.0 mol-equiv) and amine **2.26** (0.029 g, 0.16 mmol, 1.0 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material was purified by flash chromatography using EtOAc/Hex to give amide **2.39** (0.087 g, 0.16 mmol, >99%) as a white solid. R$_f$ = 0.3 (6:4 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO-$d_6$) δ 8.58 (t, *J* = 5.6 Hz, 1H), 8.33 (d, *J* = 8.8 Hz, 1H), 8.27 (d, *J* = 8.1 Hz, 1H), 8.05 (t, *J* = 5.5 Hz, 1H), 7.81 (t, *J* = 8.1 Hz, 1H), 7.71 (s, 1H), 7.60 (t, *J* = 7.5 Hz, 1H), 7.48 (d, *J* = 1.6 Hz, 1H), 7.40 (d, *J* = 8.2 Hz, 1H), 7.35 (dd, *J* = 8.2 Hz, 1.8, 1H), 7.26 (t, *J* = 7.6 Hz, 2H), 7.22–7.16 (m, 3H), 3.82–3.78 (m, 5H), 3.3 (q, *J* = 7.0 Hz, 2H), 2.72 (t, *J* = 7.6 Hz, 2H); $^{13}$C NMR (125 MHz, DMSO-$d_6$) δ 168.8, 165.8, 160.2, 155.4, 139.4, 135.3, 134.6, 133.0, 130.6, 128.7, 128.3, 127.5, 127.4, 126.1, 125.3, 125.1, 123.6, 122.8, 115.9, 112.0, 79.2, 56.5, 42.4, 40.3, 35.2 HRMS (ESI): *m/z* calculated for $C_{27}H_{24}BrN_3O_4Na$ [M+Na]$^+$ 556.0848, found 556.0844; HPLC purity: 98.0%.

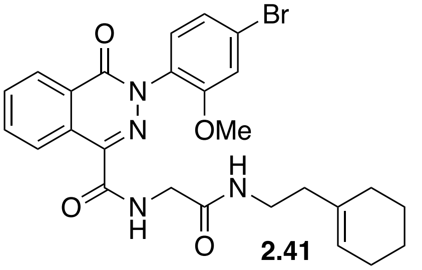
2-(4-Bromo-2-methoxyphenyl)-1-oxo-N-phenethyl-1,2-dihydroisoquinoline-4-carboxamide (**2.40**):



**2.40**

Isoquinolone carboxylic acid **2.9ac** (0.058 g, 0.16 mmol, 1.0 mol-equiv) and phenethylamine (0.019 g, 0.16 mmol, 1.0 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material was purified by flash chromatography using EtOAc/Hex to give amide **2.40** (0.067 g, 0.14 mmol, 92%) as a white solid. R$_f$ = 0.8 (6:4 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.42 (d, *J* = 8.1, 1H), 8.0 (d, *J* = 8.2, 1H), 7.7 (t, *J* = 7.3, 1H), 7.52 (t, *J* = 7.8, 1H), 7.30–7.25 (m, 3H), 7.25–7.15 (m, 5H), 7.11 (d, *J* = 8.3, 1H), 5.94 (t, *J* = 5.5, 1H), 3.76–3.70 (m, 5H), 2.95 (t, 6.9, 2H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 166.3, 161.4, 155.2, 138.7, 134.1, 133.9, 133.2, 130.0, 128.9, 128.8, 128.6, 128.3, 127.7, 126.7, 126.1, 124.7, 124.1, 123.8, 116.0, 114.4, 56.2, 41.0, 35.5; HRMS (ESI): *m/z* calculated for $C_{25}H_{21}BrN_2O_3Na$ [M+Na]$^+$ 499.0633, found 499.0637; HPLC purity: 98.9%.

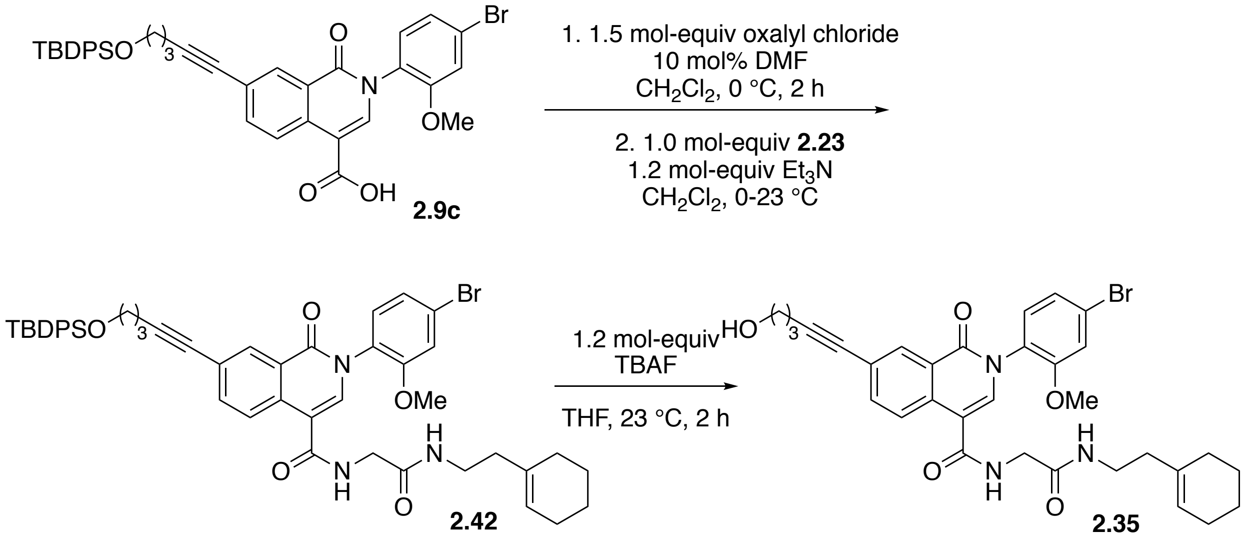
3-(4-Bromo-2-methoxyphenyl)-*N*-(2-((2-(cyclohex-1-en-1-yl)ethyl)amino)-2-oxoethyl)-4-oxo-3,4-dihydrophthalazine-1-carboxamide (**2.41**):



**2.41**

Phthalazinone carboxylic acid **2.19** (0.021 g, 0.055 mmol, 1.0 mol-equiv) and amine **2.23** (0.0099 g, 0.055 mmol, 1.0 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material was purified by flash chromatography using $CH_2Cl_2/Et_2O$ to give amide **2.41** (0.020 g, 0.047 mmol, 67%) as a white solid. R$_f$ = 0.5 (4:1 EtOAc/Hex).$^1$H NMR (500 MHz, CDCl$_3$) δ 9.13 (d, *J* = 8.2 Hz, 1H), 8.49 (d, *J* = 7.8, 1H), 7.89 (t, *J* = 8.1 Hz, 1H), 7.83 (t, *J* = 7.8 Hz, 1H), 7.74 (t, *J* = 7.0 Hz, 1H), 7.26 – 7.21 (m, 3H), 6.00 (br s, 1H), 5.42 (br s, 1H), 4.05 (d, *J* = 5.7 Hz, 2H), 3.81 (s, 3H), 3.34 (q, *J* = 5.9 Hz, 2H), 2.12 (t, *J* = 6.7 Hz, 2H), 1.88 – 1.87 (m, 4H), 1.57 – 1.56 (m, 2H), 1.48 – 1.47 (m, 2H); $^{13}$C NMR (125 MHz, CDCl$_3$) δ 168.1, 163.8, 159.1, 155.4, 136.5, 134.4, 134.0, 132.2, 129.7, 129.4, 128.3, 128.0, 127.6, 127.4, 124.12, 124.10; 124.0, 116.0, 56.3, 43.4, 37.5, 37.2, 27.8, 25.2, 22.8, 22.3; HRMS (ESI): *m/z* calculated for $C_{26}H_{27}BrN_4O_4Na$ [M+Na]$^+$ 561.1113, found 561.1127; HPLC purity: 97.8%.

2-(4-Bromo-2-methoxyphenyl)-*N*-(2-((2-(cyclohex-1-en-1-yl)ethyl)amino)-2oxoethyl)-7-(5-hydroxypent-1-yn-1-yl)-1-oxo-1,2-dihydroisoquinoline-4-carboxamide (**2.35**):

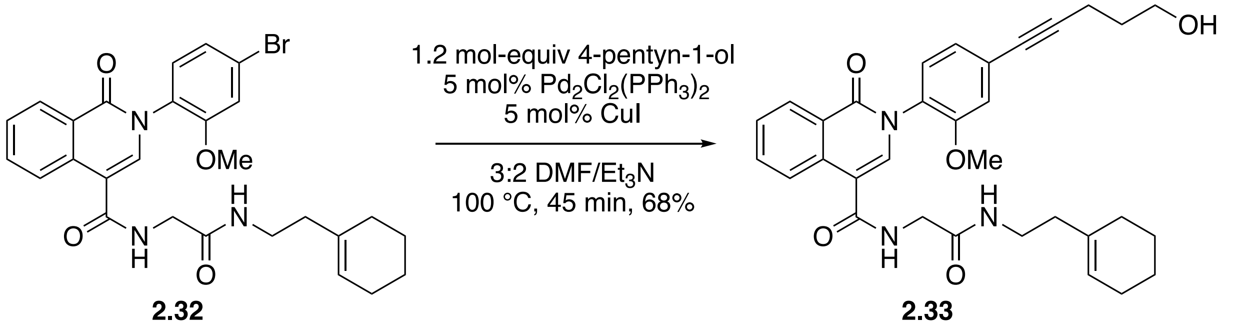


Isoquinolone carboxylic acid **2.9c** (0.045 g, 0.053 mmol, 1.0 mol-equiv) and amine **2.23** (0.0095 g, 0.053 mmol, 1.0 mol-equiv) were reacted following the general procedure for the synthesis of amides outlined above. The crude material **2.42** was used in subsequent TBDPS deprotection without further purification.

A flame–dried round bottom flask equipped with stir bar was charged with TBDPS–protected alcohol **2.42** (0.045 g, 0.053 mmol, 1.0 mol-equiv) and THF (0.2 mL, 0.3 M with respect to **2.42**). Next, TBAF (0.06 mL, 0.06 mmol, 1.2 mol-equiv) was added and the reaction mixture was stirred at 23 °C for 2 h. The resulting solution was clear. Upon consumption of **2.42**, the reaction mixture was concentrated *in vacuo* to yield a yellow oil. The crude material was purified by flash chromatography (Hex/EtOAc) to afford alcohol **2.35** (0.018 g, 0.03 mmol, 56%) as a white solid. $R_f$ = 0.7 (7:3 EtOAc/Hex). $^1$H NMR (600 MHz, $CDCl_3$) δ 8.44 (d, *J* = 1.8 Hz, 1H), 8.14 (d, *J* = 9.0 Hz, 1H), 7.67 (dd, *J* = 8.4, 1.8 Hz, 1H), 7.44 (s, 1H), 7.19-7.14 (m, 3H), 6.91-6.90 (m, 1H), 6.01-5.99 (m, 1H), 5.46 (s, 1H), 4.06 (d, *J*

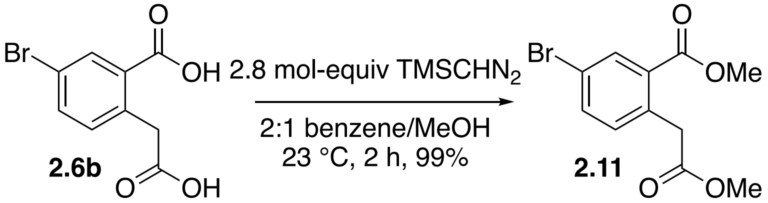
= 4.8 Hz, 2H), 3.82 (t, *J* = 6.0 Hz, 2H), 3.78 (s, 3H), 3.36-3.33 (m, 2H), 2.57 (t, *J* = 7.2 Hz, 2H), 2.18 (s, 1H), 2.14 (t, *J* = 6.6 Hz, 2H), 1.97–1.96 (m, 2H), 1.90–1.86 (m, 4H), 1.62–1.60 (m, 2H), 1.55–1.52 (m, 2H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 168.3, 166.3, 160.8, 155.1, 135.9, 134.9, 134.3, 133.1, 131.6, 129.9, 128.0, 125.9, 124.9, 124.2, 124.0, 123.9, 123.5, 116.1, 112.9, 91.6, 80.4, 61.6, 56.3, 53.8, 43.4, 37.5, 31.8, 31.3, 29.8, 29.3, 27.9, 25.2, 22.8, 22.3, 16.1; HRMS (ESI): *m/z* calculated for $C_{32}H_{34}BrN_3O_5Na$ $[M+Na]^+$ 642.1580, found 642.1574; HPLC purity: 98.4%

*N*-(2-((2-(Cyclohex-1-en-1-yl)ethyl)amino)-2-oxoethyl)-2-(4-(5-hydroxypent-1-yn-1-yl)-2-methoxyphenyl)-1-oxo-1,2-dihydroisoquinoline-4-carboxamide (**2.33**):



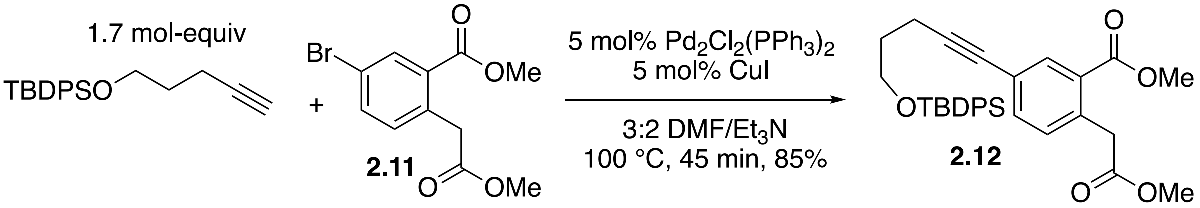
Alkynylated derivative **2.33** was synthesized by adapting a procedure developed by Reddy *et. al.*[131] A flame–dried round bottom flask was charged with aryl bromide **2.32** (0.051 g, 0.095 mmol, 1.0 mol-equiv). Next, 3:2 DMF/$Et_3N$ (1 mL) and 4–pentyn–1–ol (0.010 mL, 0.11 mmol, 1.2 mol-equiv) were added to the reaction flask via syringe and the reaction mixture was stirred for 3 min. The flask was briefly unsealed. CuI (0.90 mg, 0.0046 mmol, 5 mol%) and $Pd_2Cl_2(PPh_3)_2$ (3.3 mg, 0.0046 mmol, 5 mol%) were added. The flask was fitted with a reflux condenser and heated at reflux until aryl bromide **2.32** appeared consumed by TLC (45 min). The reaction mixture was cooled to room temperature and diluted with $CH_2Cl_2$ (10 mL). The organic layer was washed with water (5 x 10 mL) followed by brine, dried over $Na_2SO_4$, and concentrated *in vacuo* to give a red solid. The crude material was purified by flash chromatography (EtOAc/Hex) to yield alkynylated derivative **2.33** (0.035 g, 0.065 mmol, 68%) as a white solid. $R_f$ = 0.2 (4:1 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.46 (d, *J* = 8.3 Hz, 1H), 8.22 (d, *J* = 8.2 Hz, 1H), 7.73 (t, *J* = 7.8 Hz, 1H), 7.54 (t, *J* = 8.1 Hz, 1H), 7.49 (s, 1H), 7.18 (d, *J* = 7.8 Hz, 1H), 7.06–7.04 (m, 2H), 6.93 (t, *J* = 5.0 Hz, 1H), 6.12 (t, *J* = 5.1 Hz, 1H), 5.45 (s, 1H), 4.07 (d, J = 5.4 Hz, 2H), 3.82 (t, *J* = 6.6 Hz, 2H), 3.77 (s, 3H), 3.35 (q, *J* = 5.9 Hz, 2H), 2.56 (t, 7.2, 2H), 2.14 (t, *J* = 6.9 Hz, 2H), 1.98–1.70 (m, 7H), 1.63–1.49 (m, 4H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 168.4, 166.7, 161.6, 154.3, 135.0, 134.4, 134.2, 133.2, 128.8, 128.73, 128.67, 127.8, 126.24, 126.18, 124.9, 124.4, 124.0, 115.4, 113.1, 91.0, 80.6, 61.8, 56.1, 43.6, 37.55, 37.53, 31.40, 28.0, 25.3, 22.9, 22.4, 16.1; HRMS (ESI): *m/z* calculated for $C_{32}H_{35}N_3O_5Na$ $[M+Na]^+$ 564.2474, found 564.2480; HPLC purity: 96.3%.

Methyl-5-bromo-2-(2-methoxy-2-oxoethyl)benzoate (**2.11**):



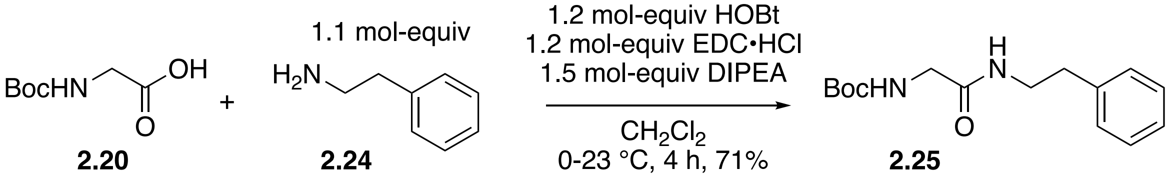
Bis(methylester) **2.11** was synthesized by adapting a procedure developed by Ochoa-Puentes *et. al.*[132] An oven-dried round bottom flask equipped with stir bar was charged with dicarboxylic acid **2.6b** (0.99 g, 3.9 mmol, 1.0 mol-equiv). Benzene (20 mL) and MeOH (10 mL) were added to the reaction flask and stirred until a homogeneous solution was obtained. $TMSCHN_2$ (2.0 M in $Et_2O$, 5.5 mL, 11 mmol, 2.8 mol-equiv) was added dropwise to the reaction flask via syringe over 2 h. The mixture was monitored for consumption of **2.6b** by TLC. The reaction mixture was concentrated *in vacuo* to afford a pale yellow oil. The crude material was purified by flash chromatography (EtOAc/Hex) to yield bis(methylester) **2.11** (1.1 g, 3.8 mmol, 99%) as a clear oil. $R_f$ = 0.9 (9:1 $CH_2Cl_2$/MeOH). $^1H$ NMR (500 MHz, $CDCl_3$) δ 8.15 (s, 1H), 7.61 (d, *J* = 8.2 Hz, 1H), 7.14 (d, *J* = 8.2 Hz, 1H), 3.97 (s, 2H), 3.88 (s, 3H), 3.70 (s, 3H); $^{13}C$ NMR (125 MHz, $CDCl_3$) δ 171.6, 166.3, 135.4, 135.1, 134.1, 134.0, 131.4, 121.3, 52.5, 52.2, 40.0; HRMS (ESI): *m/z* calculated for $C_{11}H_{11}O_4Na$ $[M+Na]^+$ 308.9738, found 308.9739.

Methyl-5-(5-((tert-butyldimethylsilyl)oxy)pent-1-yn-1-yl)-2-(2-methoxy-2-oxoethyl)benzoate (**28**):



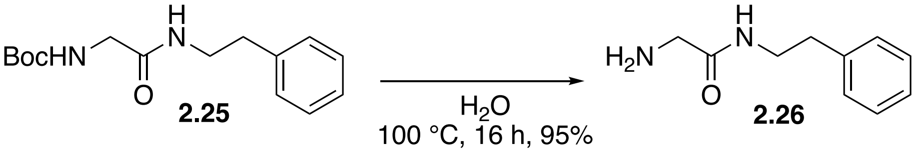
Alkynylated derivative **2.12** was synthesized by adapting a procedure developed by Reddy *et. al.* [133] A flame–dried round bottom flask equipped with stir bar was charged with bis(methylester) **2.11** (0.75 g, 2.6 mmol, 1.0 mol-equiv). DMF (18 mL), $Et_3N$ (12 mL), and tert–butylpent–4–ynyloxydiphenylsilane (1.4 g, 4.3 mmol, 1.7 mol-equiv) were added to the reaction flask via syringe. The reaction mixture was stirred for 3 min. The flask was briefly unsealed. CuI (0.025 g, 0.13 mmol, 5 mol%) and $Pd_2Cl_2(PPh_3)_2$ (0.092 g, 0.13 mmol, 5 mol%) were added. The flask was fitted with a reflux condenser and heated at reflux for 45 min. The reaction mixture was monitored by TLC for consumption of **2.11**. The reaction mixture was cooled to room temperature and diluted with $CH_2Cl_2$ (50 mL). The organic layer was washed with water (5 x 50 mL) followed by brine, dried over $Na_2SO_4$, and concentrated *in vacuo* to afford a red oil. The crude material was purified by flash chromatography (EtOAc/Hex) to yield alkyne **2.12** (1.2 g, 2.2 mmol, 85%) as a red oil. $R_f$ = 0.5 (1:4 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.02 (d, *J* =1.7 Hz, 1H), 8.03–8.00 (m, 4H), 7.45–7.35 (m, 7H), 7.2 (d, *J* = 8.1 Hz, 1H), 3.99 (s, 2H), 3.87 (s, 3H), 3.81 (t, *J* = 6.1 Hz, 2H), 3.70 (s, 3H), 2.57 (t, *J* = 7.2 Hz, 2H), 1.85 (quin, *J* = 7.2 Hz, 2H), 1.06 (s, 9H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ 171.9, 167.1, 135.7, 135.24, 135.22, 134.3, 133.9, 132.4, 129.74, 129.71, 127.8, 123.7, 91.3, 79.7, 62.5, 52.3, 52.2, 40.4, 31.6, 27.0, 19.4, 16.1; HRMS (ESI): *m/z* calculated for $C_{32}H_{36}O_5SiNa$ $[M+Na]^+$ 551.2230, found 551.2228.

*tert*-Butyl (2-oxo-2-(phenethylamino)ethyl)carbamate (**2.25**):



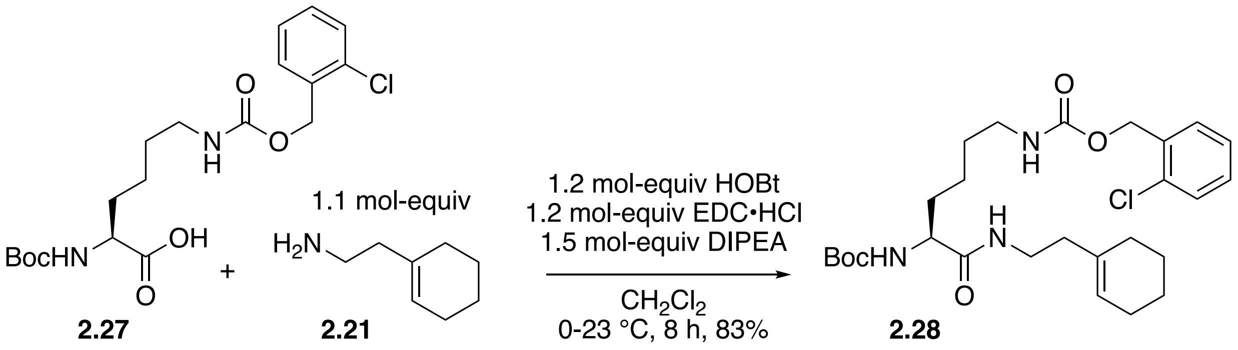
Amide **30** was synthesized by adapting a procedure developed by Liu *et. al.*[134] An oven-dried round bottom flask equipped with stir bar was charged with Boc-glycine **2.20** (0.64 g, 3.7 mmol, 1.0 mol-equiv) and HOBt (0.59 g, 4.3 mmol, 1.2 mol-equiv). $CH_2Cl_2$ (90 mL) was added to the reaction vessel followed by phenethylamine **2.24** (0.50 mL, 3.97 mmol, 1.1 mol-equiv). The reaction vessel was cooled to 0 °C with an ice-water bath. The flask was briefly unsealed and EDC•HCl (0.83 g, 4.33 mmol, 1.2 mol-equiv) was added. DIPEA (0.95 mL, 5.6 mmol, 1.5 mol-equiv) was then added to the reaction vessel via syringe and the mixture was stirred for 1 h. The reaction vessel was warmed to room temperature and stirred until Boc-amine **2.20** appeared consumed by TLC (4 h). The reaction mixture was washed with saturated $NaHCO_3$ and extracted with $CH_2Cl_2$ (3 x 100 mL). The combined organic layers were washed with brine, dried with $Na_2SO_4$, and concentrated *in vacuo* to afford a yellow oil. The crude material was purified by flash chromatography (EtOAc/Hex) to yield amide **2.25** (0.72 g, 2.6 mmol, 71%) as a yellow oil. $R_f$ = 0.57 (17:3 $CH_2Cl_2$/MeOH). $^1H$ NMR (500 MHz, $CDCl_3$) δ 7.31 (t, *J* = 7.3 Hz, 2H), 7.25–7.18 (m, 3H), 6.12 (s, 1H), 5.09 (s, 1H), 3.74 (d, *J* = 5.7 Hz, 2H), 3.54 (q, *J* = 6.6 Hz, 2H), 2.82 (t, *J* = 7.1 Hz, 2H), 1.43 (s, 9H); HRMS (ESI): *m/z* calculated for $C_{15}H_{22}N_2O_3Na$ $[M+Na]^+$ 301.1528, found 301.1531.

2-Amino-*N*-phenethylacetamide (**2.26**):



Amine **2.26** was synthesized by adapting a procedure developed by Zinelaabidine.[135] A round bottom flask equipped with stir bar was charged with Boc–protected amine **2.25** (0.25 g, 0.89 mmol, 1 mol-equiv). Next, water (20 mL) was added and the flask was fitted with a condenser. The reaction mixture was heated at reflux and monitored by TLC for disappearance of **2.25** (16 h). The reaction mixture was cooled to room temperature and extracted with $CH_2Cl_2$ (3 x 20 mL). The combined organic layers were concentrated *in vacuo* to obtain amine **2.26** (0.91 g, 0.85 mmol, 95%) as a yellow oil. $^1H$ NMR (500 MHz, $CDCl_3$) δ 7.34–7.18 (m, 6H), 3.55 (q, *J* = 6.7 Hz, 2H), 3.32 (s, 2H), 2.84 (t, *J* = 7.1 Hz, 2H), 1.40 (s, 2H); HRMS (ESI): *m/z* calculated for $C_{10}H_{14}N_2ONa$ $[M+Na]^+$ 201.1004, found 201.1002.

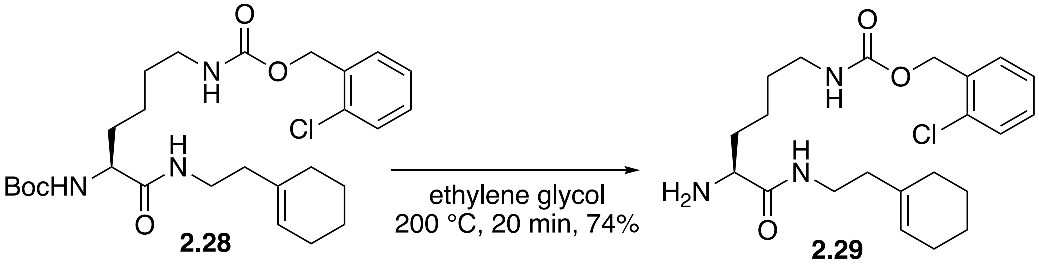
*tert*-Butyl-(2-chlorobenzyl)-(6-((2-(cyclohex-1-en-1-yl)ethyl)amino)-6-oxohexane-1,5-diyl)(*S*)-dicarbamate (**2.28**):



Amide **2.28** was synthesized by adapting a procedure developed by Liu *et. al.* [136] An oven-dried round bottom flask equipped with stir bar was charged with Boc-amino acid derivative **2.27** (1.5 g, 3.6 mmol, 1.0 mol-equiv) and HOBt (0.59 g, 4.3 mmol, 1.2 mol-equiv). $CH_2Cl_2$ (90 mL) was added to the reaction vessel followed by amine **2.21** (0.55 mL, 3.98 mmol, 1.1 mol-equiv). The reaction vessel was cooled to 0 °C with an ice-water bath. The flask was briefly unsealed and EDC•HCl (0.83 g, 4.3 mmol, 1.2 mol-equiv) was added. DIPEA (0.95 mL, 5.6 mmol, 1.5 mol-equiv) was then added to the reaction vessel via syringe and the mixture was stirred for 1 h. The reaction vessel was warmed to room temperature and stirred until Boc-amine **2.27** appeared consumed by TLC (8 h). The reaction mixture was washed with saturated $NaHCO_3$ and extracted with $CH_2Cl_2$ (3 x 100 mL). The combined organic layers were washed with brine, dried with $Na_2SO_4$, and concentrated *in vacuo* to afford a yellow oil. The crude material was purified by flash chromatography (EtOAc/Hex) to yield amide **2.28** (1.6 g, 3.0 mmol, 83%) as a white solid. $R_f$ = 0.2 (9:1 $CH_2Cl_2$/MeOH). $^1H$ NMR (500 MHz, $CDCl_3$) δ 7.41 – 7.40 (m, 1H), 7.37 – 7.35 (m, 1H), 7.26 – 7.24 (m, 2H), 6.10 (br s, 1H), 5.44 (s, 1H), 5.22 – 5.20 (m, 2H), 5.13 (br s, 1H), 4.97 (br s, 1H), 4.01 (br s, 1H), 3.36 – 3.25 (m, 2H), 3.19 (q, *J* = 6.4 Hz, 2H), 2.11 (t, *J* = 6.7 Hz, 2H), 1.98 (br s, 2H), 1.90 (br s, 2H), 1.83 (br s, 1H), 1.61 – 1.52 (m, 7H), 1.42 (s, 9H), 1.38 – 1.35 (m, 2H); $^{13}C$ NMR (125

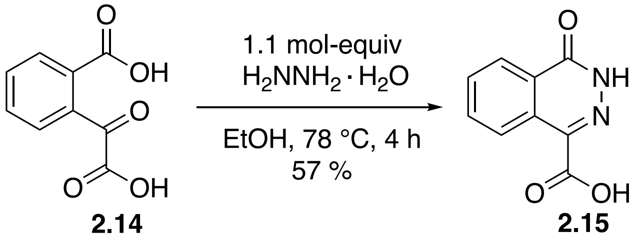
MHz, $CDCl_3$) δ 171.9, 156.4, 155.9, 134.6, 134.4, 133.6, 129.8, 129.6, 129.4, 127.0, 123.8, 80.1, 64.0, 54.5, 40.6, 37.7, 37.3, 32.3, 29.6, 28.4, 28.0, 25.3, 22.9, 22.6, 22.4: HRMS (ESI): *m/z* calculated for $C_{27}H_{40}ClN_3O_5Na$ $[M+Na]^+$ 544.2554, found 544.2558.

2-Chlorobenzyl (*S*)-(5-amino-6-((2-(cyclohex-1-en-1-yl)ethyl)amino)-6-oxohexyl)carbamate (**2.29**):



Amine **2.29** was synthesized by adapting a procedure developed by Martin *et. al.*[137] An oven-dried round bottom flask equipped with stir bar was charged with the Boc-protected amine **2.28** (0.66 g, 1.3 mmol, 1 mol-equiv). Ethylene glycol (28 mL) was added and the flask was fitted with a condenser. The reaction mixture was heated at reflux and monitored by TLC for disappearance of the Boc–protected amine **2.28** (20 min). The reaction mixture was cooled to room temperature and diluted with $CH_2Cl_2$ (50 mL). Next, the organic layer was washed with water (5 x 100 mL) followed by brine, dried over $Na_2SO_4$, and concentrated *in vacuo* to give amine **2.29** (0.39 g, 0.96 mmol, 74%) as a yellow oil. $^1H$ NMR (500 MHz, $CDCl_3$) δ 7.43–7.35 (m, 2H), 7.26–2.20 (m, 3H), 5.45 (s, 1H), 5.25–5.17 (m, 3H), 4.92 (br s, 1H), 3.34–3.29 (m, 2H), 3.21 (q, *J* = 6.5 Hz, 2H), 2.13 (t, *J* = 6.8 Hz, 2H), 2.02–1.90 (m, 4H), 1.85–1.78 (m, 1H), 1.64–1.39 (m, 11H); $^{13}C$ NMR (125 MHz, $CDCl_3$) δ 174.8, 156.4, 134.8, 134.5, 133.6, 129.8, 129.6, 129.4, 127.0, 123.6, 64.0, 55.2, 40.9, 37.9, 37.0, 34.8, 29.9, 28.0, 25.4, 23.0, 22.9, 22.5; HRMS (ESI): *m/z* calculated for $C_{22}H_{32}ClN_3O_3H$ $[M+H]^+$ 422.2210, found 422.2216.

4-Oxo-3,4-dihydrophthalazine-1-carboxylic acid (**35**):



Phthalazinone carboxylic acid **2.15** was synthesized by adapting a procedure developed by Geneste *et. al.*[138] An oven–dried round bottom flask equipped with stir bar was charged with dicarboxylic acid **2.14** (0.30 g, 1.4 mmol, 1.0 mol-equiv), EtOH (6.4 mL), and hydrazine hydrate (0.073 mL, 1.6 mmol, 1.1 mol-equiv). The flask was fitted with a condenser. The mixture was heated at reflux and monitored by TLC for disappearance of **2.14** (4 h). The mixture was cooled to room temperature and the resulting gray solid was collected via filtration using a Büchner funnel. The solid was washed with cold EtOH (3 x 3 mL) to obtain **2.15** (0.16 g, 0.82 mmol, 57%). $R_f$ = 0.2 (1:4 MeOH/$CH_2Cl_2$). $^1H$ NMR (500 MHz, DMSO-$d_6$) δ 12.93 (br s, 1H), 8.49 (d, *J* = 8.2 Hz, 1H), 8.26 (d, *J* = 7.8 Hz, 1H), 7.94 (t, *J* = 8.1 Hz, 1H), 7.86 (t, *J* = 7.8, 1H); $^{13}C$ NMR (125 MHz, DMSO-$d_6$) δ 165.3, 159.6, 138.8, 133.7, 131.7, 128.0, 127.5, 126.6, 125.8; HRMS (ESI): *m/z* calculated for $C_9H_7N_2O_3$ $[M+H]^+$ 191.0457, found 191.0462.

## Biological evaluations:

*Strains, media, and compounds:* The *C. albicans* strain HLY4123 was used to assay analogues for antifungal activity in the presence of azole drugs. HLY4123 carries a GFP reporter for ERG3 expression and was constructed by plasmid transformation of the commonly used *C.*

*albicans* strain CAI4. Selected resistant fungal strains[139] with different mechanisms of drug resistance were obtained from Dr. David Rogers (Department of Clinical Pharmacy, University of Tennessee Health Sciences Center, Memphis, Tennessee, USA). *C. neoformans var. grubii* H99[140] and *C. glabrata* BG2[141] were also tested. The strains were cultured at 30 °C under constant shaking (200 rpm) in synthetic complete (SC) medium containing 2% glucose. The stock solution of fluconazole (Sigma–Aldrich, USA) was prepared in sterile $H_2O$. Stock solutions of isavuconazole and analogues **2.1** and **2.30**-**2.41** were prepared in DMSO.

*Dose–response curves for analogues tested against HLY4123 C. albicans with and without fluconazole: C. albicans* was grown in SC medium overnight and then diluted to an effective $OD_{600}$ of 0.0625. Serial ten-fold dilutions of analogues **2.1** and **2.30**-**2.41** (15 mM -0.0015 mM) were prepared in DMSO in 1.5 mL Eppendorf tubes. To each well in columns B, C, and D (triplicate analysis) of a 24-well Falcon plate (4 columns x 6 rows) was added 2.5 μL of a 0.1 mg/mL fluconazole solution. No azole was added to column A, which was used to assay the anti-fungal activity of analogues **2.1** and **2.30**-**2.41** in the absence of azole. To every well of the plate was added 1 mL of cells in SC medium, to achieve a final azole concentration of 0.25 μg/mL in columns B, C, and D.

Next, a given analogue was added at varying concentration to rows two through six. To every well of row 2 was added 2 μL of a given 15 mM analogue solution, to achieve a concentration of 30 μM in each well. Addition of 2 μL of analogue solutions was continued for rows 3, 4, 5, and 6, using 1.5 mM, 0.15 mM, and 0.015 mM, and 0.0015 mM DMSO solutions, respectively. Rows 3, 4, 5, and 6 therefore had a final analogue concentration of 3 μM, 0.3 μM, 0.03 μM, and 0.003 μM, respectively. After both azole and analogue were added to the cells, every well was mixed thoroughly by repeated pipetting.

The plates were incubated in a rotary shaker/incubator at 30 °C for 16 h. After incubation, the contents of each well were re-suspended with a micropipette. A 50 μL aliquot was added to a polystyrene cuvette and diluted with 950 μL deionized water (20-fold dilution). The contents of the cuvettes were re-suspended immediately before measuring the absorbance at l = 600 nm ($OD_{600}$) for cell densities. $EC_{50}$ values were determined by fitting to a standard curve using the Excel-based tool ED50PLUS v. 1.0 (Mario H. Vargas).

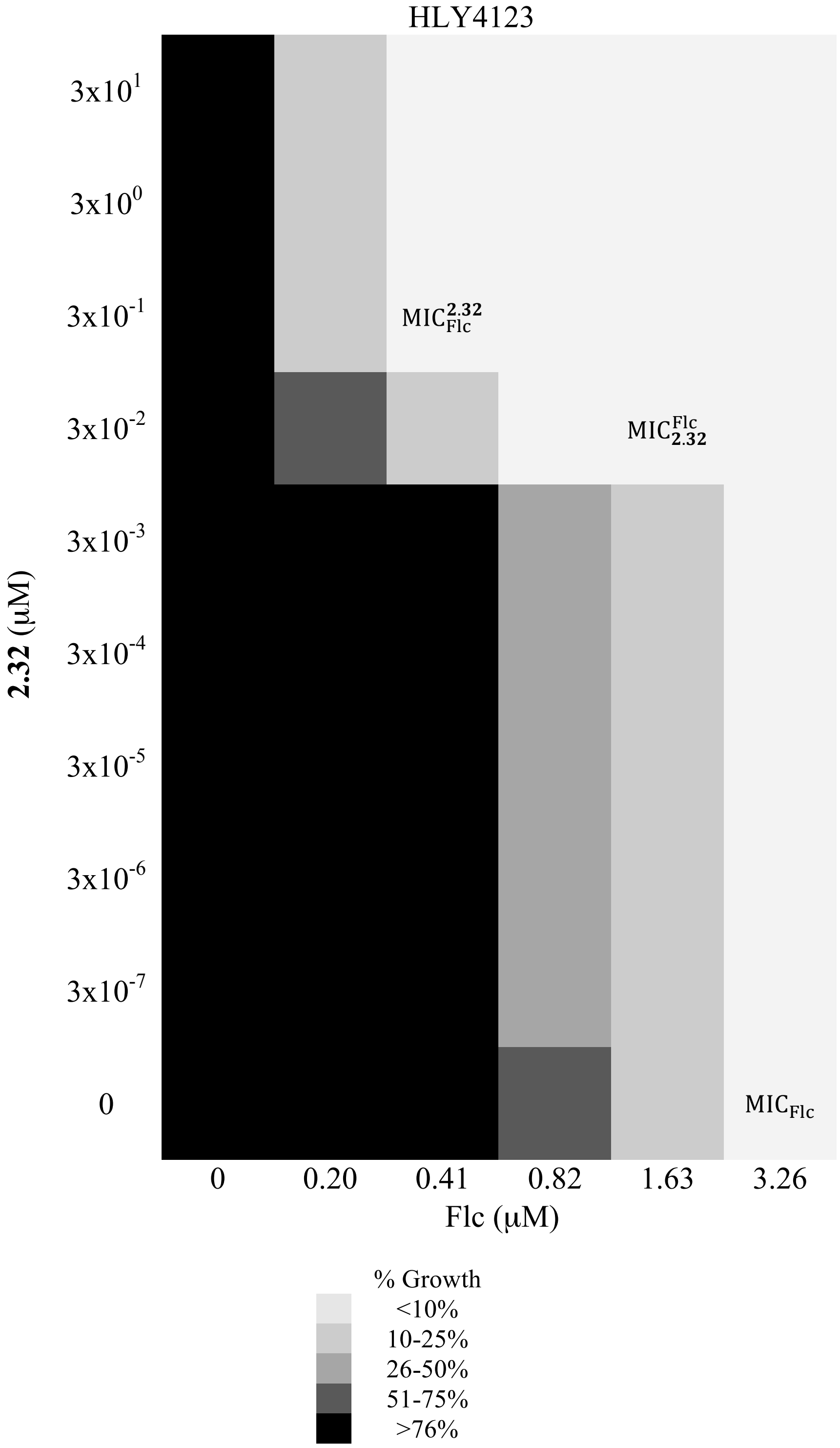
*Determination of $MIC_{90}$ values by checkerboard assay:* Checkerboard assays were carried out using four 24-well plates (6 rows x 4 columns), to create an effective 96-well plate (12 rows x 8 columns). *C. albicans* was grown in SC medium overnight and then diluted to an effective $OD_{600}$ of 0.0625. Serial tenfold dilutions of the analogues **2.32** or **2.41** were prepared in DMSO (15 mM – 0.015 nM) in 1.5 mL Eppendorf tubes. Serial twofold dilutions of fluconazole (0.5 mg/mL - 0.03125 mg/mL) were prepared in sterile $H_2O$ in 1.5 mL Eppendorf tubes.

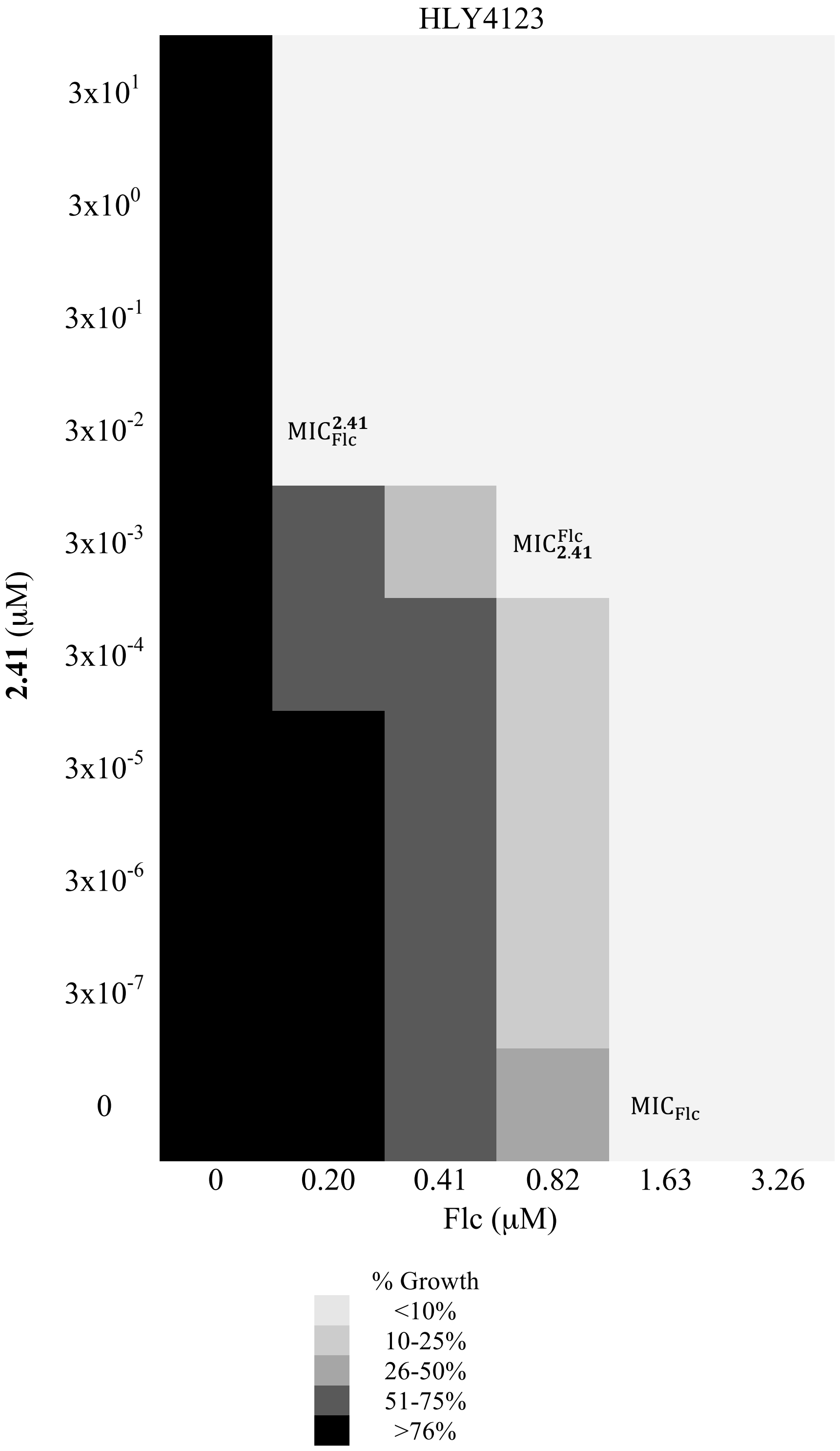
To each well was added 2 μL of a given analogue DMSO solution and 2 μL of the fluconazole solution. Concentrations of analogues in rows 1–6 varied from 30 μM to 0.3 nM. Concentrations of analogues in rows 7–11 varied from 3 nM to 0.0003 nM. Rows 5 and 7 both had analogue concentrations of 3 nM and rows 6 and 8 both had analogue concentrations of 0.3 nM to normalize cell densities between plates. No analogue was added to the last row 12. Concentrations of fluconazole in columns A–D varied from 1 μg/mL – 0.125 μg/mL. Concentrations of fluconazole in columns E–G varied from 0.25

μg/mL – 0.0625 μg/mL. Columns D and E both had analogue concentrations of 0.25 μg/mL to normalize cell densities between plates. No fluconazole was added to the final column H. After both azole and analogue were added to the cells, every well was mixed thoroughly by repeated pipetting.

The plates were incubated in a rotary shaker/incubator at 30 ºC for 16 h. The contents of each well were re-suspended with a micropipette. A 50 μL aliquot was added to a polystyrene cuvette and diluted with 950 μL deionized water (20-fold dilution). The contents of the cuvettes were re-suspended immediately before measuring the absorbance at l = 600 nm ($OD_{600}$). $MIC_{90}$ values were determined as the lowest drug concentrations (alone or in combination) that inhibited fungal growth by 90% compared to wells containing no analogue.

**Figure 2-2**: Plots of Checkerboard Assays for Compounds **2.32** and **2.41**. $\mathrm{MIC}_{\mathrm{Flc}}$ is the $\mathrm{MIC}_{90}$ for fluconazole in the absence of **2.32** or **2.41**. $\mathrm{MIC}_{\mathrm{Flc}}^{\mathbf{2.32}}$ and $\mathrm{MIC}_{\mathrm{Flc}}^{\mathbf{2.41}}$ are the lowest $\mathrm{MIC}_{90}$ for fluconazole in the presence of **2.32** or **2.41**. $\mathrm{MIC}_{\mathbf{2.32}}^{\mathrm{Flc}}$ and $\mathrm{MIC}_{\mathbf{2.41}}^{\mathrm{Flc}}$ are the lowest $\mathrm{MIC}_{90}$ for **2.32** or **2.41** in the presence of fluconazole. The $\mathrm{MIC}_{90}$ for both **2.32** and **2.41** in the absence of fluconazole was above the solubility limit (30 mM).




HLY4123
3x10^1
3x10^0
3x10^-1
3x10^-2
3x10^-3
3x10^-4
3x10^-5
3x10^-6
3x10^-7
0
2.41 (μM)
$\mathrm{MIC}_{\mathrm{Flc}}^{\mathbf{2.41}}$
$\mathrm{MIC}_{\mathbf{2.41}}^{\mathrm{Flc}}$
$\mathrm{MIC}_{\mathrm{Flc}}$
0
0.20
0.41
0.82
1.63
3.26
Flc (μM)
% Growth
<10%
10-25%
26-50%
51-75%
>76%

*Determination of $EC_{50}$ values for analogues **2.32** and **2.41** tested against resistant C. albicans strains*

*Part I: Determination of fluconazole $MIC_{50}$ values for resistant C. albicans strains*: Selected resistant C*. albicans* isolates (CaCi-17, 26, 33, 36, and 45) were obtained from Dr. David Rogers. $MIC_{50}$ values were re-measured in our own laboratory by incubating each isolate with fluconazole concentrations between 512 ug/mL to 8 ug/mL. After incubation, the $MIC_{50}$ was determined by absorption at l = 600 nm (see above). MIC values agreed with those provided for Rogers except for strains CaCi-17 and CaCi-45 (12 mg/mL vs. 32 mg/mL and 96 mg/mL vs. 128 mg/mL).

**Table 2-6**: Measured Fluconazole $MIC_{50}$ Values for Resistant C. albicans Clinical Isolates

| Isolate | Fluconazole $MIC_{50}$ (µg/mL) |
|---|---|
| 17 | 12 |
| 26 | 32 |
| 33 | 64 |
| 36 | 64 |
| 45 | 96 |

*Part II: Determination of $EC_{50}$ values for analogues **2.32** and **2.41***:

The aforementioned isolates were grown in SC medium overnight and then diluted to an effective $OD_{600}$ of 0.0625. Serial ten-fold dilutions of analogues **2.32** and **2.41** (15 mM-0.0015 mM) were prepared in DMSO in 1.5 mL Eppendorf tubes. To each well in columns B, C, and D (triplicate analysis) of a 24-well Falcon plate (4 columns x 6 rows) was added 6.0 µL for CaCi-17, 16.0 µL for CaCi-26, 32.0 µL for CaCi-33, 32.0 µL for CaCi-36, and 48.0 µL for CaCi-45 of a 2.0 mg/mL fluconazole solution. No azole was added to column A, which was used to assay the anti-fungal activity of analogues **2.32** and **2.41** in the absence of azole. To every well of the plate was added 1 mL of cells in SC medium, to achieve a final azole concentration of 12 µg/mL for CaCi-17, 32 µg/mL for CaCi-26, 64 µg/mL for CaCi-33, 64 µg/mL for CaCi-36, 96 µg/mL for CaCi-45 in columns B, C, and D.

Next, a given analogue was added at varying concentration to rows two through six. To every well of row 2 was added 2 µL of a given 15 mM analogue solution, to achieve a concentration of 30 µM in each well. Addition of 2 µL of analogue solutions was continued for rows 3, 4, 5, and 6, using 1.5 mM, 0.15 mM, and 0.015 mM, and 0.0015 mM DMSO solutions, respectively. Rows 3, 4, 5, and 6 therefore had a final analogue concentration of 3 µM, 0.3 µM, 0.03 µM, and 0.003 µM, respectively. After both azole and analogue were added to the cells, every well was mixed thoroughly by repeated pipetting.

The plates were incubated in a rotary shaker/incubator at 30 °C for 16 h. After incubation, the contents of each well were re-suspended with a micropipette. A 50 µL aliquot was added to a polystyrene cuvette and diluted with 950 µL deionized water (20-fold dilution). The contents of the cuvettes were re-suspended immediately before measuring the absorbance at l = 600 nm ($OD_{600}$) for cell densities. $EC_{50}$ values were determined by fitting to a standard curve using the Excel-based tool ED50PLUS v. 1.0 (Mario H. Vargas).

**Table 2-7**: Antifungal Activities of Analogues **2.32** and **2.41** Against Resistant Isolates of *C. albicans* in the Presence of Fluconazole

| | | $EC_{50}$[a] | |
|---|---|---|---|
| *Isolate* | *[Flu]*[b] | ***2.32*** | ***2.41*** |
| 17 | 12 | 74 ± 10 | 39 ± 3 |
| 26 | 32 | 11 ± 1 | 17 ± 2 |
| 33 | 64 | 371 ± 23 | 72 ± 6 |
| 36 | 64 | 32 ± 4 | 20 ± 2 |
| 45 | 96 | 170 ± 20 | 65 ± 15 |

[a] $EC_{50}$ (nM) expressed as arithmetic mean ± S.D. of three independent experiments.
[b] Measured $MIC_{50}$ values for fluconazole alone; $EC_{50}$ values were deteremined at these concentrations of fluconazole.

### *Determination of $EC_{50}$ values for analogues **2.32** and **2.41** tested against C. glabrata and C. neoformans*

*C. glabrata* BG2 *and C. neoformans var. grubii* H99 were assayed in the same manner as described above for resistant *C. albicans* isolates*,* except the final concentrations of fluconazole used was 4.0 μg/mL for *C. neoformans* and 128 μg/mL for *C. glabrata*, corresponding to $MIC_{50}$ values measured in our laboratory for these species.

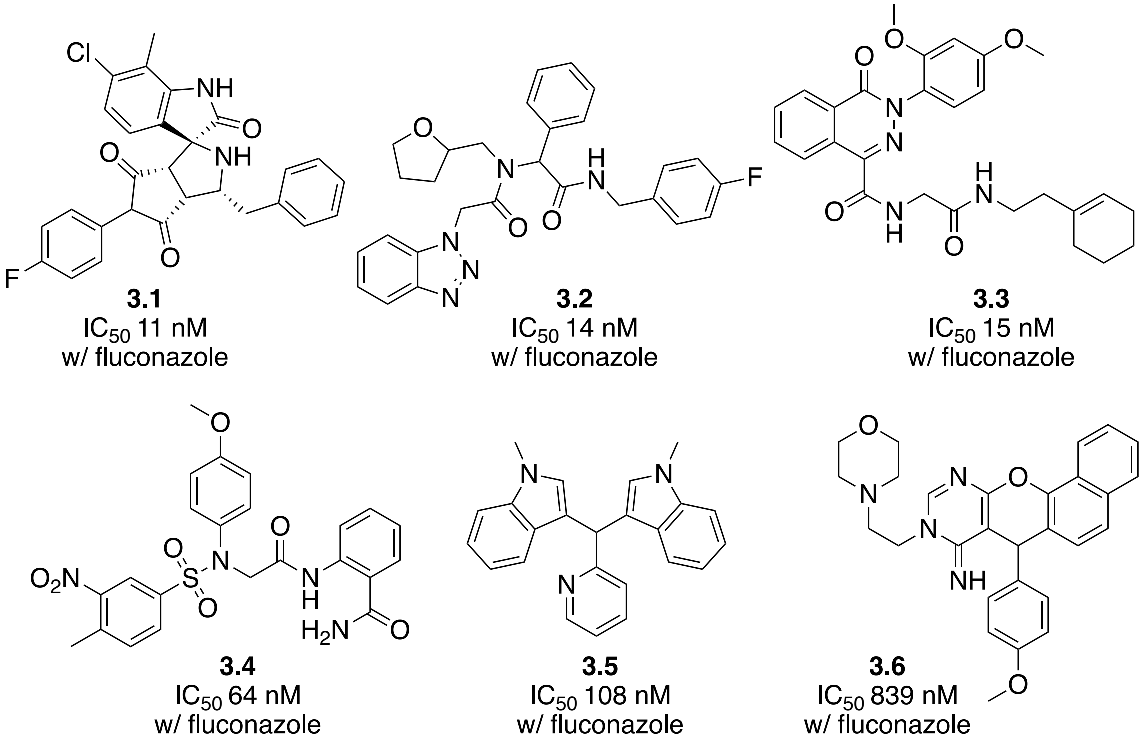
# Chapter 3: Spiroindolinone Azole Synergizers

## Introduction

As described in chapters 1 and 2, fungal diseases remain a worldwide health problem. About 1.5 million people will die every year due to fungal infections. Fungal infection incidence is getting worse, not better. As with other pathogens, resistance in fungi towards drugs is becoming a major health problem. Those most likely to die from fungal infections are those who have compromised immune systems. The genus *Candida* accounts for roughly 80% of major systemic fungal infections. *Candida albicans* and *Candida glabrata* are two of the most common fungal pathogens that cause *candidiasis*. Because of the great threat that fungal infections cause researchers across the world have been searching for better ways and drugs to treat patients with fungal infections.

As mentioned in the previous chapters, Lindquist and Schreiber screened 300,000 compounds to try identify those that enhanced the antifungal activity of fluconazole. They found 296 compounds with good activity that were not cytotoxic to mammalian cells. In cooperation with the Liu lab, we selected and ordered 51 out of the 296 compounds to test them against the *Candida albicans* strain HLY4123 in the presence of fluconazole. The Liu lab then tested the effects of those compounds on transcription of *ERG3* and *ERG11* with the hope of identifying transcriptional modulators. They found 5 downregulators that did not exhibit any antifungal activity against the *C. albicans* reporter strain HLY4123. Luckily they found 6 upregulators that had good antifungal activity against HLY4123 (Figure 3-1). The upregulators were tested with a fluconazole concentration of 0.25 µg/mL.

**Figure 3-1**: Potent Up-Regulators and Potent Enhancers



**3.1** $IC_{50}$ 11 nM w/ fluconazole

**3.2** $IC_{50}$ 14 nM w/ fluconazole

**3.3** $IC_{50}$ 15 nM w/ fluconazole

**3.4** $IC_{50}$ 64 nM w/ fluconazole

**3.5** $IC_{50}$ 108 nM w/ fluconazole

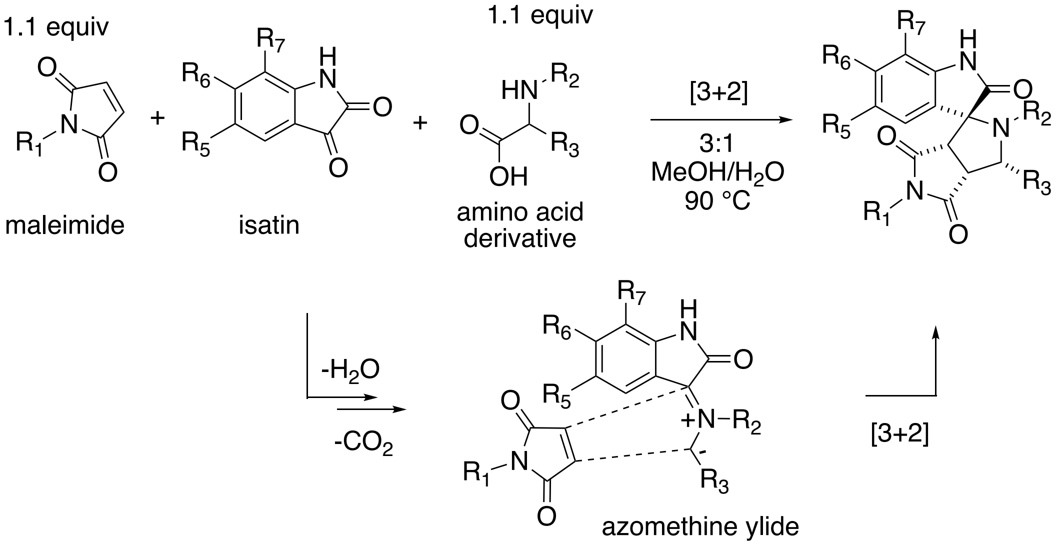
**3.6** $IC_{50}$ 839 nM w/ fluconazole

In the Van Vranken lab, Udara Premachandra attempted to synthesize analogues of bis-indolylmethane **3.5**. This proved problematic because the compounds were susceptible to oxidation by air and had very low solubility. Only one compound was successfully purified. That bisindole analogue was no better than the original **3.5**. Premachandra and coworkers turned their attention towards another promising lead compound, spiroindolinone **3.1**.[142]

## Previous Spiroindolinone Azole Synergizers

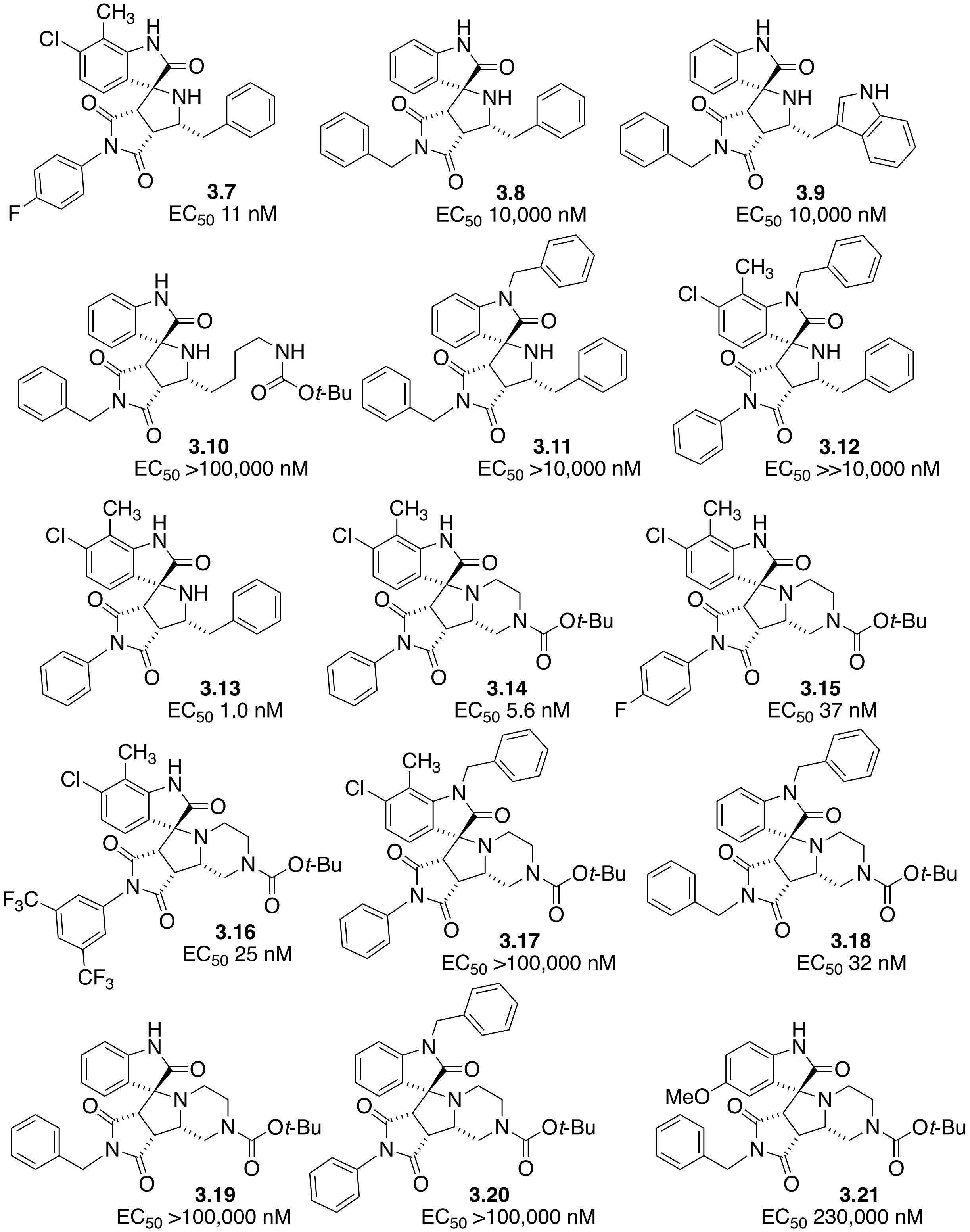
Premachandra and coworkers synthesized their spiroindolinones through a three-component coupling of an amino acid derivative, an isatin, and a maleimide (Scheme 3-1). The reaction mechanism involves two stages. First the amino acid derivative condenses with the isatin to form an iminium ion intermediate that loses carbon dioxide to form an azomethine ylide that undergoes a 1,3-dipolar cycloaddition with the maleimide to form the spiroindolinone. Premachandra and coworkers give a detailed review of the stereochemistry of these reactions in their paper.[143] They found that the stereochemistry of the spiroindolinone **3.1** reported in the PubChem database was assigned incorrectly. With the exception of proline, all amino acids generated spiroindolinones with the relative stereochemistry shown in Scheme 3-1. Some analogues were made with further modifications from the spiroindolinone core.

**Scheme 3-1:** Synthesis of Spiroindolinones



As seen in Figure 3-2, Premachandra and two undergraduates were able to synthesize 25 spiroindolinones and test their activity against the *C. albicans* strain HLY4123 with a constant concentration of 0.25 µg/mL of fluconazole. It should be noted that compounds **3.1** and **3.7** were found to be the same diastereomer. It is believed that compound **3.1** was misassigned. Most spiroindolinones that were made fall into two main classes. The first class is like compound **3.7,** which are acyclic amino acid derivatives. The second class is like compound **3.29**, which are made from cyclic amino acid derivatives. They found that both motifs can be very active. Compound **3.13**, which only differed by a fluorine atom on the maleimide was found to activity of 1 nM. Compound **3.29**, termed synazo-1, prepared from a cyclic piperazine amino acid derivative, had the lowest activity with an $EC_{50}$ 0.3 nM. It was found that substitution on the phenyl ring of the isatin was necessary for activity, with disubstitution in the 2 and 3 position preferred. Substitution on the amide of the isatin fragment was generally not beneficial for activity. In spite of all the analogues made there is still plenty of room to make more modifications such as the phenyl ring of the maleimide.

**Figure 3-2**: Spiroindolinone Synthesized by Premachandra and Coworkers with their Activities against HLY4123 with 0.25 μg/mL of Fluconazole



**3.7** EC$_{50}$ 11 nM

**3.8** EC$_{50}$ 10,000 nM

**3.9** EC$_{50}$ 10,000 nM

**3.10** EC$_{50}$ >100,000 nM

**3.11** EC$_{50}$ >10,000 nM

**3.12** EC$_{50}$ >>10,000 nM

**3.13** EC$_{50}$ 1.0 nM

**3.14** EC$_{50}$ 5.6 nM

**3.15** EC$_{50}$ 37 nM

**3.16** EC$_{50}$ 25 nM

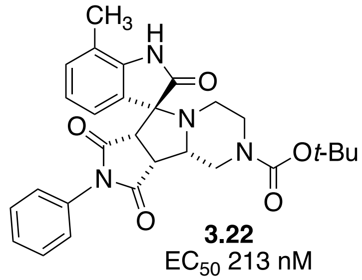
**3.17** EC$_{50}$ >100,000 nM

**3.18** EC$_{50}$ 32 nM

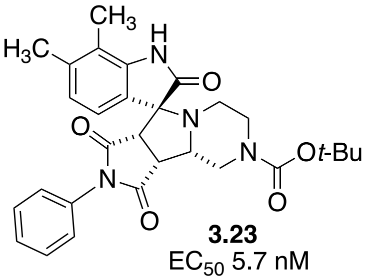
**3.19** EC$_{50}$ >100,000 nM

**3.20** EC$_{50}$ >100,000 nM

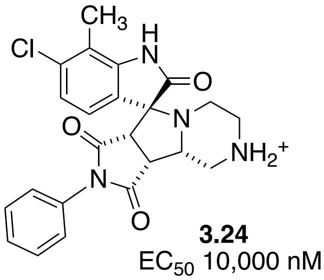
**3.21** EC$_{50}$ 230,000 nM



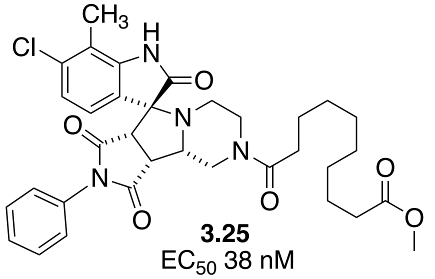
**3.22**
EC$_{50}$ 213 nM



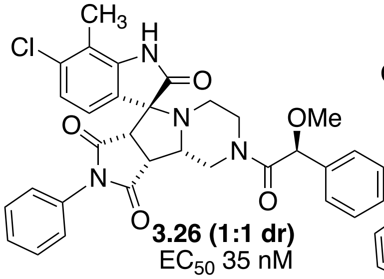
**3.23**
EC$_{50}$ 5.7 nM



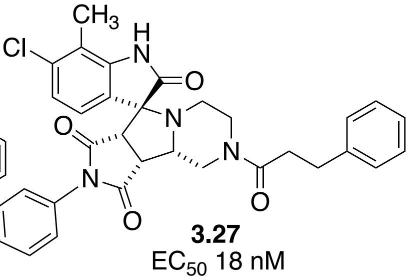
**3.24**
EC$_{50}$ 10,000 nM



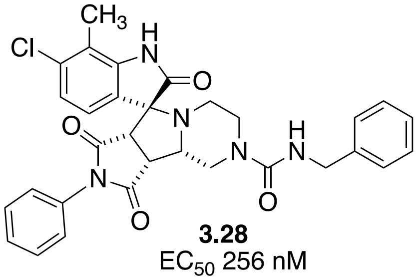
**3.25**
EC$_{50}$ 38 nM



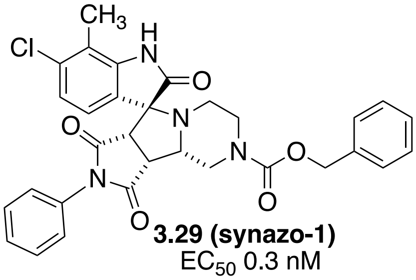
**3.26 (1:1 dr)**
EC$_{50}$ 35 nM



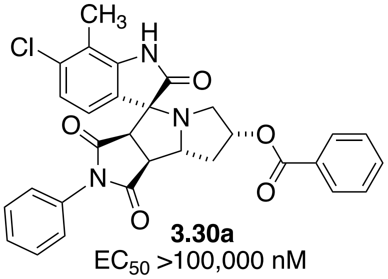
**3.27**
EC$_{50}$ 18 nM



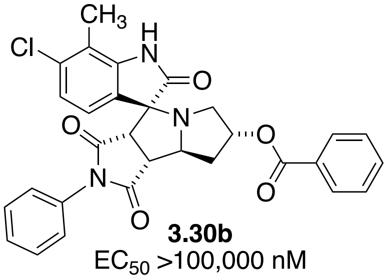
**3.28**
EC$_{50}$ 256 nM



**3.29 (synazo-1)**
EC$_{50}$ 0.3 nM



**3.30a**
EC$_{50}$ >100,000 nM



**3.30b**
EC$_{50}$ >100,000 nM

Premachandra and coworkers also showed that compound **3.29** was active against resistant *C. albicans* strains as described in Chapter 2. For example, compound **3.29** has an EC$_{50}$ of 16 nM against one of the most resistant strains tested, clinical isolate 45. Compound **3.29** was also determined to be a true synergizer with an FIC index below 0.25 with HLY4123 and an FIC index below 0.13 with isolate 45. Lastly and importantly, compounds **3.7** and **3.29** were both shown to be nontoxic to mammalian cells.

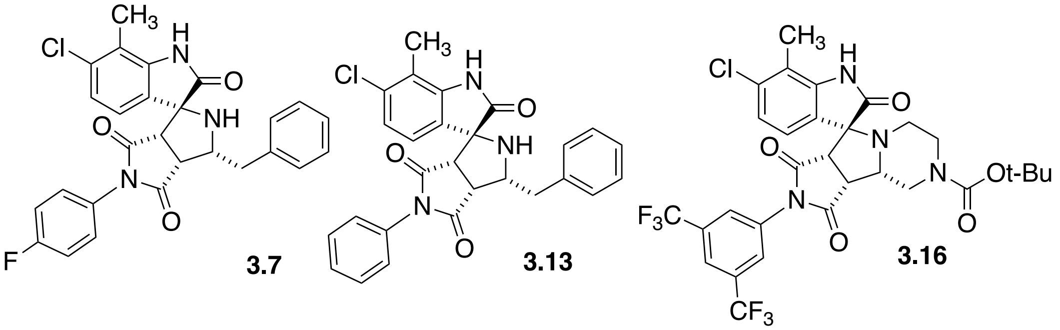
## Further Biological Evaluations of Spiroindolinones

As described in Chapter 2, phthalazinone and isoquinolone analogues were shown to be potent against susceptible and resistant strains of *C. albicans.* Unfortunately these analogues were not active against *Candida glabrata* BG2[144,145] nor *C. neoformans var. grubii* H99.[146] Our broad goal was to develop a spiroindolinone analogue that would be active against a broad range of pathogenic fungal species. We set out to first test previous spiroindolinone analogues for potent synergy with fluconazole against resistant strains of *C. albicans* and *C. glabrata*. Next, we sought to design, synthesize, and test new more potent analogues against both resistant fungal species. While I did the majority of the design and a plurality of the synthesis and testing, Dr. Stan Hiew, and a team of undergraduates trained and mentored by me (Pauline Nguyen, Marina Hettick, Steven Snow, Marlon Rea, Patrick Lam, Kassidy Tincup, and Francis Liu) also heavily contributed. Our collaborators in the Liu lab, Dr. Fuqiang Wang, Yi Sun, and Lingmei Sun, prepared the fungal cells for assays.

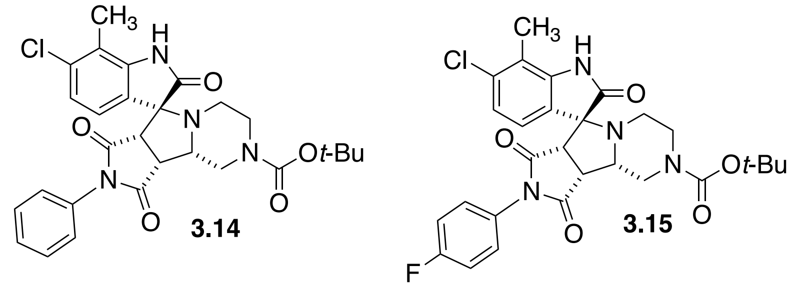
We began by testing the 25 of the spiroindolinone analogues previously prepared by Udara Premachandra (Figure 3-1). Given the importance of antifungal drug resistance we took the analogues that had activities below 200 nM against the laboratory strain of *C. albicans*, HLY4123 and tested them against the resistant *C. albicans* clinical isolate 45 and resistant *C. glabrata* BG2 in conjunction with fluconazole. Assays were carried out with constant concentration of fluconazole (64 μg/mL for *C. albicans* isolate 45 and 128 μg/mL for *C. glabrata* BG2) while varying the concentration of the spiroindolinone.

Surprisingly we found that only five of the analogues had any activity against both the resistant *C. albicans* and resistant *C. glabrata* strains. Most strikingly the most active analogue against HLY4123, compound **3.29**, had no activity against *C. glabrata*. The compounds that were active against the resistant *C. albicans* and *C. glabrata* are shown in Figure 3-3 along with their activities against both species. Compound **3.7** had similar activity against *C. albicans* ci-45 compared to compound **3.13** but compound **3.7** was much more active against *C. glabrata*. Compound **3.16** was the most active against *C. glabrata* but had the worst activity against *C. albicans.* Overall, the piperazine analogues of synazo-1 (compounds **3.14** and **3.15**) were not as good as compound **3.7**. In light of the fact that compound **3.29** (synazo-1) had no activity against *C. glabrata*, we decided to use compound **3.7** as our lead compound. Moreover, the benzylic derivative **3.7**, derived from phenylalanine, was easier to access than the corresponding piperazines. Modifications on the isatin, maleimide, and the amino acid fragments were ripe for development.

**Figure 3-3**: Activities of Spiroindolinones Against Resistant *C. albicans* and Resistant *C. glabrata* Strains



| | 3.7 | 3.13 | 3.16 |
|---|---|---|---|
| $EC_{50}$ [nM] *C. albicans* CI-45 | 440 nM | 490 nM | 750 nM |
| $EC_{50}$ [nM] *C. glabrata* BG2 | 640 nM | 1700 nM | 240 nM |



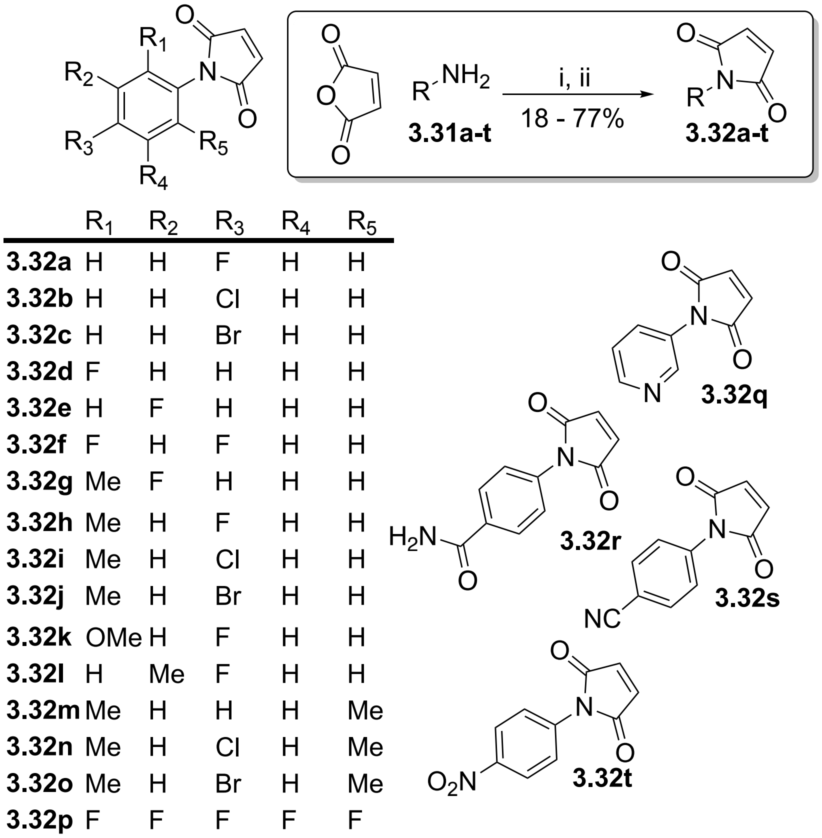
| | 3.14 | 3.15 |
|---|---|---|
| $EC_{50}$ [nM] *C. albicans* CI-45 | 760 nM | 1060 nM |
| $EC_{50}$ [nM] *C. glabrata* BG2 | 540 nM | 220 nM |

## Results and Discussion

### Chemistry

As seen in Scheme 3-2, all of the necessary maleimides, **3.32a-t,** were synthesized through a two step condensation procedure between maleic anhydride and an aniline or other $NH_2$ compound.[147] In the first step, the aniline condenses with the maleic anhydride to form *N*-phenylmaleamic acids. The crude *N*-phenylmaleamic acids are heated with acetic anhydride to cyclize to the corresponding maleimide.

**Scheme 3-2:** Synthesis of Maleimides

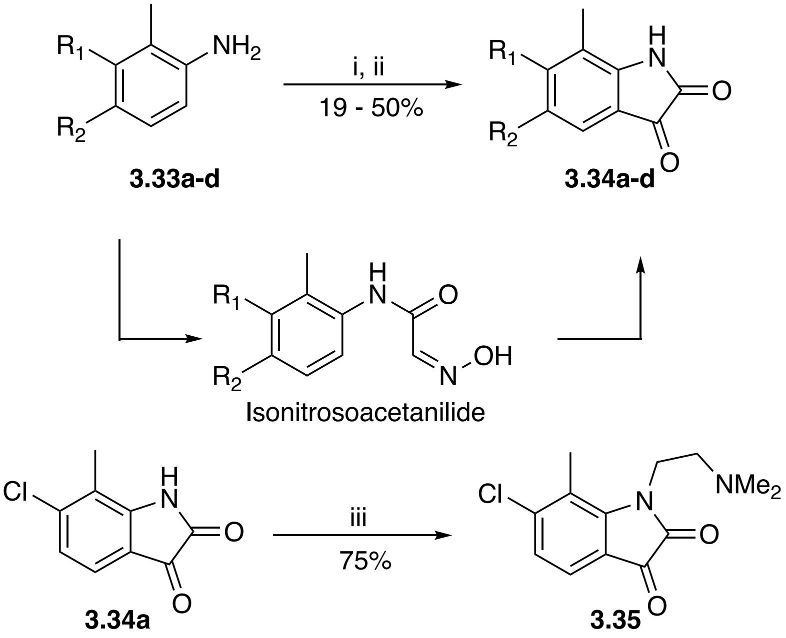


|  | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_5$ |
|---|---|---|---|---|---|
| **3.32a** | H | H | F | H | H |
| **3.32b** | H | H | Cl | H | H |
| **3.32c** | H | H | Br | H | H |
| **3.32d** | F | H | H | H | H |
| **3.32e** | H | F | H | H | H |
| **3.32f** | F | H | F | H | H |
| **3.32g** | Me | F | H | H | H |
| **3.32h** | Me | H | F | H | H |
| **3.32i** | Me | H | Cl | H | H |
| **3.32j** | Me | H | Br | H | H |
| **3.32k** | OMe | H | F | H | H |
| **3.32l** | H | Me | F | H | H |
| **3.32m** | Me | H | H | H | Me |
| **3.32n** | Me | H | Cl | H | Me |
| **3.32o** | Me | H | Br | H | Me |
| **3.32p** | F | F | F | F | F |

*Reagents and conditions:* (i) 1 equiv maleic anhydride, 1 equiv R-$NH_2$, $Et_2O$, 23 °C, 0.5-1 h (ii) 0.7 equiv NaOAC, $Ac_2O$, 70 °C, 4-6 h.

Isatins **3.34a-d** were synthesized through a two-step Sandmeyer procedure (Scheme 3-3).[148,149] In the first step, anilines are converted to isonitrosoacetanilides through the use of chloral hydrate and hydroxylamine. The crude isonitrosoacetanilide was cyclized in the presence of hot sulfuric acid to give the isatin product. Isatin **3.34a** was converted to dimethyl amino isatin derivative **3.35** using 2-chloro-*N*,*N*-dimethylethylamine hydrochloride.[150] All amino acids and amino acid derivatives used were commercially available.

**Scheme 3-3:** Synthesis of Isatins

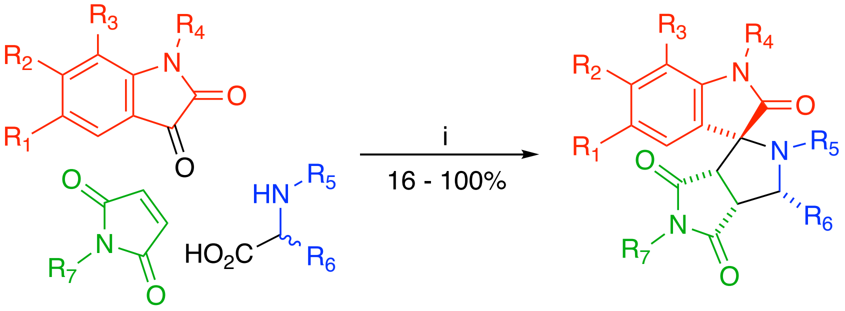


| | 3.34a | 3.34b | 3.34c | 3.34d |
|---|---|---|---|---|
| $R_1$ | Cl | H | F | Br |
| $R_2$ | H | Cl | H | H |

*Reagents and conditions:* (i) 1.0 equiv aniline, 1.1 equiv chloral hydrate, 3.1 equiv hydroxylamine hydrochloride, 9 equiv $Na_2SO_4$, 1.1 equiv 12 M HCl, $H_2O$, 80 °C, 1-2 h (ii) $H_2SO_4$, 60°C, 0.5 h (iii) 1.0 equiv isatin derivative, 4.0 equiv 2-Chloro-N,N-dimethylethylamine hydrochloride, 10 equiv $K_2CO_3$, 40 equiv $H_2O$, EtOAC, 77 °C, 3 h, 75%.

All spiroindolinone analogues were synthesized through a one pot, three-component coupling involving an isatin, maleimide, and an amino acid derivative (Scheme 3-4). As described previously, the reaction mechanism involves the condensation of the amino acid and the isatin to give an azomethine ylide that does a 1,3 dipolar cycloaddition with the maleimide. All spiroindolinones were isolated as racemates that gave a single diastereomer as described above.

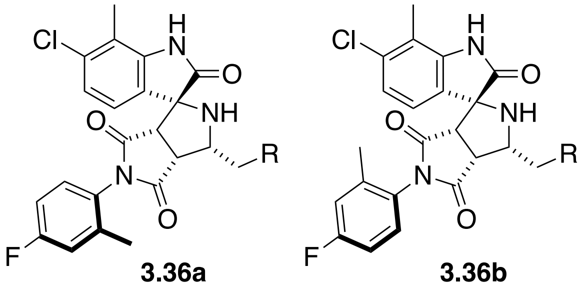
**Scheme 3-4:** Synthesis of Spiroindolinones



*Reagents and conditions:* (i) 1.0 equiv isatin, 1.05 equiv maleimide, 1.1 equiv amino acid derivative, MeOH/$H_2O$ (3:1), 90° C, 4-16 h.

Spiroindolinones with ortho-substituted *N*-aryl groups exhibit restricted rotation about the N-C bond in the maleimide and were isolated as a mixture of rotamers (Figure 3-4), inseparable by thin layer chromatography, silica gel chromatography or HPLC. Cycloadditon products of this type are known to exist as *N*-aryl rotamers that do not rotate on the NMR time scale but will equilibrate at room temperature.[151, 152, 153, 154, 155]

**Figure 3-4:** Example of a Spiroindolinone that has Two Different Rotamers

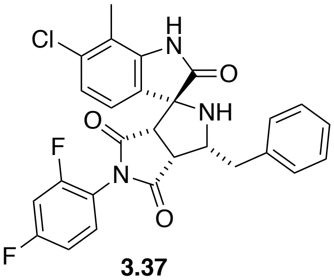


**3.36a** **3.36b**

## Structure Activity Relationships and Biological Evaluations

We determined the enhancement of antifungal activity for all of the new analogues against resistant *C. albicans* isolate 45 and resistant *C. glabrata* BG2. In the presence of a constant, nonlethal concentration of fluconazole fluconazole (64 μg/mL for *C. albicans* isolate 45 and 128 μg/mL for *C. glabrata* BG2), the analogues inhibited fungal cell growth in a dose-dependent fashion, from which $EC_{50}$ values were determined (Figure 3-5).

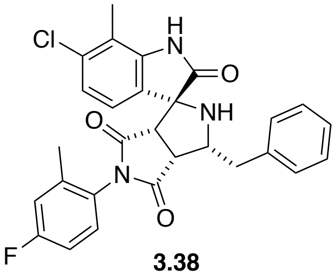
**Figure 3-5:** Spiroindolinone Activity



**3.37**

$EC_{50}$ = 1100 nM
*C. albicans* CI-45

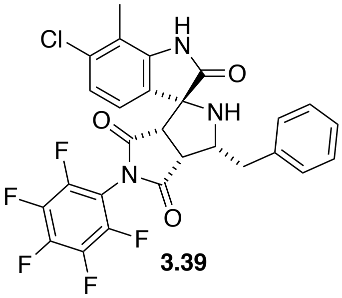
$EC_{50}$ = 1100 nM
*C. glabrata* BG2



**3.38**

$EC_{50}$ = 220 nM
*C. albicans* CI-45

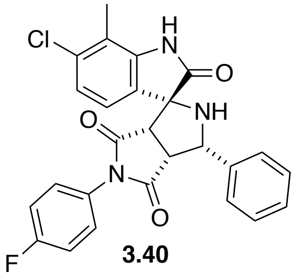
$EC_{50}$ = 530 nM
*C. glabrata* BG2



**3.39**

$EC_{50}$ = 470 nM
*C. albicans* CI-45

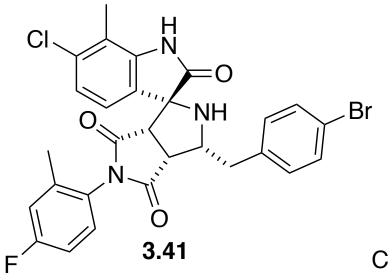
$EC_{50}$ > 30,000 nM
*C. glabrata* BG2



**3.40**

$EC_{50}$ > 30,000 nM
*C. albicans* CI-45

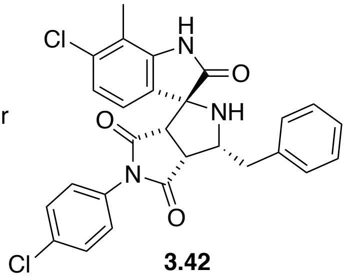
$EC_{50}$ > 30,000 nM
*C. glabrata* BG2



**3.41**

$EC_{50}$ = 140 nM
*C. albicans* CI-45

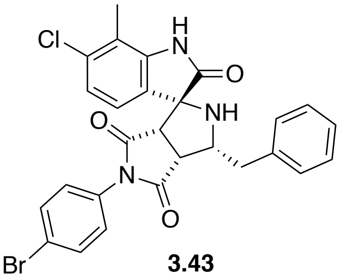
$EC_{50}$ = 310 nM
*C. glabrata* BG2



**3.42**

$EC_{50}$ = 470 nM
*C. albicans* CI-45

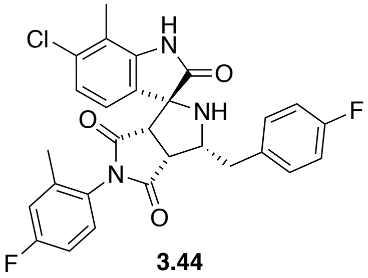
$EC_{50}$ = 500 nM
*C. glabrata* BG2



**3.43**

$EC_{50}$ = 330 nM
*C. albicans* CI-45

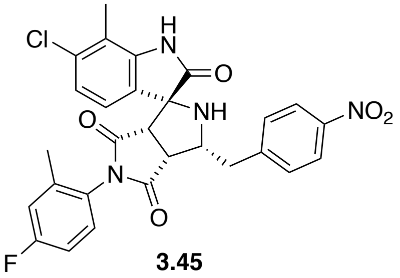
$EC_{50}$ = 260 nM
*C. glabrata* BG2



**3.44**

$EC_{50}$ = 128 nM
*C. albicans* CI-45

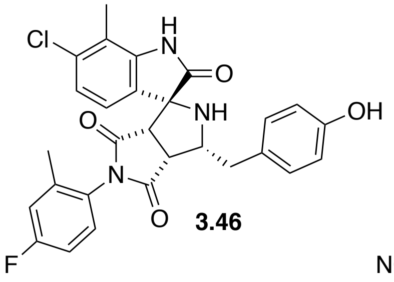
$EC_{50}$ = 280 nM
*C. glabrata* BG2



**3.45**

$EC_{50}$ = 130 nM
*C. albicans* CI-45

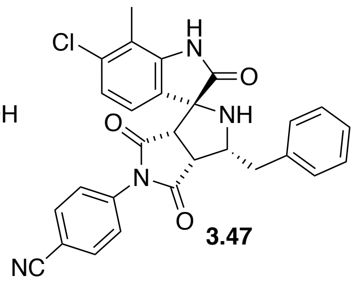
$EC_{50}$ = 219 nM
*C. glabrata* BG2



**3.46**

EC$_{50}$ = 600 nM
*C. albicans* CI-45

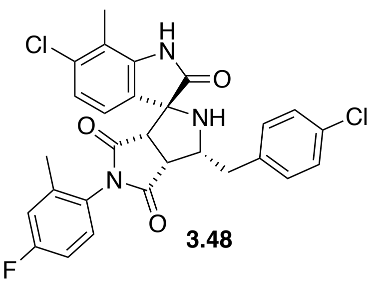
EC$_{50}$ = 570 nM
*C. glabrata* BG2



**3.47**

EC$_{50}$ = 560 nM
*C. albicans* CI-45

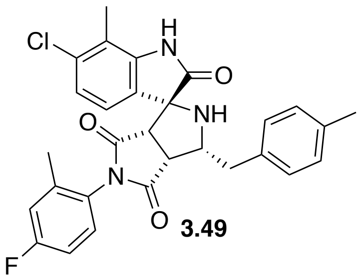
EC$_{50}$ = 760 nM
*C. glabrata* BG2



**3.48**

EC$_{50}$ = 80 nM
*C. albicans* CI-45

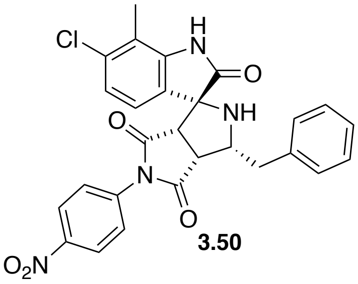
EC$_{50}$ = 260 nM
*C. glabrata* BG2



**3.49**

EC$_{50}$ = 320 nM
*C. albicans* CI-45

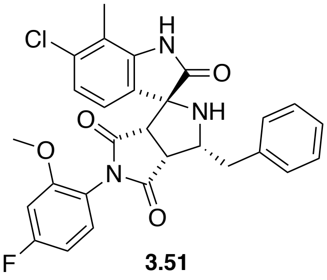
EC$_{50}$ = 390 nM
*C. glabrata* BG2



**3.50**

EC$_{50}$ = 800 nM
*C. albicans* CI-45

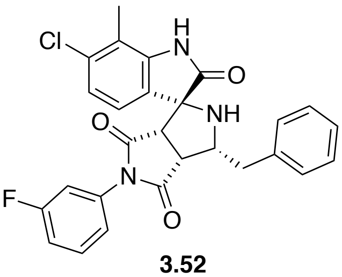
EC$_{50}$ = 550 nM
*C. glabrata* BG2



**3.51**

EC$_{50}$ = 500 nM
*C. albicans* CI-45

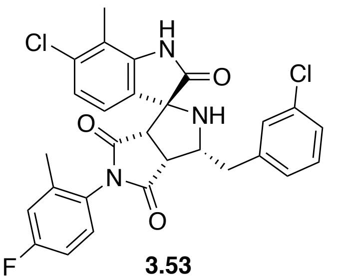
EC$_{50}$ = 600 nM
*C. glabrata* BG2



**3.52**

EC$_{50}$ = 890 nM
*C. albicans* CI-45

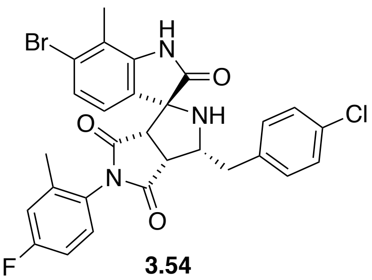
EC$_{50}$ = 600 nM
*C. glabrata* BG2



**3.53**

EC$_{50}$ = 160 nM
*C. albicans* CI-45

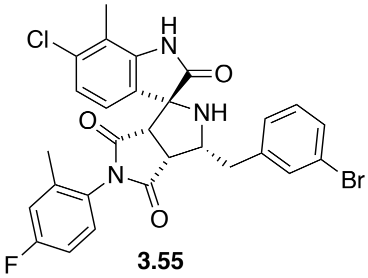
EC$_{50}$ = 700 nM
*C. glabrata* BG2



**3.54**

EC$_{50}$ = 100 nM
*C. albicans* CI-45

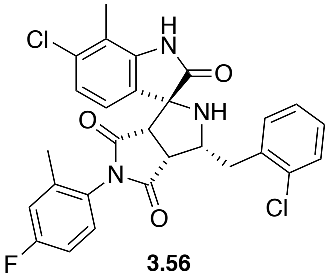
EC$_{50}$ = 340 nM
*C. glabrata* BG2



**3.55**

EC$_{50}$ = 60 nM
*C. albicans* CI-45

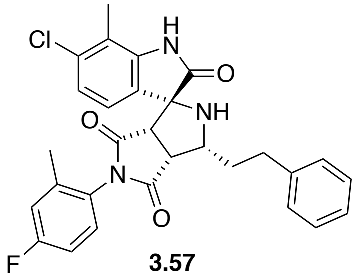
EC$_{50}$ = 290 nM
*C. glabrata* BG2



**3.56**

EC$_{50}$ = 44 nM
*C. albicans* CI-45

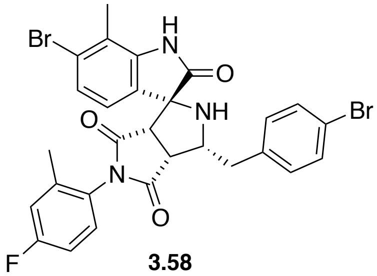
EC$_{50}$ = 160 nM
*C. glabrata* BG2



**3.57**

EC$_{50}$ = 33 nM
*C. albicans* CI-45

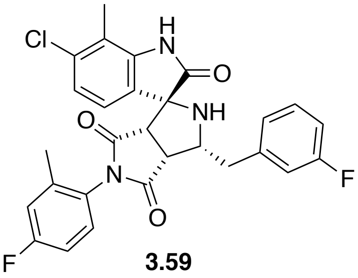
EC$_{50}$ = 440 nM
*C. glabrata* BG2



**3.58**

EC$_{50}$ = 110 nM
*C. albicans* CI-45

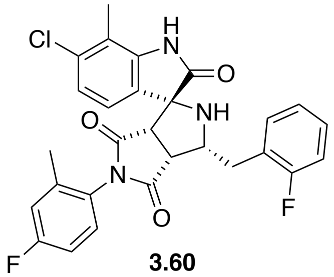
EC$_{50}$ = 140 nM
*C. glabrata* BG2



**3.59**

EC$_{50}$ = 98 nM
*C. albicans* CI-45

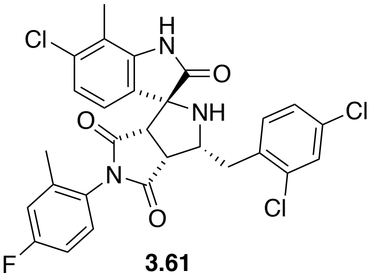
EC$_{50}$ = 369 nM
*C. glabrata* BG2



**3.60**

EC$_{50}$ = 150 nM
*C. albicans* CI-45

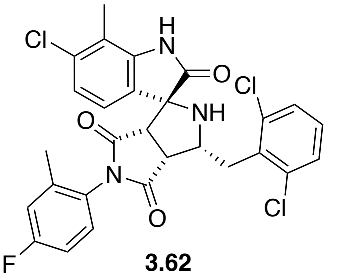
EC$_{50}$ = 460 nM
*C. glabrata* BG2



**3.61**

EC$_{50}$ = 53 nM
*C. albicans* CI-45

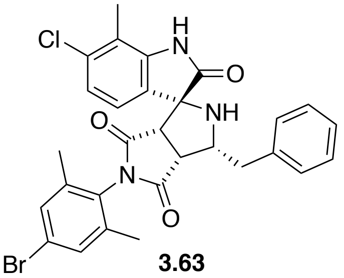
EC$_{50}$ = 90 nM
*C. glabrata* BG2



**3.62**

EC$_{50}$ = 190 nM
*C. albicans* CI-45

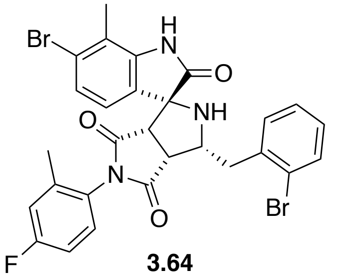
EC$_{50}$ = 260 nM
*C. glabrata* BG2



**3.63**

EC$_{50}$ = 450 nM
*C. albicans* CI-45

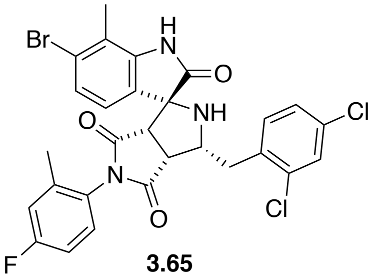
EC$_{50}$ = 37 nM
*C. glabrata* BG2



**3.64**

EC$_{50}$ = 38 nM
*C. albicans* CI-45

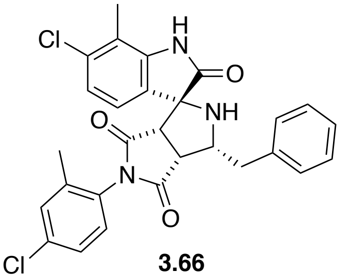
EC$_{50}$ = 210 nM
*C. glabrata* BG2



**3.65**

EC$_{50}$ = 74 nM
*C. albicans* CI-45

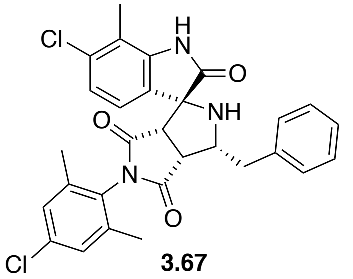
EC$_{50}$ = 130 nM
*C. glabrata* BG2



**3.66**

EC$_{50}$ = 180 nM
*C. albicans* CI-45

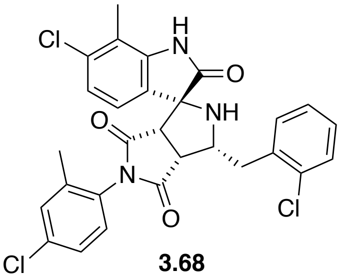
EC$_{50}$ = 236 nM
*C. glabrata* BG2



**3.67**

EC$_{50}$ > 30,000 nM
*C. albicans* CI-45

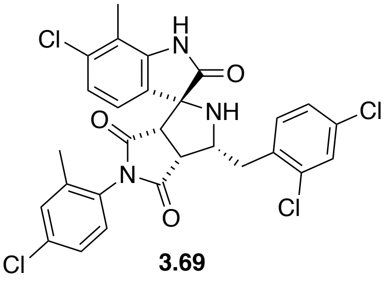
EC$_{50}$ = 43 nM
*C. glabrata* BG2



**3.68**

EC$_{50}$ = 280 nM
*C. albicans* CI-45

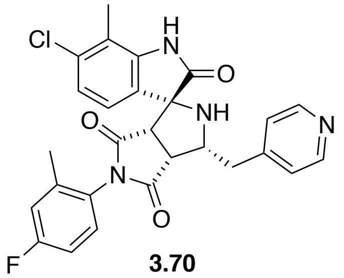
EC$_{50}$ = 214 nM
*C. glabrata* BG2



**3.69**

EC$_{50}$ = 325 nM
*C. albicans* CI-45

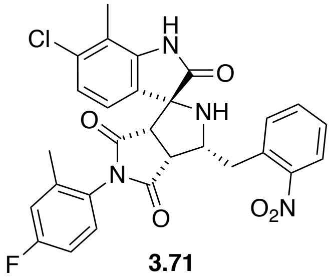
EC$_{50}$ = 80 nM
*C. glabrata* BG2



**3.70**

EC$_{50}$ > 30,000 nM
*C. albicans* CI-45

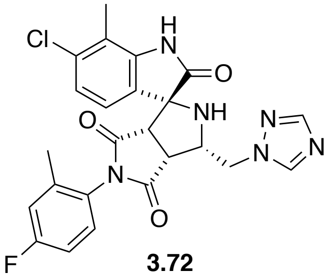
EC$_{50}$ > 30,000 nM
*C. glabrata* BG2



**3.71**

EC$_{50}$ = 80 nM
*C. albicans* CI-45

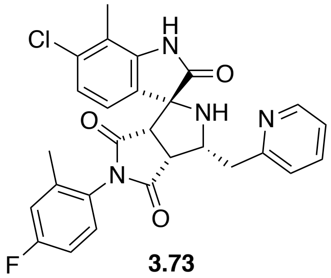
EC$_{50}$ = 100 nM
*C. glabrata* BG2



**3.72**

EC$_{50}$ > 30,000 nM
*C. albicans* CI-45

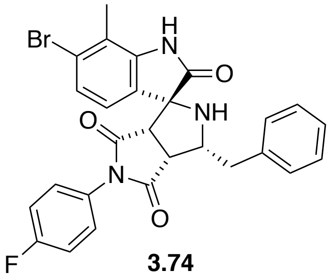
EC$_{50}$ > 30,000 nM
*C. glabrata* BG2



**3.73**

$EC_{50}$ > 30,000 nM
*C. albicans* CI-45

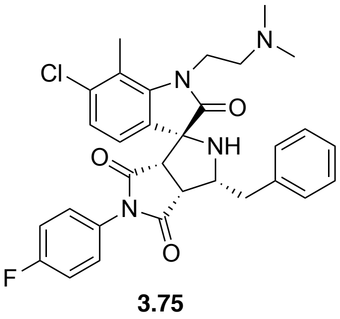
$EC_{50}$ = 2,900 nM
*C. glabrata* BG2



**3.74**

$EC_{50}$ = 490 nM
*C. albicans* CI-45

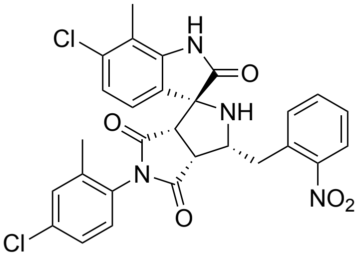
$EC_{50}$ = 3,400 nM
*C. glabrata* BG2



**3.75**

$EC_{50}$ > 30,000 nM
*C. albicans* CI-45

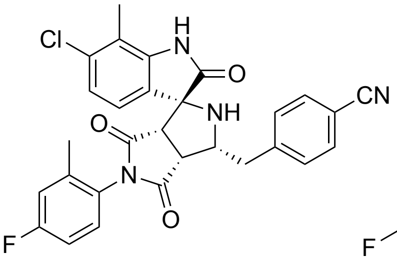
$EC_{50}$ > 30,000 nM
*C. glabrata* BG2



**3.76**

$EC_{50}$ = 22 nM
*C. albicans* CI-45

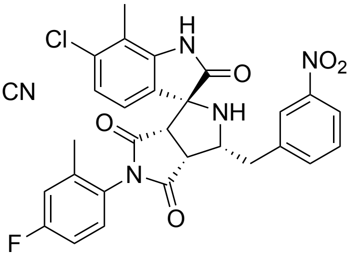
$EC_{50}$ = 120 nM
*C. glabrata* BG2



**3.77**

$EC_{50}$ = 240 nM
*C. albicans* CI-45

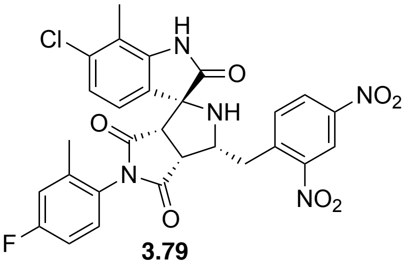
$EC_{50}$ = 100 nM
*C. glabrata* BG2



**3.78**

$EC_{50}$ = 21 nM
*C. albicans* CI-45

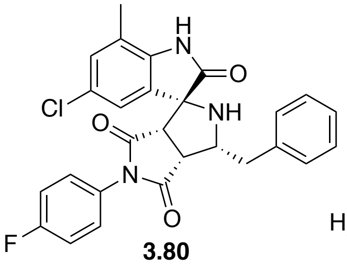
$EC_{50}$ = 95 nM
*C. glabrata* BG2



**3.79**

$EC_{50}$ = 230 nM
*C. albicans* CI-45

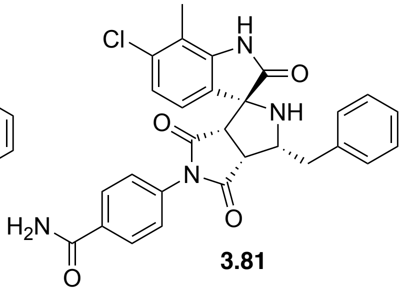
$EC_{50}$ = 90 nM
*C. glabrata* BG2



**3.80**

$EC_{50}$ > 30,000 nM
*C. albicans* CI-45

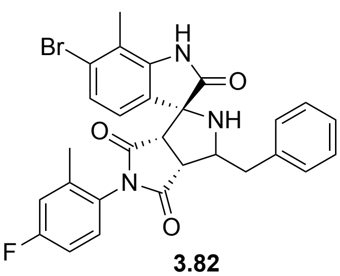
$EC_{50}$ = 700 nM
*C. glabrata* BG2



**3.81**

$EC_{50}$ > 30,000 nM
*C. albicans* CI-45

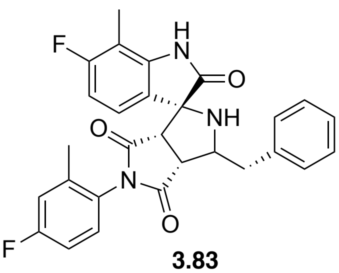
$EC_{50}$ > 30,000 nM
*C. glabrata* BG2



**3.82**

EC$_{50}$ = 170 nM
*C. albicans* CI-45

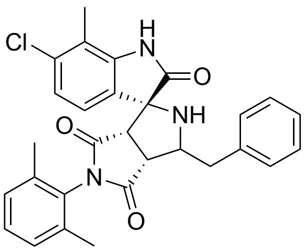
EC$_{50}$ = 400 nM
*C. glabrata* BG2



**3.83**

EC$_{50}$ = 3,600 nM
*C. albicans* CI-45

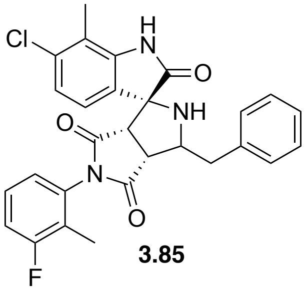
EC$_{50}$ = 500 nM
*C. glabrata* BG2



**3.84**

EC$_{50}$ = 800 nM
*C. albicans* CI-45

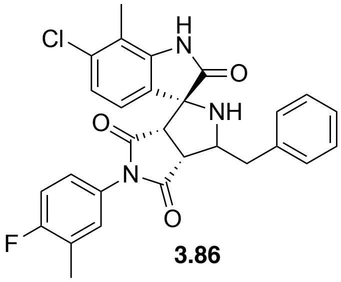
EC$_{50}$ = 220 nM
*C. glabrata* BG2



**3.85**

EC$_{50}$ = 900 nM
*C. albicans* CI-45

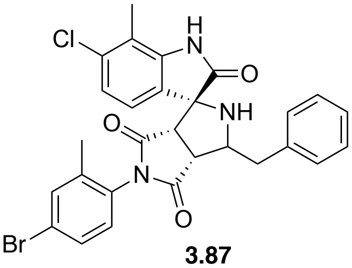
EC$_{50}$ = 1,590 nM
*C. glabrata* BG2



**3.86**

EC$_{50}$ = 550 nM
*C. albicans* CI-45

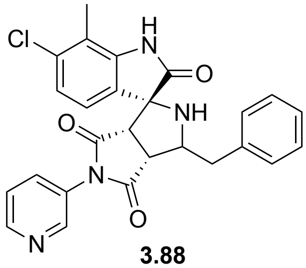
EC$_{50}$ = 710 nM
*C. glabrata* BG2



**3.87**

EC$_{50}$ = 500 nM
*C. albicans* CI-45

EC$_{50}$ = 140 nM
*C. glabrata* BG2



**3.88**

EC$_{50}$ > 30,000 nM
*C. albicans* CI-45

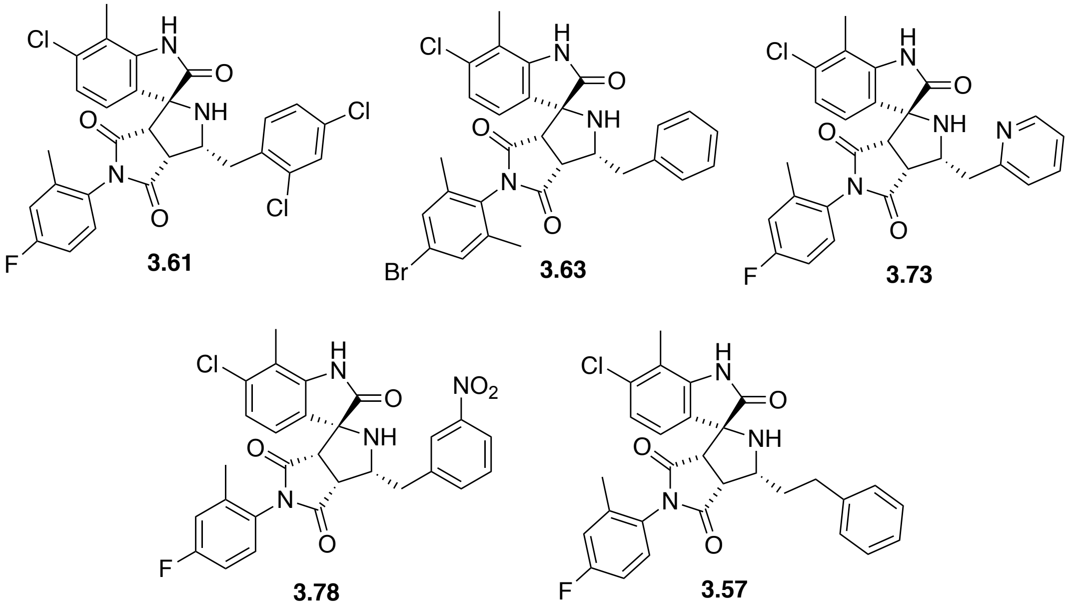
EC$_{50}$ = 4,300 nM
*C. glabrata* BG2

The three main regions of the spiroindolinone that were modified were, the isatin, the maleimide and amino acid fragments. Fewer modifications were made to the indolone than the other two fragments but the 5- and 6-positions of the indolone ring were modified. Comparing **3.38** and **3.83**, a chlorine at the 6-position led to better activity against *C. albicans* compared to fluorine although the activity against *C. glabrata* was comparable. Transposing the chlorine and hydrogen at the 5 and 6 positions (**3.80**) led to no activity against *C. albicans* and decreased potency against *C. glabrata* compared to lead compound **3.7**. Substituting the chlorine for larger bromine at the 6-position gave better activity for both species as seen in compounds **3.38** and **3.82**. However, comparing bromoindolone **3.65** with chloroindolone **3.61** and bromoindolone **3.54** with chloroindolone **3.48** shows that chloroindolones were more active against both species. These compounds with chlorine at the 6 position also gave lower absolute activity. Chlorine seemed to be a good middle ground in terms of electronegativity and size. Adding a polar *N*,*N*-dimethylaminoethyl group to the isatin (**3.75**) rendered the molecule completely inactive. It was determined that the isatin substitution of the lead compound, **3.7**, was the best.

Substitution of the maleimide fragment was explored in more detail than the isatin. Substitution with polar substituents on the maleimide fragments as seen in compounds the *N*-(3-pyridyl)succinimide analogue **3.88** and amide analogue **3.81** made the compounds inactive. Compared to lead compound **3.7**, adding a methyl at the ortho position of the *N*-phenyl ring to restrict rotation (**3.38**) led to better activity for both species. Having a methyl at the ortho position and a fluorine at the para position was the optimal substitution pattern for the N-aryl substituent as seen from 2-methyl, 3-flouro analogue **3.85** and 3-methyl, 4-flouro analogue **3.86**. 2,4-Difluorophenyl and pentafluorophenyl substituents on the succinimide were not beneficial for activity overall, (**3.37** and **3.39**). Electron withdrawing groups like *para*-$NO_2$ and *para*-CN (**3.50** and **3.47**) on the succinimide were slightly worse for activity overall compared to the original fluorine substitution. Having methyl groups on both the *ortho* positions of the *N*-phenyl ring (**3.84**, **3.67**, and **3.63**) was beneficial for activity for *C. glabrata* but was not beneficial against *C. albicans*. While having bromine at the para position of the *N*-phenyl ring (**3.43** and **3.87**) helped more against *C. glabrata*, chlorine and fluorine substitution was the best overall. For instance chlorine was better when comparing **3.38** and **3.66** but fluorine was better overall when comparing *p*-fluorophenylsuccinimide **3.61** with the *p*-chlorophenylsuccinimide **3.69**. Simultaneous optimization against two resistant strains was challenging but overall it was determined that ortho methyl group, serving as a steric lock, and an electron-withdrawing para-fluorine or chlorine group were the best substituents for the N-phenyl ring..

The last region of substitution was on the amino acid side chain. Replacing the phenyl substituent with very polar groups like pyridine derivatives was detrimental to activity against both species (**3.70**, **3.72**, and **3.73**). However, a tyrosine derivate, **3.46**, gave similar activity as the lead compound **3.7**. Adding a methyl group to the phenyl ring, **3.49**, was beneficial for *C. glabrata* activity but hurt *C. albicans* activity. Using phenylglycine as the amino acid, **3.40**, showed no activity while using homophenylalanine, **3.57**, greatly increased the activity against *C. albicans*. Generally, putting electron withdrawing groups on the phenyl ring of phenylalanine greatly increased the activity against both species. While fluorine, cyano, and bromine substitution on phenylalanine increased the activity against both species, substitution with chlorine (**3.61**) or nitro groups (**3.78**) was the most beneficial for activity. Overall, three compounds (**3.61**, **3.78**, and **3.71**) had activity at or below 100 nM against both species.

**Figure 3-6:** Analogues Tested for Cytotoxicity



**3.61** **3.63** **3.73** **3.78** **3.57**

**3.61**, **3.63**, **3.73**, **3.78**, and **3.57** (figure 3-6) were tested against 3T3 mammalian fibroblasts for cytotoxicity. All analogues except **3.57** displayed no cytotoxicity up to 45 μM (the limit of the assay). **3.57** did not display cytotoxicity up to 15 μM. These molecules are active against *Candida* at concentrations much lower than those used in the cytotoxicity assay.

## Conclusion

In conclusion we have designed, synthesized, and studied spiroindolinone analogues of lead compound **3.7** which was active against resistant species of *C. albicans* and *C. glabrata* in the presence of fluconazole. Most of the analogues synthesized showed potent activities against both resistant strains. Three spiroindolinone analogues were shown to be active at or below 100 nM against both resistant species. These compounds were shown to not be active against 3T3 mammalian fibroblasts.

## Experimental Section

### General Experiment Procedure:

NMR spectral data were recorded at 25 °C using a Bruker 500 MHz spectrometer. The NMR data are reported as follows: chemical shifts in ppm are calibrated to tetramethylsilane (0 ppm), or residual solvents signals of $CDCl_3$ (7.26 ppm) or DMSO-$d_6$ (2.50 ppm), multiplicity (br = broad, app = apparent, s = singlet, d = doublet, t = triplet, q = quartet and m = multiplet), coupling constants (Hz), and integration. Analytical thin layer chromatography (TLC) was performed using EMD Reagents 0.25 mm silica gel 60–F plates. Silica gel chromatography was performed using Silicycle silica gel (40–63 µm). All reactions were carried out under an atmosphere of nitrogen unless otherwise noted. Reactions were carried out at ambient temperature unless otherwise indicated. Unless otherwise noted, all reagents were commercially obtained and, where appropriate, purified prior to use. THF and $CH_2Cl_2$ were dried by filtration through alumina according to the procedure of Grubbs and coworkers.[156] The purity of compounds tested for antifungal activity was determined by reversed-phase high-performance liquid chromatography using an ACE C-18 PFP column. A mixture of $H_2O$ (with 0.1% formic acid) and MeCN was used as eluent.

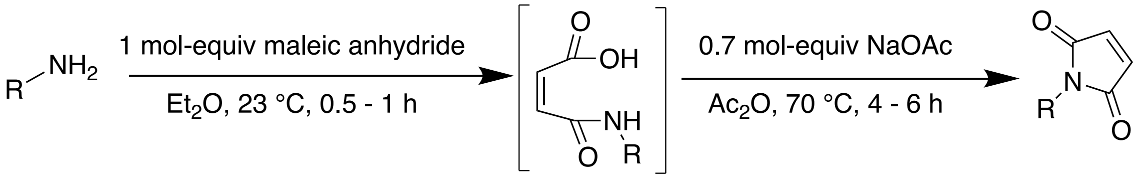
### Synthetic Procedures and Characterization:

### Synthesis of maleimides:

All maleimides were synthesized according to the procedure below unless otherwise specified. Synthesis and characterization for uncharacterized compounds are listed below. Previously characterized compounds are listed as follows: 1-(4-fluorophenyl)-1*H*-pyrrole-2,5-dione[157], 1-(2,6-dimethylphenyl)-1*H*-pyrrole-2,5-dione[158], 1-(2,4-difluorophenyl)-1*H*-pyrrole-2,5-dione[159], 1-(5-methylisoxazol-3-yl)-1*H*-pyrrole-2,5-

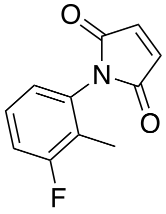
dione[160], 1-(perfluorophenyl)-1*H*-pyrrole-2,5-dione[161], 1-(4-chlorophenyl)-1*H*-pyrrole-2,5-dione[162], 1-(4-bromophenyl)-1*H*-pyrrole-2,5-dione[163], 4-(2,5-dioxo-2,5-dihydro-1*H*-pyrrol-1-yl)benzonitrile[164], 1-(4-nitrophenyl)-1*H*-pyrrole-2,5-dione[165], 1-(3-fluorophenyl)-1*H*-pyrrole-2,5-dione[166] and 1-(2-fluorophenyl)-1*H*-pyrrole-2,5-dione[167].

**General procedure for the synthesis of maleimides:**



An oven-dried round bottom flask was charged with maleic anhydride (1.0 equiv), ether (0.90 M), and a stir bar. A separate round bottom flask was charged with an aniline or amine (1 equiv), ether (0.90 M), and a stir bar. The contents of the flask with the aniline or amine were transferred to the flask with the anhydride dropwise via syringe. The reaction mixture was monitored by TLC for disappearance of aniline or amine. Once the aniline or amine was consumed (0.5 h – 1 h) the resulting precipitate was filtered in a Büchner funnel with cold ether. The crude acid intermediate was added to an oven-dried round bottom flask. Sodium acetate (0.6 – 0.8 equiv), acetic anhydride (0.83 M), and a stir bar were also added to the flask. The reaction mixture was heated to 70 °C and monitored by TLC for disappearance of the acid intermediate. Upon disappearance of the acid intermediate (1 h to 4 h) the reaction mixture was cooled to room temperature. The reaction mixture was poured into a mixture of $CH_2Cl_2$ and a saturated solution of $NaHCO_3$ and allowed to stir for 1 h. The mixture was extracted with $CH_2Cl_2$. The combined organic layers were dried with $Na_2SO_4$. The $CH_2Cl_2$ was removed by reduced pressure and the crude material was purified by flash chromatography (EtOAc:hex) to yield pure maleimides.

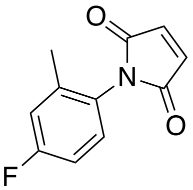
1-(3-Fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (**3.32g**):



**3.32g**

Maleic anhydride (0.86 g, 8.8 mmol, 1.1 equiv), 3-fluoro-2-methylaniline (1.0 g, 8.0 mmol, 1.0 equiv) and 10 mL of $CH_2Cl_2$ were added to an oven-dried round bottom flask and stirred at 40°C for 2 h. After completion, the precipitate was filtered with $CH_2Cl_2$. All of the crude product was added to 11 mL of acetic anhydride and sodium acetate (0.56 g, 6.8 mmol, 0.85 equiv) and stirred at 70°C for 16 hours. The crude material was diluted with saturated $NaHCO_3$ and EtOAc, extracted, and purified with column chromatography to afford maleimide **3.32g** (0.99 g, 4.8 mmol, 60%) as a white solid. $R_f$ = 0.6 (3:7 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 7.26 (dd, *J* = 14.2, 8.2 Hz, 1H), 7.13 (t, *J* = 8.8 Hz, 1H), 6.94 (d, *J* = 7.9 Hz, 1H), 6.87 (s, 2H), 2.06 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 169.4, 162.7, 160.7, 134.6, 131.7, 131.6, 127.3, 127.2, 124.8, 124.6, 124.5, 124.4, 116.3, 116.1, 10.4, 10.3; HRMS (ESI): *m/z* calculated for $C_{11}H_8FNO_2NaCH_3OH$ $[M+Na+CH_3OH]^+$ 260.0699, found 260.0704.

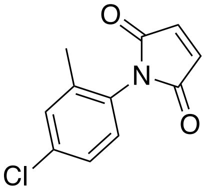
1-(4-Fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione, (**3.32h**):



**3.32h**

An oven-dried round bottom flask was charged with maleic anhydride (1.8 g, 18 mmol, 1.0 equiv), ether (20 mL, 0.90 M), and a stir bar. A separate round bottom flask was charged with 4-fluoro-2-methyl-aniline (2.3 g, 18.0 mmol, 1 equiv), ether (20 mL, 0.90 M), and a stir bar. The contents of the flask with the aniline were transferred to the flask with the anhydride dropwise via syringe. The reaction mixture was monitored by TLC for disappearance of aniline. Once the aniline or amine was consumed (0.5 h) the resulting precipitate was filtered in a Büchner funnel with cold ether to give the crude acid intermediate (2.9 g, 13.0 mmol, 72%). Some of the crude acid intermediate (1.0 g, 4.5 mmol, 1.0 equiv) was added to an oven-dried round bottom flask. Sodium acetate (0.28 g, 3.4 mmol, 0.76 equiv), acetic anhydride (5.4 mL, 0.83 M), and a stir bar were also added to the flask. The reaction mixture was heated to 70 °C and monitored by TLC for disappearance of the acid intermediate. Upon disappearance of the acid intermediate (1 h) the reaction mixture was cooled to room temperature. The reaction mixture was poured into a mixture of $CH_2Cl_2$ and a saturated solution of $NaHCO_3$ and allowed to stir for 1 h. The mixture was extracted with $CH_2Cl_2$. The combined organic layers were dried with $Na_2SO_4$. The $CH_2Cl_2$ was removed by reduced pressure and the crude material was purified by flash chromatography (EtOAc:hex) to yield maleimide **3.32h** (0.64 g, 3.1 mmol, 91%) as a yellow solid. $R_f$ = 0.5 (3:2 EtOAc:hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 7.14 (dd, *J* = 8.7, 5.3 Hz, 1H), 7.10 (dd, *J* = 9.1, 2.7, 1H), 7.05 (td, *J* = 8.1, 2.8, 1H), 6.93 (s, 2H), 2.20 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 169.6, 163.8, 161.8, 139.3, 139.2, 134.5, 130.5, 130.4, 125.9, 125.9, 118.0, 117.8, 114.0, 113.9, 18.2; HRMS (ESI): *m/z* calculated for $C_{11}H_8NO_2F$ $[M]^+$ 205.0539, found 205.0539.

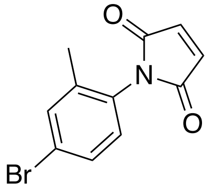
1-(4-Chloro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (**3.32i**):



**3.32i**

Using the general procedure for maleimide synthesis outlined above, 4-chloro-2-methylaniline (2.55 g, 18.0 mmol, 1 equiv) and maleic anhydride (1.76 g, 18.0 mmol, 1 equiv) were used to yield the crude acid intermediate (3.84 g, 16.0 mmol, 89%). The crude acid intermediate (1.53 g, 6.37 mmol, 1 equiv) was combined with sodium acetate (0.39 g, 4.8 mmol, 0.75 equiv) and acetic anhydride to give **3.32i** (1.13 g, 5.10 mmol, 80%) as a white solid. $R_f$ = 0.4 (3:7 EtOAc:hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 7.33 (s, 1H), 7.28 (m, 1H), 7.05 (d, *J* = 8.4 Hz, 1H), 6.87 (s, 2H), 2.13 (s, 3H) ; $^{13}$C NMR (500 MHz, $CDCl_3$) δ 169.4, 138.5, 135.2, 134.6, 131.2, 130.0, 128.6, 127.2, 18.0; HRMS (ESI): *m/z* calculated for $C_{11}H_8ClNO_2NaCH_3OH$ $[M+Na+CH_3OH]^+$ 276.0403, found 276.0409.

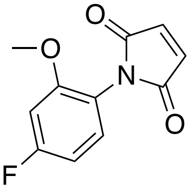
1-(4-Bromo-2-methylphenyl)-1*H*-pyrrole-2,5-dione (**3.32j**):



**3.32j**

Using the general procedure for maleimide synthesis outlined above, 4-bromo-2-methylaniline (3.35 g, 18.0 mmol, 1 equiv) and maleic anhydride (1.76 g, 18.0 mmol, 1 equiv) were used to yield the crude acid intermediate (4.17 g, 15.0 mmol, 83%). The crude acid intermediate (1.81 g, 6.4 mmol, 1 equiv) was combined with sodium acetate (0.39 g, 4.8 mmol, 0.75 equiv) and acetic anhydride to yield **3.32j** (1.26 g, 4.8 mmol, 75%) as a yellow solid. $R_f$ = 0.4 (3:7 EtOAc:hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 7.49 (d, *J* = 1.8 Hz, 1H), 7.43 (dd, *J* = 8.4, 2.0 Hz, 1H), 6.98 (d, *J* = 8.4 Hz, 1H), 6.87 (s, 2H), 2.13 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 169.3, 138.9, 134.6, 134.2, 130.3, 130.2, 129.1, 123.5, 18.0; HRMS (ESI): *m/z* calculated for $C_{11}H_8BrNO_2NaCH_3OH$ $[M+Na+CH_3OH]^+$ 319.9898, found 319.9914.

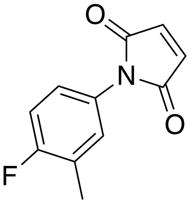
1-(4-Fluoro-2-methoxyphenyl)-1*H*-pyrrole-2,5-dione (**3.32k**):



**3.32k**

Using the general procedure for maleimide synthesis outlined above, 4-fluoro-2-methoxyaniline (0.50 g, 3.5 mmol, 1 equiv) and maleic anhydride (0.35 g, 3.5 mmol, 1 equiv) were used to yield the crude acid intermediate (0.71 g, 3.0 mmol, 85%). The crude acid intermediate (0.60 g, 2.5 mmol, 1 equiv) was combined with sodium acetate (0.16 g, 2.0 mmol, 0.8 equiv) and acetic anhydride to yield **3.32k** (0.22 g, 0.99 mmol, 39%) as a white solid. $R_f$ = 0.4 (3:7 EtOAc:hex). $^1$H NMR (500 MHz, CDCl$_3$) δ 7.13 (t, *J* = 7.9 Hz, 1H), 6.85 (s, 2H), 6.76 – 6.72 (m, 2H), 3.78 (s, 3H); $^{13}$C NMR (500 MHz, CDCl$_3$) δ 169.8, 165.1, 163.1, 156.8, 156.7, 134.6, 131.2, 131.1, 115.72, 115.70, 107.7, 107.5, 100.7, 100.5, 56.2; HRMS (ESI): *m/z* calculated for $C_{11}H_8FNO_3NaCH_3OH$ [M+Na+CH$_3$OH]$^+$ 276.0648, found 276.0657.

1-(4-Fluoro-3-methylphenyl)-1*H*-pyrrole-2,5-dione (**3.32l**):

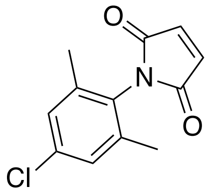


**3.32l**

Maleic anhydride (0.86 g, 8.8 mmol, 1.1 equiv), 4-fluoro-3-methylaniline (1.0 g, 8.0 mmol, 1.0 equiv) and 10 mL of CH$_2$Cl$_2$ were added to an oven-dried round bottom flask and stirred at 40°C for 1 h. After completion, the precipitate was filtered with CH$_2$Cl$_2$. All of the crude product was added to 11 mL of acetic anhydride and sodium acetate (0.56 g, 6.8

mmol, 0.85 equiv) in an oven-dried round bottom flask. The solution was stirred at 70°C for 4 hours. The crude material was diluted with saturated $NaHCO_3$ and EtOAc, extracted, and purified with column chromatography to afford maleimide **3.32l** (1.3 g, 6.2 mmol, 77%) as a yellow solid. $R_f$ = 0.4 (3:7 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 7.15 – 7.06 (m, 3H), 6.83 (s, 2H), 2.30 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 169.6, 161.6, 159.6, 134.3, 129.44, 129.39, 126.76, 126.74, 126.23, 126.08, 125.5, 125.4, 115.9, 115.7, 14.69, 14.67; HRMS (ESI): *m/z* calculated for $C_{11}H_8FNO_2NaCH_3OH$ $[M+Na+CH_3OH]^+$ 260.0699, found 260.0700.

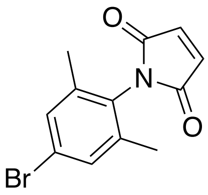
1-(4-Chloro-2,6-dimethylphenyl)-1*H*-pyrrole-2,5-dione (**3.32n**):



**3.32n**

Using the general procedure for maleimide synthesis outlined above, 4-chloro-2,6-dimethylaniline (0.33 g, 2.14 mmol, 1 equiv) and maleic anhydride (0.21 g, 2.14 mmol, 1 equiv) were used to yield the crude acid intermediate (0.35 g, 1.38 mmol, 64%). The crude acid intermediate (0.35 g, 1.38 mmol, 1 equiv) was combined with sodium acetate (0.08 g, 0.98 mmol, 0.71 equiv) and acetic anhydride to give **3.32n** (0.17 g, 0.74 mmol, 53%) as a white solid. $R_f$ = 0.5 (3:7 EtOAc:hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 7.15 (d, *J* = 0.4 Hz, 2H), 6.88 (s, 2H), 2.09 (s, 6H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 169.3. 139.0, 135.2, 134.6, 128.6, 127.9, 18.0; HRMS (ESI): *m/z* calculated for $C_{12}H_{10}ClNO_2NaCH_3OH$ $[M+Na+CH_3OH]^+$ 290.0560, found 290.0562.

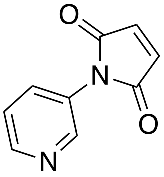
1-(4-Bromo-2,6-dimethylphenyl)-1*H*-pyrrole-2,5-dione (**3.32o**):



**3.32o**

Using the general procedure for maleimide synthesis outlined above, 4-bromo-2,6-dimethylaniline (1.80 g, 9.0 mmol, 1 equiv) and maleic anhydride (0.88 g, 9.0 mmol, 1 equiv) were used to yield the crude acid intermediate (2.05 g, 6.9 mmol, 77%). The crude acid intermediate (0.30 g, 1.00 mmol, 1 equiv) was combined with sodium acetate (0.062 g, 0.76 mmol, 0.76 equiv) and acetic anhydride to yield **3.32o** (0.18 g, 0.63 mmol, 63%) as a yellow solid. $R_f$ = 0.5 (3:7 EtOAc:hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 7.31 (s, 2H), 6.88 (s, 2H), 2.08 (d, *J* = 0.4 Hz, 6H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 169.3, 139.2, 134.6, 131.6, 128.5, 123.5, 17.9; HRMS (ESI): *m/z* calculated for $C_{12}H_{10}BrNO_2Na$ [M+Na]$^+$ 301.9792, found 301.9802.

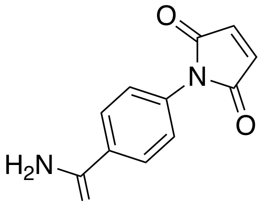
1-(Pyridin-3-yl)-1*H*-pyrrole-2,5-dione (**3.32q**):



**3.32q**

Maleic anhydride (0.57 g, 5.8 mmol, 1.1 equiv), pyridin-3-amine (0.50 g, 5.3 mmol, 1.0 equiv) and 5 mL of $CH_2Cl_2$ were added to an oven-dried round bottom flask and stirred at 40°C for 1 h. After completion, the precipitate was filtered with $CH_2Cl_2$. All of the crude product was added to 10 mL of acetic anhydride and sodium acetate (0.25 g, 3.0 mmol, 0.56 mol-equiv) and stirred at 60°C for 2 h. The crude material was diluted with saturated $NaHCO_3$ and EtOAc, extracted, and purified with column chromatography to afford maleimide **3.32q** (0.17 g, 0.97 mmol, 18%) as a white solid. R*f* = 0.5 (6:4 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$) δ 8.68 (d, *J* = 2.3 Hz, 1H), 8.59 (dd, *J* = 4.8, 3.5 Hz, 1H), 7.72 (dt, *J* = 8.2, 1.6 Hz, 1H), 7.40 (dd, *J* = 8.2, 4.8 Hz, 1H), 6.89 (s, 2H); $^{13}$C NMR (500 MHz, CDCl$_3$) δ 169.0, 148.8, 146.9, 134.6, 133.1, 128.5, 123.8; HRMS (ESI): *m/z* calculated for $C_9H_6N_2O_2NaCH_3OH$ [M+Na+CH$_3$OH]$^+$ 229.0589, found 229.0589.

4-(2,5-Dioxo-2,5-dihydro-1*H*-pyrrol-1-yl)benzamide (**3.32r**):



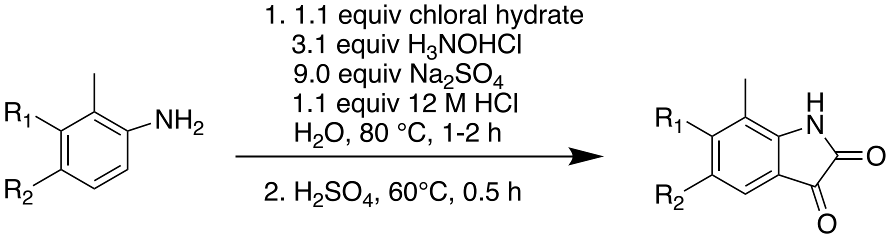
**3.32r**

Maleic anhydride (0.36 g, 3.7 mmol, 1.0 equiv), 4-aminobenzamide (0.50 g, 3.7 mmol, 1.0 equiv) and 5 mL of $CH_2Cl_2$ were added to an oven-dried round bottom flask and stirred at 40 °C for 16 h. After completion, the precipitate was filtered with $CH_2Cl_2$. All of the crude product was added to 10 mL of acetic anhydride and sodium acetate (0.50 g, 6.1 mmol, 1.6 equiv) in an oven-dried round bottom flask. The solution was stirred at 70°C for 6 hours. After reaction completion, the precipitate was washed with water and dried to afford maleimide **3.32r** (0.40 g, 1.8 mmol, 50%) as a white solid. R*f* = 0.2 (7:3 EtOAc:Hex). $^1$H NMR (500 MHz, DMSO) δ 8.03 (s, 1H), 7.96 (d, *J* = 8.5 Hz, 2H), 7.44 – 7.42 (m, 3H), 7.21 (s, 2H); $^{13}$C NMR (500 MHz, DMSO) δ 167.7, 167.2, 134.8, 134.1, 133.3, 128.1, 126.1; HRMS (ESI): *m/z* calculated for $C_{11}H_8N_2O_3NaCH_3OH$ [M+Na+CH$_3$OH]$^+$ 271.0695, found 271.0705.

**Synthesis of isatins:**

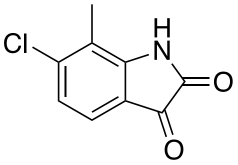
All isatins were synthesized according to the procedure below unless otherwise specified. Synthesis and characterization for uncharacterized compounds are listed below.

**General procedure for the synthesis of isatins:**



An oven-dried round bottom flask was charged with an aniline (1.0 equiv), DI water (0.4 M with respect to the aniline), and a stir bar. Sodium sulfate (9.0 equiv) was added to the round bottom flask with stirring. Chloral hydrate (1.1 equiv) and hydroxylamine hydrochloride (3.1 equiv) were then added to the stirred solution. Lastly, concentrated hydrochloric acid (1.1. equiv) was added to the flask. The reaction mixture was heated to 80°C until a purple-brown color was observed (1-2 h). The reaction was poured over ice. The resulting precipitate was filtered in a Buchner funnel with cold DI water. Meanwhile, in a separate oven-dried round bottom flask was charged with concentrated sulfuric acid (1.2 M with respect to the original aniline) and heated to 60°C. The crude precipitate was then added to the flask with sulfuric acid in portions over a course of five minutes and was allowed to stir for an additional thirty minutes. After thirty minutes, the solution was poured over ice and filtered in a Buchner funnel with cold DI water. The product was then dissolved in 2.0 M sodium hydroxide and stirred for fifteen minutes. The solution was filtered in a Buchner funnel with cold DI water. The filtrate was collected and made acidic with concentrated hydrochloric acid until the solution reached a pH of 1. The orange precipitate was filtered in a Buchner funnel with cold DI water and collected.

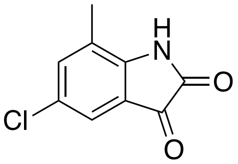
6-Chloro-7-methylindoline-2,3-dione (**3.34a**):



**3.34a**

Using the general procedure for isatin synthesis outlined above, 3-chloro-2-methylaniline (6.0 g, 42.4 mmol, 1 equiv), chloral hydrate (7.7 g, 46.6 mmol, 1.1 equiv), and hydroxylamine hydrochloride (9.1 g, 131.4 mmol, 3.1 equiv) were combined to give crude isonitrosoacetanilide. The crude product was further dissolved in sulfuric acid to yield isatin **3.34a** (4.1 g, 21.0 mmol, 45%) as an orange solid. R*f* = 0.4 (2:3 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO) δ 11.30 (s, 1H), 7.36 (d, *J* = 8.0 Hz, 1 H), 7.14 (d, *J* = 8.1 Hz, 1H), 2.21 (s, 3H); $^{13}$C NMR (500 MHz, DMSO) δ 183.7, 160.1, 150.5, 142.9, 123.18, 123.15, 119.9, 116.5, 13.1; HRMS (ESI): *m/z* calculated for $C_9H_6ClNO_2Na$ [M+Na]$^+$ 217.9985, found 217.9995.

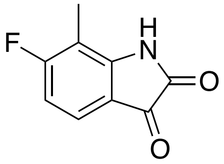
5-Chloro-7-methylindoline-2,3-dione (**3.34b**):



**3.34b**

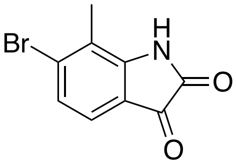
Using the general procedure for isatin synthesis outlined above, 4-chloro-2-methylaniline (2.0 g, 14.2 mmol, 1 equiv), chloral hydrate (2.6 g, 15.5 mmol, 1.1 equiv), and hydroxylamine hydrochloride (3.1 g, 44.0 mmol, 3.1 equiv) were combined to give crude isonitrosoacetanilide. The crude product was further dissolved in sulfuric acid to yield isatin **3.34b** (1.4 g, 7.2 mmol, 50%) as an orange solid. R*f* = 0.4 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO) δ 11.20 (s, 1H), 7.50 (d, *J* = 2.0 Hz, 1H), 7.63 (d, *J* = 1.6 Hz, 1H), 2.20 (s, 3H); $^{13}$C NMR (500 MHz, DMSO) δ 183.7, 159.7, 148.1, 138.0, 126.6, 123.9, 121.3, 118.7, 15.2; HRMS (ESI): *m/z* calculated for $C_9H_6ClNO_2Na$ $[M+Na]^+$ 217.9985, found 217.9982.

6-Fluoro-7-methylindoline-2,3-dione (**3.34c**):


**3.34c**

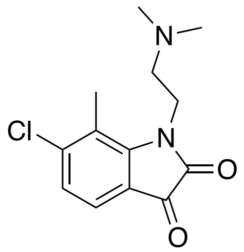
Using the general procedure for isatin synthesis outlined above, 3-fluoro-2-methylaniline (2.0 g, 16.0 mmol, 1 equiv), chloral hydrate (2.9 g, 17.6 mmol, 1.1 equiv), and hydroxylamine hydrochloride (3.4 g, 50.0 mmol, 3.1 equiv) were combined to give crude isonitrosoacetanilide. The crude product was further dissolved in sulfuric acid to yield isatin **3.34c** (0.15 g, 0.84 mmol, 32%) as an orange solid. $R_f$ = 0.5 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO) δ 11.29 (s, 1H), 7.44 (dd, *J* = 8.2, 5.7 Hz, 1H), 6.84 (dd, *J* = 10.0, 8.6 Hz, 1H), 2.10 (s, 3); $^{13}$C NMR (500 MHz, DMSO) δ 182.9, 167.5, 165.4, 160.3, 152.0, 151.9, 124.8, 124.7, 114.37, 114.35; 109.7, 109.52, 109.47, 109.32, 8.18, 8.15; HRMS (ESI): *m/z* calculated for $C_9H_6FNO_2Na$ $[M+Na]^+$ 202.0280, found 202.0278.

6-Bromo-7-methylindoline-2,3-dione (**3.34d**):


**3.34d**

Using the general procedure for isatin synthesis outlined above, 3-bromo-2-methylaniline (2.7 g, 14.1 mmol, 1 equiv), chloral hydrate (2.6 g, 15.5 mmol, 1.1 equiv), and hydroxylamine hydrochloride (3.04 g, 43.8 mmol, 3.1 equiv) were combined to give crude isonitrosoacetanilide. The crude product was further dissolved in sulfuric acid to yield isatin **3.34d** (0.6 g, 2.7 mmol, 19%) as an orange solid. $R_f$ = 0.6 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO) δ 11.26 (s, 1H), 7.32 (d, *J* = 8.0 Hz, 1H), 7.26 (d, *J* = 8.0 Hz, 1H), 2.29 (s, 3H $^{13}$C NMR (500 MHz, DMSO) δ 184.0, 160.0, 150.0, 134.8, 126.4, 123.2, 121.7, 117.0, 16.0; HRMS (ESI): *m/z* calculated for $C_9H_6BrNO_2Na$ $[M+Na]^+$ 261.9480, found 261.9477.

6-Chloro-1-(2-(dimethylamino)ethyl)-7-methylindoline-2,3-dione (**3.35**):

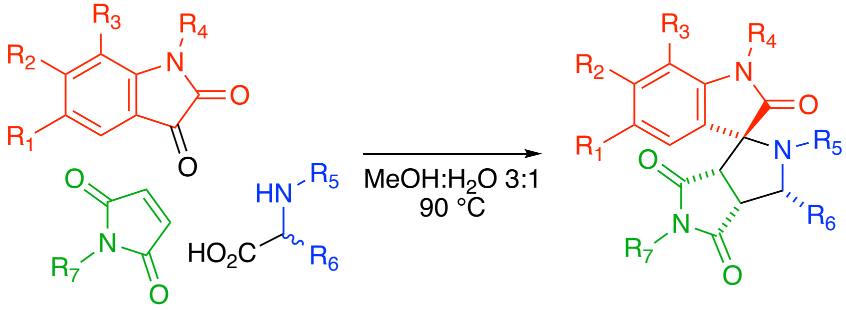


**3.35**

An oven-dried round bottom flask was charged with 6-chloro-7-methylindoline-2,3-dione (0.3 g, 1.5 mmol, 1 equiv), ethyl acetate (30 mL, 0.05 M with respect to the indoline), water (1.02 mL, 1.5 M with respect to the indoline), and a stir bar. 2-Chloro-N,N-dimethylethylamine hydrochloride (0.9 g, 6.1 mmol, 4 equiv) and potassium carbonate (2.1 g, 15.3 mmol, 10 equiv) were subsequently added. The reaction was heated to 77°C for 3 h. The solvent was removed by reduced pressure and the crude material was purified by flash chromatography (EtOAc:hex) to yield **3.35** (0.30 g, 1.1 mmol, 75%) as an orange solid. $R_f$ = 0.2 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 7.41 (d, *J* = 8.0 Hz, 1H), 7.17 (d, *J* = 8.0 Hz, 1H), 4.09 (t, *J* = 7.0 Hz, 2H), 2.55 (s, 3H), 2.52 (t, *J* = 7.0 Hz, 2H), 2.26 (s, 6H); $^{13}$C NMR (500

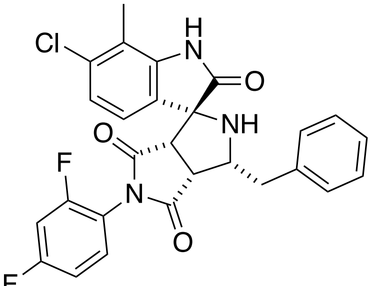
MHz, $CDCl_3$) δ 128.8, 160.1, 150.1, 146.6, 125.3, 123.7, 121.0, 118.0, 59.3, 45.8, 41.4, 15.1; HRMS (ESI): *m/z* calculated for $C_{13}H_{15}ClN_2O_2Na$ $[M+Na]^+$ 289.0720, found 289.0723.

**General procedure for the synthesis of spiroindolinones:**



A round bottom flask was charged with substituted isatin (1.0 equiv), N-substituted maleimide (1.05 equiv), the amino acid derivative (1.1 equiv), and a stir bar. A 3:1 (v/ v) mixture of MeOH and water was added to the reaction flask such that the concentration of isatin was 0.3 M. The reaction was heated at reflux by immersing the reaction flask in a hot oil bath at 90 °C up to the level of the flask's contents. Initially a clear solution was obtained, and $CO_2$ evolution was observed. However, after 30 minutes to a few hours the reaction mixture became cloudy. The reaction was stirred for 4 to 16 hours. Upon consumption of the substituted isatin, the reaction was cooled to room temperature. Next, the reaction mixture was quenched by pouring cold DI water into it. The resulting precipitate was washed thoroughly with water in a Büchner funnel to afford a solid. The solid was purified by flash chromatography to afford the racemic substituted spiroindolinone. Best column results were achieved with two successive columns of first $CH_2Cl_2$:Acetone and second EtOAc:Hex.

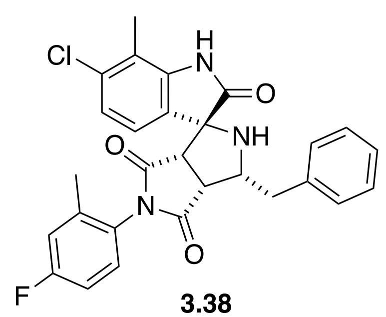
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(2,4-difluorophenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.37**):



**3.37**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.27 g, 1.4 mmol, 1.0 equiv), 1-(2,4-difluorophenyl)-1H-pyrrole-2,5-dione (0.30 g, 1.4 mmol, 1.05 equiv), and phenylalanine (0.25 g, 1.5 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.37** (0.14 g, 0.27 mmol, 20%) as a light brown solid. R*f* = 0.4 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.48 (s, 1H), 7.26 – 7.18 (m, 5H), 7.04 – 6.92 (m, 5H), 4.72 (s, 1H), 3.78 (s, 2H), 3.44 (d, *J* = 11.5 Hz, 1H), 2.70 (s, 1H), 2.14 (s, 1H), 1.94 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 174.4, 174.1, 164.4, 162.4, 158.7, 156.85, 156.75, 140.6, 139.2, 136.3, 130.44, 130.36, 129.0, 128.9, 126.7, 124.8, 124.4, 123.6, 118.4, 115.9, 115.8, 112.5, 112.4, 105.6, 68.4, 58.9, 51.9, 48.2, 38.2, 13.5; HRMS (ESI): *m/z* calculated for $C_{27}H_{20}ClF_2N_3O_3Na$ [M+Na]$^+$ 530.1059, found 530.1060; HPLC purity: 98.2%.

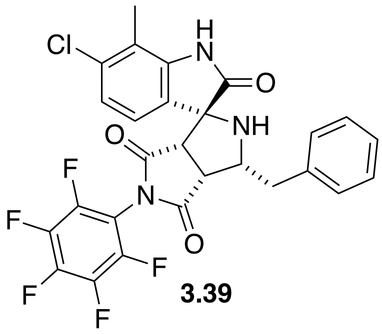
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.38**):



**3.38**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.27 g, 1.4 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.30 g, 1.4 mmol, 1.05 equiv), and phenylalanine (0.25 g, 1.5 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.38** (0.11 g**,** 0.22 mmol**,** 16%) as a white solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.2) δ 8.38 (s, 1H, minor rotamer), 8.32 (s, 1H, major rotamer), 7.27 – 6.97 (m, 9H, major and minor rotamers), 6.85 (s, *J* = 8.1 Hz, 1H, minor rotamer), 6.78 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.79 – 4.72 (m, 1H, major and minor rotamers), 3.78 – 3.75 (m, 2H, minor rotamer), 3.78 – 3.75 (m, 1H, major rotamer), 3.66 (d, *J* = 8.1 Hz, 1H, major rotamer), 3.48 – 3.44 (m, 1H, major and minor rotamers), 2.72 (dd, *J* = 13.9, 10.3 Hz, 1H, minor rotamer), 2.60 (dd, *J* = 13.8, 10.8 Hz, 1H, major rotamer), 2.44 (s, 3H, major rotamer), 2.16 – 2.12 (m, 4H, minor rotamer), 2.16 – 2.12 (m, 1H, major rotamer), 2.03 (s, 3H, major rotamer), 1.98 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.9, 180.8, 175.2, 175.1, 174.5, 174.3, 164.2, 164.0, 162.2, 162.0, 140.739, 140.732, 139.27, 139.26, 138.74, 138.67, 138.1, 138.0, 136.4, 136.3, 130.0, 129.96, 129.93, 129.85, 129.01, 128.99, 128.94, 128.91, 127.07, 127.05, 127.04, 127.02, 126.83, 126.78, 125.2, 124.8, 124.6, 124.1, 123.5, 124.4, 118.48, 118.46, 118.28, 118.24, 118.20, 118.0, 114.44, 114.40, 114.3, 114.2, 68.5, 68.4, 58.9, 58.3, 51.8, 51.7, 47.9, 47.6, 38.9, 38.3, 18.9, 18.2, 13.7, 13.6; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}ClFN_3O_3Na$ $[M+Na]^+$ 526.1310**,** found 526.1292**;** HPLC purity: 99.8%.

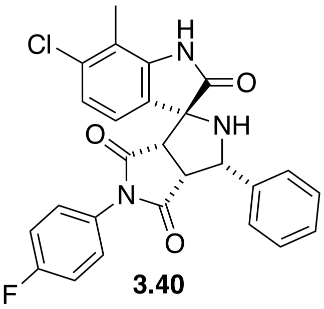
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(perfluorophenyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.39**):



**3.39**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.04 g, 0.19 mmol, 1.0 equiv), 1-(perfluorophenyl)-1*H*-pyrrole-2,5-dione (0.05 g, 0.20 mmol, 1.05 equiv), and phenylalanine (0.04 g, 0.21 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.39** (0.05 g, 0.09 mmol, 47%) as an off white solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1H$ NMR (500 MHz, $CDCl_3$) δ 8.13 (s, 1H), 7.29 – 7.19 (m, 6H), 7.05 (d, *J* = 8.2 Hz, 1H), 6.88 (d, *J* = 8.1 Hz, 1H), 4.75 (s, 1H), 3.88 (t, *J* = 8.0 Hz, 1H), 3.75 (d, *J* = 8.1 Hz, 1H), 3.42 (d, *J* = 11.4 Hz, 1H), 2.63 (t, *J* = 11.0 Hz, 1H), 2.10 (s, 3H); $^{13}C$ NMR (500 MHz, $CDCl_3$) δ 180.4, 173.0, 172.1, 140.5, 138.9, 136.5, 129.0, 128.9, 126.8, 124.9, 123.8, 123.6, 118.1, 68.3, 58.5, 52.1, 48.4, 38.4, 13.7; HRMS (ESI): *m/z* calculated for $C_{26}H_{15}ClF_5N_3O_3Na$ $[M+Na]^+$ 584.0776**,** found 584.0768**;** HPLC purity: 99.2%.

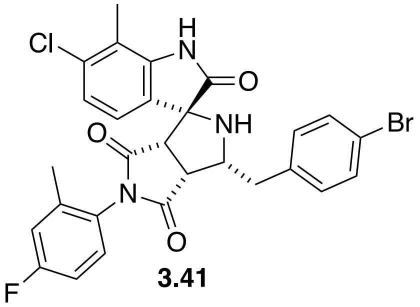
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(4-fluorophenyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.40**):



**3.40**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.26 g, 1.4 mmol, 1.0 equiv), 1-(4-fluorophenyl)-1*H*-pyrrole-2,5-dione (0.28 g, 1.4 mmol, 1.05 equiv), and phenylglycine (0.23 g, 1.5 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.40** (0.28 g, 0.63 mmol, 46%) as an off white solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO) δ 10.73 (s, 1H), 7.48 (d, *J* = 7.4 Hz, 2H), 7.34 – 7.28 (m, 4H), 7.25 – 7.20 (m, 3H), 7.05 (d, *J* = 8.1 Hz, 1H), 6.99 (d, *J* = 8.1 Hz, 1H), 5.53 (dd, *J* = 8.6, 3.9, 1H), 4.30 (d, *J* = 3.8 Hz, 1H), 3.88 (t, *J* = 8.2 Hz, 1H), 3.52 (d, J = 7.8, 1H), 2.26 (s, 3H); $^{13}$C NMR (500 MHz, DMSO) δ 181.4, 174.3, 173.7, 162.4, 160.4, 142.4, 139.4, 134.0, 129.1, 129.0, 128.6, 128.5, 127.8, 127.5, 127.3, 126.1, 125.4, 121.4, 116.8, 116.0, 115.8, 67.8, 60.1, 51.4, 49.9, 13.8; HRMS (ESI): *m/z* calculated for $C_{27}H_{21}ClFN_3O_3Na$ [M+Na]$^+$ 498.0997**,** found 498.0979**;** HPLC purity: 99.9%.

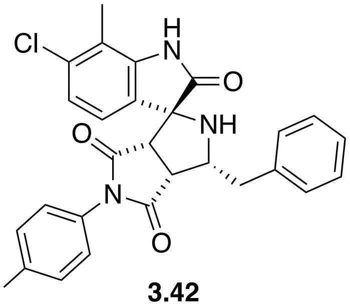
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-(4-Bromobenzyl)-6-chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.41**):



**3.41**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(4-bromophenyl)propanoic acid (0.25 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.41** (0.12 g, 0.21 mmol, 23%) as a white solid. R$_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$, rotamer ratio = 1:0.86) δ 8.35 (s, 1H, minor rotamer), 8.28 (s, 1H, major rotamer), 7.40 – 7.38 (m, 2H, major and minor rotamer), 7.21 – 6.99 (m, 6H, major rotamer and minor rotamer), 6.83 (d, *J* = 8.2 Hz, 1H, minor rotamer), 6.76 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.72 – 4.71 (m, 1H, major and minor rotamer), 3.80 – 3.72 (m, 1H, major rotamer, 2H, minor rotamer), 3.68 (d, *J* = 8.0 Hz, 1H, major rotamer), 3.42 – 3.37 (m, 1H, major and minor rotamer), 2.69 (dd, *J* = 13.6 Hz, 10.1 Hz, 1H, minor rotamer), 2.57 (dd, *J* = 13.8 Hz, 10.7 Hz, 1H, major rotamer), 2.43 (s, 3H, major rotamer), 2.12 (s, 4H, minor rotamer, 1H major rotamer), 2.03 (s, 3H, major rotamer), 1.97 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, CDCl$_3$) δ 180.9, 180.7, 175.4, 175.2, 174.7, 174.5, 164.3, 164.2, 162.4, 162.2, 140.8, 138.9, 138.7, 138.3, 138.1, 138.0, 136.61, 136.57, 132.19, 132.15, 131.0, 130.9, 130.2, 130.1, 130.0, 129.9, 127.05, 127.02, 127.01, 126.99, 125.3, 124.9, 124.5, 124.0, 123.8, 123.7, 120.93, 120.90, 118.8, 118.7, 118.53, 118.50, 118.4, 118.2, 114.7, 114.6, 114.5, 114.48, 68.5, 68.4, 58.9, 58.3, 51.8, 51.7, 47.9, 47.6, 38.4, 37.7, 19.0, 18.4, 13.9, 13.8; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}BrClFN_3O_3Na$ [M+Na]$^+$ 604.0415, found 604.0431; HPLC purity: 98.2%.

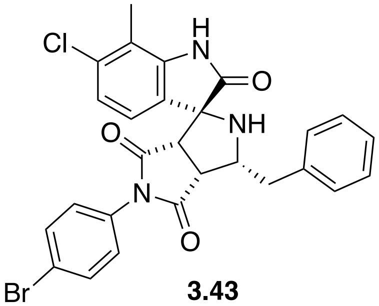
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(4-chlorophenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.42**):



**3.42**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-chlorophenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and phenylalanine (0.17 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.42** (0.11 g, 0.21 mmol, 23%) as a white solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.49 (s, 1H), 7.50 (d, *J* = 8.7 Hz, 2H), 7.37 (d, *J* = 8.7 Hz, 2H) 7.265 – 7.256 (m, 4H), 7.20 – 7.17 (m, 1H), 7.02 (d, *J* = 8.1 Hz, 1H), 6.79 (d, *J* = 8.1 Hz, 1H), 4.73 – 4.68 (m,1H), 3.84 (d, *J* = 8.1 Hz, 1H), 3.70 (t, *J* = 7.5 Hz, 1H), 3.46 (dd, *J* = 13.9 Hz, 3.8 Hz, 1H), 2.76 (dd, *J* = 13.9, 10.2 Hz , 1H), 2.16 (d, *J* = 3.0 Hz, 1H), 1.90 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.8, 175.0, 174.8, 140.7, 139.1, 136.4, 134.9, 130.1, 129.7, 128.95, 128.87, 127.7, 126.8, 124.8, 124.4, 123.6, 118.7, 68.2, 59.2, 51.7, 47.8, 37.8, 13.5; HRMS (ESI): *m/z* calculated for $C_{27}H_{21}Cl_2N_3O_3Na$ [M+Na]$^+$ 528.0588**,** found 528.0875**;** HPLC purity: 95.0%.

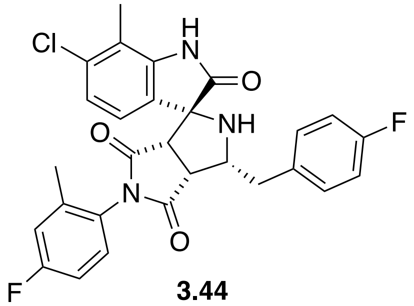
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-5'-(4-bromophenyl)-6-chloro-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.43**):



**3.43**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-bromophenyl)-1*H*-pyrrole-2,5-dione (0.25 g, 0.97 mmol, 1.05 equiv), and phenylalanine (0.17 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.43** (0.15 g, 0.27 mmol, 29%) as a light brown solid. R$_f$ = 0.3 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$) δ 8.28 (s, 1H), 7.66 (d, *J* = 8.3 Hz, 2H), 7.32 – 7.27 (m, 6H), 7.19 (d, *J* = 4.1 Hz, 1H), 7.02 (d, *J* = 8.1 Hz, 1H), 6.79 (d, *J* = 8.0 Hz, 1H), 4.72 (s, 1H), 3.79 (d, *J* = 7.8 Hz, 1H), 3.70 (t, *J* = 7.4, 1H), 3.46 (dd, *J* = 16.1 Hz, 5.4 Hz, 1H), 2.76 (t, *J* = 10.6 Hz, 1H), 2.17 (s, 1H), 1.96 (s, 3H); $^{13}$C NMR (500 MHz, CDCl$_3$) δ 180.8, 174.9, 174.5, 140.6, 139.2, 136.4, 132.7, 130.7, 129.0, 128.9, 128.0, 126.8, 124.8, 124.5, 123.6, 122.9, 118.6, 68.3, 59.1, 51.8, 47.8, 37.9, 13.5; HRMS (ESI): *m/z* calculated for $C_{27}H_{21}BrClN_3O_3Na$ [M+Na]$^+$ 572.0353**,** found 572.0345**;** HPLC purity: 94.0%.

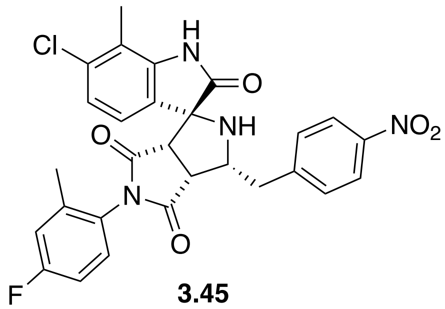
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-3'-(4-fluorobenzyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.44**):



**3.44**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(4-fluorophenyl)propanoic acid (0.19 g, 1.0 mmol, 1.1 equiv) were used . The crude material was purified by flash chromatography to afford spiroindolinone **3.44** (0.14 g, 0.27 mmol, 29%) as a white solid. $R_f$ = 0.7 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.16) δ 8.58 (s, 1H, minor rotamer), 8.53 (s, 1H, major rotamer), 7.24 – 6.93 (m, 8H, major and minor rotamer), 6.84 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.77 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.72 – 4.68 (m, 1H, major and minor rotamer), 3.84 (d, *J* = 8.0 Hz, 1H, minor rotamer), 3.77 – 3.71 (m, 2H, major rotamer, 1H, minor rotamer), 3.44 – 3.40 (m, 1H, major and minor rotamer), 2.72 (dd, *J* = 10 Hz, 14.0 Hz, 1H, minor rotamer), 2.60 (dd, *J* = 10.6 Hz, 13.8 Hz, 1H, major rotamer), 2.44 (s, 3H, major rotamer), 2.16 – 2.13 (m, 4H, minor rotamer, 1H major rotamer), 1.99 (s, 3H, major rotamer), 1.92 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.9, 180.8, 175.2, 175.0, 174.7, 174.6, 164.1, 163.9, 162.82, 162.79, 162.1, 161.9, 160.9, 160.8, 140.7, 138.6, 138.0, 137.9, 136.4, 136.3, 134.8, 134.7, 130.43, 130.39, 130.37, 130.3, 130.0, 129.9, 129.8, 129.7, 126.9, 126.83, 126.80, 126.78, 125.0, 124.6, 124.5, 124.0, 123.6, 123.5, 118.7, 118.5, 118.4, 118.3, 118.2, 118.0, 115.8, 115.7, 115.62, 115.58, 114.46, 114.42, 114.3, 114.2, 68.3, 68.2, 59.0, 58.4, 51.62, 51.58, 47.8, 47.5, 37.9, 37.2, 18.8, 18.1, 13.6, 13.5; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}ClF_2N_3O_3$ $[M+H]^+$ 522.1396**,** found 522.1402**;** HPLC purity: 99.2%.

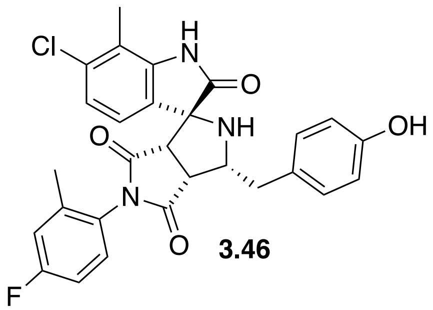
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-3'-(4-nitrobenzyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.45**):



**3.45**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(4-nitrophenyl)propanoic acid (0.21 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.45** (0.18 g, 0.32 mmol, 34%) as a white solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1H$ NMR (500 MHz, DMSO, rotamer ratio = 1:1.19) δ 10.68 (s, 1H, minor rotamer), 10.62 (s, 1H, major rotamer), 8.18 – 8.15 (m, 2H, major and minor rotamer), 7.61 (d, *J* = 8.7 Hz, 2H, minor rotamer), 7.56 (d, *J* = 8.6 Hz, 2H, major rotamer), 7.48 – 7.46 (m, 1H, minor rotamer), 7.33 (dd, *J* = 9.0 Hz, 9.7 Hz, 1H, major rotamer), 7.28 – 7.17 (m, 2H, major rotamer and minor rotamer), 7.02 – 6.97 (m, 1H, major and minor rotamer), 6.91 (d, *J* = 8.1 Hz, 1H minor rotamer), 6.68 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.65 – 4.60 (m, 1H, major rotamer), 4.49 – 4.43 (m, 1H, minor rotamer), 3.94 – 3.91 (m, 1H, major and minor rotamer), 3.86 (t, *J* = 7.7 Hz, 1H, minor rotamer), 3.71 (t, *J* = 8.0 Hz, 1H, major rotamer), 3.65 (d, *J* = 7.9 Hz, 1H, minor rotamer), 3.48 – 3.37 (m, 2H, major rotamer, 1H, minor rotamer), 2.88 (dd, *J* = 9.35 Hz, 14.0 Hz, 1H, minor rotamer), 2.66 (t, *J* = 4.7 Hz, 1H, major rotamer), 2.36 (s, 3H, major rotamer), 2.21 – 2.20 (m, 3H, major and minor rotamer), 2.07 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.7, 181.1, 176.5, 176.4, 175.0, 174.6, 163.9, 163.7, 162.0, 161.8, 149.4, 149.0, 147.0, 146.9, 143.4, 143.2, 139.83, 139.76, 139.14, 139.10, 135.0, 134.8, 131.7, 131.6, 131.4, 131.3, 131.2, 131.1, 129.0, 128.9, 128.60, 128.58, 126.6, 126.4, 125.8, 125.7, 124.3, 124.2, 122.3, 122.2, 118.4, 118.2, 118.1, 118.0, 117.8, 117.6, 114.7, 114.6, 114.5, 114.4, 69.6, 68.7, 60.2, 58.4, 53.5, 52.8, 50.1, 48.9, 38.9, 37.4, 18.8, 18.2, 14.7, 14.6; HRMS (ESI): *m/z* calculated for $C_{28}H_{21}ClFN_4O_5$ [M-H]$^-$ 547.1185**,** found 547.1208**;** HPLC purity: 99.6%.

(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-3'-(4-hydroxybenzyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.46**):

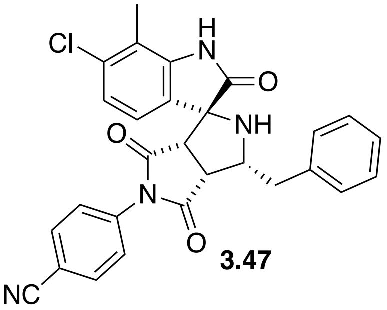


**3.46**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-

1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and tyrosine (0.19 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.46** (0.18 g, 0.35 mmol, 38%) as a white solid. $R_f$ = 0.3 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.18) δ 8.72 (s, 1H, minor rotamer), 8.66 (s, 1H, major rotamer), 7.24 (t, *J* = 5.2 Hz, 1H, minor rotamer), 7.14 – 6.97 (m, 6H, major rotamer, 5H, minor rotamer), 6.84 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.75 (d, *J* = 8.2 Hz, 1H, major rotamer), 6.65 – 6.64 (m, 2H, major and minor rotamers), 6.50 – 6.46 (m, 1H, major and minor rotamer), 4.71 – 4.65 (m, 1H, major and minor rotamer), 3.81 (d, *J* = 7.9 Hz, 1H, minor rotamer), 3.72 – 3.64 (m, 2H, major rotamer, 1H, minor rotamer), 3.36 – 3.33 (m, 1H, major and minor rotamer), 2.68 (t, *J* = 10.0 Hz, 1H, minor rotamer), 2.55 (t, *J* = 10.2 Hz, 1H, major rotamer), 2.43 (s, 3H, major rotamer), 2.24 – 2.20 (s, 1H, major and minor rotamer), 2.13 (s, 3H, minor rotamer), 1.85 (s, 3H, major rotamer), 1.82 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 181.45, 181.44, 175.4, 175.3, 175.0, 164.1, 163.9, 162.1, 161.9, 154.81, 154.80, 140.5, 140.4, 138.84, 138.77, 138.0, 137.9, 136.4, 136.3, 130.86, 130.85, 130.0, 129.9, 129.86, 129.77, 126.9, 126.86, 126.76, 126.74, 124.8, 124.7, 124.4, 124.3, 123.8, 123.7, 118.9, 119.0, 118.8, 118.5, 118.3, 118.1, 118.0, 115.63, 115.60, 114.43, 114.40, 114.24, 114.22, 68.33. 68.27, 59.6, 59.0, 52.0, 51.9, 47.8, 47.5, 37.4, 36.7, 18.8, 18.2, 13.45, 13.41 HRMS (ESI): *m/z* calculated for $C_{28}H_{23}ClFN_3O_4Na$ $[M+Na]^+$ 542.1259**,** found 542.1263**;** HPLC purity: 96.2%.

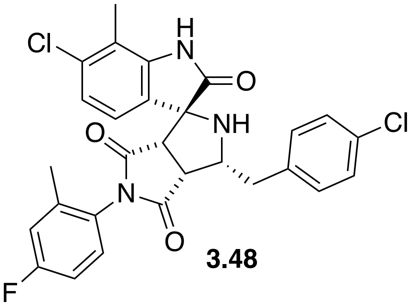
4-((3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-7-methyl-2,4',6'-trioxo-2',3',3a',4',6',6a'-hexahydro-5'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrol]-5'-yl)benzonitrile (**3.47**):



**3.47**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 4-(2,5-dioxo-2,5-dihydro-1*H*-pyrrol-1-yl)benzonitrile (0.19 g, 0.97 mmol, 1.05 equiv), and phenylalanine (0.17 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.47** (0.21 g, 0.42 mmol, 46%) as a white solid. $R_f$ = 0.4 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.60 (s, 1H), 7.83 (d, *J* = 8.5 Hz, 2H), 7.62 (d, *J* = 8.5 Hz, 2H), 7.27 (t, *J* = 8.0 Hz, 4H), 7.20 (d, *J* = 6.0 Hz, 1H), 7.03 (d, *J* = 8.1 Hz, 1H), 6.78 (d, *J* = 8.1 Hz, 1H), 4.73 (s, 1H), 3.83 (d, *J* = 8.0 Hz, 1H), 3.73 (t, *J* = 7.5 Hz, 1H), 3.46 (dd, *J* = 13.9 Hz, 3.7 Hz, 1H), 2.76 (dd, *J* = 13.8 Hz, 10.3 Hz, 1H), 2.20 (s, 1H), 1.95 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.8, 174.6, 174.3, 140.7, 140.0, 136.5, 135.5, 133.3, 128.9, 126.9, 126.8, 124.6, 124.3, 123.6, 118.7, 118.0, 112.6, 68.3, 59.2, 51.7, 47.8, 37.8, 13.5; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}ClN_4O_3$ [M+H]$^+$ 497.1380**,** found 497.1392**;** HPLC purity: 97.1%.

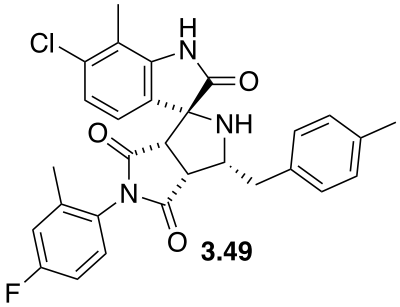
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-3'-(4-chlorobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.48**):



**3.48**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(4-chlorophenyl)propanoic acid (0.20 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.48** (0.23 g, 0.43 mmol, 46%) as a white solid. R$_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$, rotamer ratio= 1:1.16) δ 8.56 (s, 1H, minor rotamer), 8.50 (s, 1H, major rotamer), 7.25 – 6.99 (m, 8H, major and minor rotamer), 6.83 (d, *J* = 8.3 Hz, 1H, minor rotamer), 6.76 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.74 – 4.65 (m, 1H, major and minor rotamer), 3.83 (d, *J* = 8.0 Hz, 1H, minor rotamer), 3.77 – 3.71 (m, 2H, major rotamer, 1H, minor rotamer), 3.45 – 3.39 (m, 1H, major and minor rotamer), 2.72 (dd, *J* = 9.9 Hz, 14.0 Hz, 1H, minor rotamer), 2.59 (dd, *J* = 10.6 Hz, 13.8 Hz, 1H, major rotamer), 2.44 (s, 3H, major rotamer), 2.15 – 2.13 (m, 1H, major rotamer, 4H, minor rotamer), 2.00 (s, 3H, major rotamer), 1.93 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, CDCl$_3$) δ 180.8, 180.7, 175.2, 175.0, 174.6, 174.5, 164.1, 164.0, 162.1, 162.0, 140.7, 138.7, 138.6, 137.9, 137.8, 137.6, 136.4, 136.36, 132.7, 132.6, 130.3, 130.29, 129.9, 129.86, 129.8, 129.7, 129.0, 128.9, 126.83. 126.8, 126.78, 126.76, 125.0, 124.6, 124.4, 123.9, 123.6, 123.5, 118.7, 118.5, 118.4, 118.3, 118.2, 118.0, 114.5, 114.4, 114.3, 114.27, 68.3, 68.2, 58.8, 58.2, 51.6, 51.5, 47.7, 47.5, 38.1, 37.4, 18.8, 18.2, 13.6, 13.5; HRMS (ESI): *m/z* calculated for $C_{27}H_{19}Cl_2FN_3O_3Na$ $[M+Na]^+$ 560.0920**,** found 560.0904**;** HPLC purity: 99.9%.

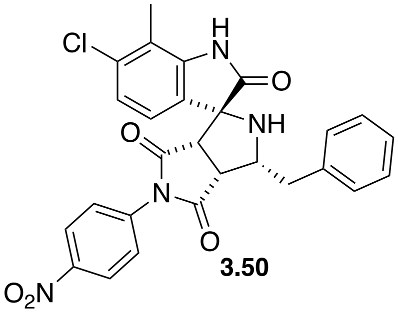
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-3'-(4-methylbenzyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.49**):



**3.49**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(*p*-tolyl)propanoic acid (0.18 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.49** (0.10 g, 0.19 mmol, 21%) as a light brown solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.18) δ 10.65 (s, 1H, minor rotamer), 10.59 (s, 1H, major rotamer), 7.47 – 7.45 (m, 1H, minor rotamer), 7.34 – 7.31 (m, 1H, major rotamer), 7.28 – 7.08 (m, 6H, major and minor rotamer), 7.01 – 6.91 (m, 1H, major rotamer, 2H, minor rotamer), 6.67 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.60 – 4.55 (m, 1H, major rotamer), 4.44 – 4.38 (m, 1H, minor rotamer), 3.83 – 3.76 (m, 1H, major rotamer, 2H, minor rotamer), 3.66 – 3.62 (m, 1H, major and minor rotamer), 3.44 (d, *J* = 7.9 Hz, 1H, major rotamer), 3.25 – 3.18 (m, 1H, major and minor rotamer), 2.72 – 2.67 (m, 1H, minor rotamer), 2.49 – 2.46 (m, 1H, major rotamer), 2.35 (s, 3H, major rotamer), 2.26 (s, 3H, major and minor rotamer), 2.22 – 2.21 (m, 3H, major and minor rotamer), 2.06 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.0, 180.5, 175.6, 175.5, 174.1, 173.7, 163.0, 162.8, 161.0, 160.8, 142.4, 142.3, 138.9, 138.8, 138.2, 138.1, 136.9, 136.6, 134.9, 134.8, 134.0, 133.8, 130.8, 130.7, 130.5, 130.4, 128.83, 128.8, 128.76, 128.1, 128.0, 127.8, 127.7, 125.9, 125.8, 124.8, 124.77, 121.3, 121.2, 117.4, 117.3, 117.1, 116.8, 116.6, 113.7, 113.64, 113.6, 113.5, 68.6, 67.8, 59.9, 58.1, 52.7, 52.0, 49.0, 47.9, 37.7, 36.1, 20.6, 17.9, 17.3, 13.8, 13.75; HRMS (ESI): *m/z* calculated for $C_{29}H_{25}ClFN_3O_3Na$ [M+Na]$^+$ 540.1466**,** found 540.1473**;** HPLC purity: 97.5%.

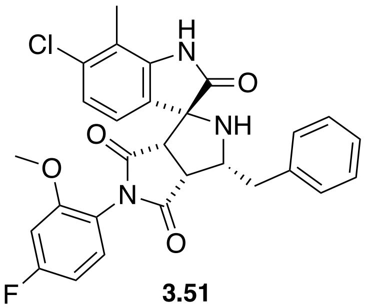
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-7-methyl-5'-(4-nitrophenyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.50**):



**3.50**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-nitrophenyl)-1*H*-pyrrole-2,5-dione (0.21 g, 0.97 mmol, 1.05 equiv), and phenylalanine (0.17 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.50** (0.23 g, 0.44 mmol, 48%) as a light brown solid. R$_f$ = 0.4 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$) δ 8.59 (s, 1H), 8.39 (d, *J* = 8.9, 2H), 7.69 (d, *J* = 8.9, 2H), 7.26 (m, 4H), 7.20 (s, 1H), 7.03 (d, *J* = 8.1 Hz, 1H), 6.78 (d, *J* = 8.1 Hz, 1H), 4.74 (s, 1H), 3.85 (d, *J* = 8.0 Hz, 1H), 3.75 (t, *J* = 7.5 Hz, 1H), 3.47 (dd, *J* = 13.9 Hz, 3.7 Hz, 1H), 2.77 (dd, *J* = 13.8 Hz, 10.3 Hz, 1H), 2.22 (s, 1H), 2.00 (s, 3H); $^{13}$C NMR (500 MHz, CDCl$_3$) δ 180.2, 174.5, 174.2, 147.3, 140.7, 138.9, 137.1, 136.5, 128.91, 128.90, 126.9, 126.8, 124.7, 124.6, 124.3, 123.6, 118.7, 68.3, 59.2, 51.8, 47.8, 37.8, 13.5; HRMS (ESI): *m/z* calculated for $C_{27}H_{22}ClN_4O_5$ $[M+H]^+$ 517.1279**,** found 517.1259**;** HPLC purity: 99.7%.

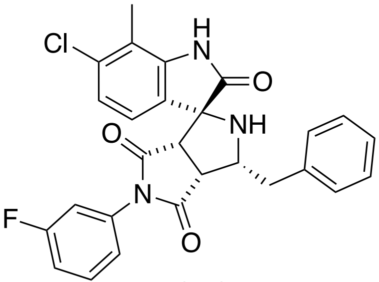
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(4-fluoro-2-methoxyphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.51**):



**3.51**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methoxyphenyl)-1*H*-pyrrole-2,5-dione (0.22 g, 0.97 mmol, 1.05 equiv), and phenylalanine (0.15 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.51** (0.15 g, 0.29 mmol, 31%) as a white solid. R$_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.88) δ 10.63 (s, 1H, minor rotamer), 10.58 (s, 1H, major rotamer), 7.47 (dd, *J* = 6.4 Hz, 8.7 Hz, 1H, minor rotamer), 7.32 – 6.88 (m, 10H, major rotamer, 9H, minor rotamer), 4.51 – 4.40 (m, 1H, major and minor rotamer), 3.94 (s, 3H, major rotamer), 3.83, (d, *J* = 7.4 Hz, 1H, minor rotamer), 3.77 – 3.74 (m, 1H, major rotamer, 3H, minor rotamer), 3.64 – 3.60 (m, 1H, mjor rotamer, 2H, minor rotamer), 3.41 (d, *J* = 7.9 Hz, 1H, major rotamer), 3.29 – 3.21 (m, 1H, major and minor rotamer), 2.74 (dd, *J* = 8.75 Hz, 14.1 Hz, 1H, minor rotamer), 2.60 (dd, *J* = 8.1 Hz, 21.9 Hz, 1H, major rotamer), 2.21 (d, *J* = 2.85 Hz, 3H, major and minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.2, 180.4, 175.6, 175.2, 173.8, 173.5, 164.3, 164.0, 162.3, 162.1, 156.14, 156.1, 156.06, 156.0, 142.3, 142.26, 140.0, 136.9, 134.0, 133.8, 131.1, 131.0, 130.8, 130.76, 129.0, 128.9 128.2, 128.19, 126.4, 126.0, 125.9, 125.8, 125.0, 124.7, 121.4, 121.3, 117.53, 117.5, 117.2, 117.16, 116.8, 116.5, 107.2, 107.1, 107.0, 106.9, 101.1, 101.0, 100.9, 100.8, 68.7, 67.8, 59.9, 58.7, 56.42, 56.4, 52.5, 52.1, 48.9, 48.4, 37.4, 36.3, 13.8; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}ClFN_3O_4Na$ $[M+Na]^+$ 542.1259**,** found 542.1272**;** HPLC purity: 99.9%.

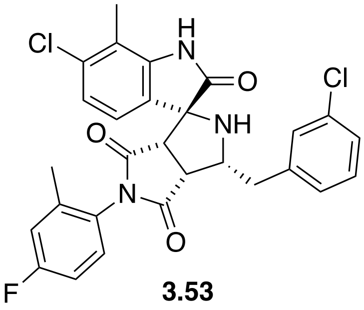
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(3-fluorophenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.52**):



**3.52**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(3-fluorophenyl)-1*H*-pyrrole-2,5-dione (0.19 g, 0.97 mmol, 1.05 equiv), and phenylalanine (0.17 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.52** (0.11 g, 0.22 mmol, 24%) as a light yellow solid. R*f* = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 10.66 (s, 1H), 7.60 (dd, *J* = 8.1 Hz, 14.8 Hz, 1H), 7.34 – 7.26 (m, 7H), 7.19 (t, *J* = 7.3 Hz, 1H), 7.02 (d, *J* = 8.1 Hz, 1H), 6.91 (d, *J* = 8.1 Hz, 1H), 4.44 – 4.38 (m, 1H), 3.81 (d, *J* = 7.6 Hz, 1H), 3.68 (t, *J* = 7.6 Hz, 1H), 3.49 (d, *J* = 7.8, 1H), 3.29 (dd, *J* = 14.1 Hz, 5.1 Hz, 1H), 2.76 (dd, 14.1 Hz, 8.8 Hz, 1H), 2.22 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.5, 175.3, 173.7, 162.8, 160.8, 142.3, 140.1, 134.1, 133.9, 133.8, 130.7, 130.6, 128.9, 128.2, 126.0, 125.9, 124.6, 123.43, 123.41, 121.5, 116.9, 115.5, 115.4, 114.5, 114.3, 68.7, 60.0, 52.8, 49.3, 36.3, 13.8; HRMS (ESI): *m/z* calculated for $C_{27}H_{21}ClFN_3O_3Na$ $[M+Na]^+$ 512.1153**,** found 512.1166**;** HPLC purity: 99.6%.

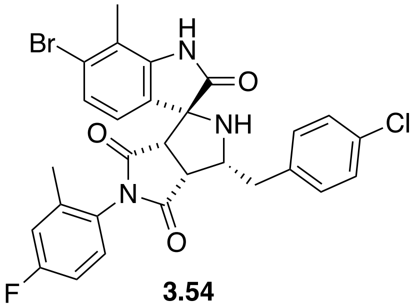
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-3'-(3-chlorobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.53**):



**3.53**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(3-chlorophenyl)propanoic acid (0.20 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.53** (0.28 g, 0.52 mmol, 56%) as a white solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.25) δ 8.55 (s, 1H, minor rotamer), 8.51 (s, 1H, major rotamer), 7.26 – 6.99 (m, 8H, major and minor rotamer), 6.84 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.77 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.76 – 4.67 (m, 1H, major and minor rotamer), 3.82 (d, *J* = 8.0 Hz, 1H, minor rotamer), 3.78 – 3.75 (m, 1H, major and minor rotamer), 3.71 (d, *J* = 8.0 Hz, 1H, major rotamer), 3.47 – 3.42 (m, 1H, major and minor rotamer), 2.71 (dd, *J* = 11.4 Hz, 13.9 Hz, 1H, minor rotamer), 2.58 (dd, *J* = 10.6 Hz, 13.8 Hz, 1H, major rotamer), 2.44 (s, 3H, major rotamer), 2.17 – 2.13 (m, 1H, major rotamer, 4H, minor rotamer), 2.02 (s, 3H, major rotamer), 1.96 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 181.1, 180.9, 175.4, 175.2, 174.8, 174.6, 164.4, 164.2, 162.4, 162.2, 141.4, 140.9, 138.9, 138.8, 138.2, 138.1, 136.6, 136.59, 134.83, 134.8, 130.4, 130.3, 130.1, 130.07, 130.0, 129.9, 129.3, 129.2, 127.4, 127.3, 127.2, 127.04, 127.0, 126.9, 125.3, 124.9, 124.6, 124.1, 123.8, 123.7, 118.9, 118.7, 118.6, 118.5, 118.4, 118.2, 114.7, 114.6, 114.5, 114.4, 68.6, 68.5, 58.9, 58.3, 51.7, 51.6, 47.9, 47.7, 38.7, 38.0, 19.1, 18.4, 13.8, 13.7; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}Cl_2FN_3O_3Na$ $[M+Na]^+$ 560.0920**,** found 560.0918**;** HPLC purity: 99.7%.

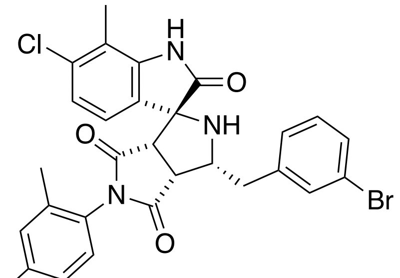
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Bromo-3'-(4-chlorobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.54**):



**3.54**

Using the general procedure for spiroindolinone synthesis outlined above, 6-bromo-7-methylindoline-2,3-dione (0.22 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(4-chlorophenyl)propanoic acid (0.20 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.54** (0.28 g, 0.48 mmol, 52%) as a white solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.11) δ 8.58 (s, 1H, minor rotamer), 8.52 (s, 1H, major rotamer), 7.29 – 7.03 (m, 8H, major and minor rotamer), 6.80 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.72 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.75 – 4.70 (m, 1H, major and minor rotamer), 3.88 (d, *J* = 8.0 Hz, 1H, minor rotamer), 3.78 – 3.75 (m, 2H, major rotamer, 1H, minor rotamer), 3.48 – 3.42 (m, 1H, major and minor rotamer), 2.75 (dd, *J* = 10.3 Hz, 14.0 Hz, 1H, minor rotamer), 2.62 (dd, *J* = 11.1 Hz, 13.7 Hz, 1H, major rotamer), 2.47 (s, 3H, major rotamer), 2.18 – 2.16 (m, 1H, major rotamer, 4H, minor rotamer), 2.05 (s, 3H, major rotamer), 1.98 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.9, 180.8, 175.4, 175.1, 174.8, 174.7, 164.3, 164.1, 162.3, 162.2, 140.6, 138.8, 138.7, 138.1, 138.0, 137.7, 132.9, 132.8, 130.5, 130.4, 130.1, 130.04, 130.0, 129.9, 129.2, 129.1, 127.2, 127.1, 127.0, 126.9, 125.5, 125.4, 125.1, 124.9, 120.6, 120.3, 118.7, 118.5, 118.4, 118.2, 114.7, 114.6, 114.5, 114.4, 68.5, 68.4, 59.1, 58.5, 51.74, 51.7, 47.9, 47.7, 38.3, 37.6, 19.0, 18.4, 16.7, 16.6; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}BrClFN_3O_3Na$ $[M+Na]^+$ 604.0415**,** found 604.0412**;** HPLC purity: 99.5%.

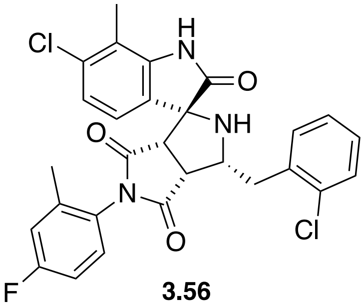
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-(3-Bromobenzyl)-6-chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.55**):



**3.55**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(3-bromophenyl)propanoic acid (0.25 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.55** (0.33 g, 0.57 mmol, 61%) as a white solid. $R_f$ = 0.57 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.11) δ 8.52 (s, 1H, minor rotamer), 8.47 (s, 1H, major rotamer), 7.42 (s, 1H, minor rotamer), 7.37 (s, 1H, major rotamer), 7.34 – 7.32 (m, 1H, major and minor rotamer), 7.24 – 6.99 (m, 6H, major and minor rotamer), 6.84 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.77 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.76 – 4.68 (m, 1H, major and minor rotamer), 3.81 (d, *J* = 8.0 Hz, 1H, minor rotamer), 3.78 – 3.74 (m, 1H, major and minor rotamer), 3.70 (d, *J* = 8.0 Hz, 1H, major rotamer), 3.47 – 3.41 (m, 1H, major and minor rotamer), 2.70 (dd, *J* = 10.1 Hz, 13.9 Hz, 1H, minor rotamer), 2.57 (dd, *J* = 10.6 Hz, 13.8 Hz, 1H, major rotamer), 2.44 (s, 3H, major rotamer), 2.17 – 2.13 (m, 1H, major rotamer, 4H, minor rotamer), 2.03 (s, 3H, major rotamer), 1.96 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 181.0, 180.9, 175.3, 175.1, 174.7, 174.6, 164.4, 164.2, 162.4, 162.2, 141.7, 140.9, 138.9, 138.8, 138.2, 138.1, 136.64, 136.6, 132.2, 132.1, 130.7, 130.6, 130.3, 130.2, 130.1, 130.07, 130.0, 129.9, 127.9, 127.1, 127.0, 126.9, 125.3, 124.9, 124.6, 124.1, 123.8, 123.7, 123.13, 123.1, 118.9, 118.7, 118.6, 118.5, 118.4, 118.2, 114.7, 114.6, 114.5, 114.4, 68.6, 68.5, 59.0, 58.4, 51.7, 51.6, 47.9, 47.7, 38.7, 38.0, 19.1, 18.4, 13.9, 13.8; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}BrClFN_3O_3Na$ $[M+Na]^+$ 604.0415**,** found 604.0421**;** HPLC purity: 99.9%.

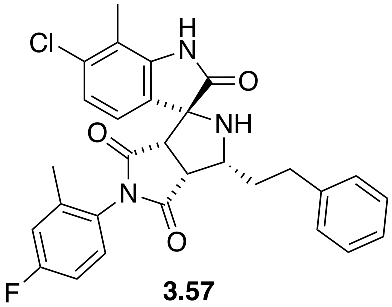
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-3'-(2-chlorobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.56**):



**3.56**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(2-chlorophenyl)propanoic acid (0.20 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.56** (0.26 g, 0.47 mmol, 51%) as a light brown solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.25) δ 8.88 (s, 1H, minor rotamer), 8.85 (s, 1H, major rotamer), 7.34 – 7.32 (m, 1H, major rotamer, 2H, minor rotamer), 7.28 – 7.22 (m, 2H, major rotamer, 1H, minor rotamer), 7.14 – 6.98 (m, 5H, major and minor rotamer), 6.84 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.76 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.88 – 4.78 (m, 1H, major and minor rotamer), 3.83 – 3.61 (m, 3H, major and minor rotamer), 2.89 – 2.78 (m, 1H, major and minor rotamer), 2.46 (s, 3H, major rotamer), 2.13 (s, 1H, major rotamer, 4H, minor rotamer), 1.99 (s, 3H, major rotamer), 1.94 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 181.3, 181.2, 175.5, 175.2, 174.9, 174.7, 164.3, 164.1, 162.3, 162.1, 141.0, 138.9, 138.8, 138.2, 138.1, 137.0, 136.6, 136.5, 134.6, 134.5, 131.4, 131.3, 130.2, 130.1, 130.06, 130.0, 129.9, 128.5, 127.34, 127.3, 127.1, 127.05, 127.0, 125.1, 124.74, 124.7, 124.2, 123.7, 123.6, 119.0, 118.7, 118.67, 118.5, 118.4, 118.2, 114.7, 114.6, 114.5, 114.4, 68.6, 68.5, 57.2, 56.8, 51.8, 51.7, 48.0, 47.7, 36.4, 35.9, 19.1, 18.4, 13.8, 13.7; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}Cl_2FN_3O_3Na$ $[M+Na]^+$ 560.0920**,** found 560.0911**;** HPLC purity: 99.7%.

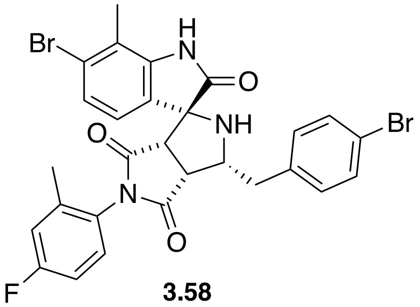
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-3'-phenethyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.57**):



**3.57**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-4-phenylbutanoic acid (0.18 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.57** (0.30 g, 0.57 mmol, 62%) as a white solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.11) δ 8.72 (s, 1H, minor rotamer), 8.67 (s, 1H, major rotamer), 7.28 – 7.00 (m, 9H, major and minor rotamer), 6.83 (d, *J* = 8.0 Hz, 1H, minor rotamer), 6.75 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.58 – 4.47 (m, 1H, major and minor rotamer), 3.84 – 3.72 (m, 2H, major and minor rotamer), 2.95 – 2.90 (m, 1H, major and minor), 2.77 – 2.71 (m, 1H, major and minor rotamer), 2.34 – 2.26 (m, 2H, minor rotamer, 5H major rotamer), 2.14 (s, 3H, minor rotamer), 2.03 – 1.98 (m, 3H, major and minor rotamer), 1.91 – 1.80 (m, 1H, major and minor rotamer). $^{13}$C NMR (500 MHz, CDCl$_3$) δ 181.2, 181.1, 175.3, 175.1, 175.0, 174.8, 164.3, 164.1, 162.3, 162.1, 141.8, 141.7, 141.0, 140.9, 138.9, 138.8, 138.2, 138.1, 136.6, 136.5, 130.1, 130.04, 130.00, 128.81 ,128.80, 128.7, 128.6, 127.10, 127.07, 127.05, 127.00, 126.4, 125.0, 124.8, 124.6, 124.4, 123.8, 123.7, 118.9, 118.7, 118.6, 118.5, 118.4, 118.2, 114.6, 114.5, 114.4, 114.3, 68.9, 58.2, 57.6, 51.9, 51.8, 48.2, 47.8, 34.5, 34.0, 19.1, 18.4, 13.9, 13.8. HRMS (ESI): *m/z* calculated for $C_{29}H_{25}ClFN_3O_3Na$ [M+Na]$^+$ 540.1466, found 540.1491; HPLC purity: 99.9%.

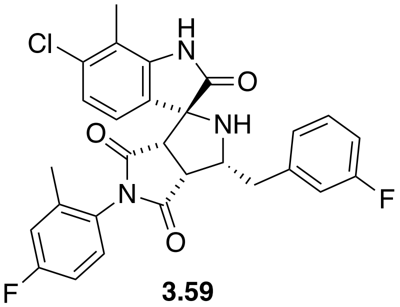
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Bromo-3'-(4-bromobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.58**):



**3.58**

Using the general procedure for spiroindolinone synthesis outlined above, 6-bromo-7-methylindoline-2,3-dione (0.22 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(4-bromophenyl)propanoic acid (0.24 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.58** (0.17 g, 0.27 mmol, 29%) as a white solid. R$_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$, rotamer ratio = 1:1.11) δ 8.45 (s, 1H, major rotamer), 8.39 (s, 1H, major rotamer), 7.39 – 7.38 (m, 2H, major and minor rotamer), 7.37 – 6.99 (m, 6H, major and minor rotamer), 6.76 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.69 (d, *J* = 8.3 Hz, 1H, major rotamer), 4.73 – 4.68 (m, 1H, major and minor rotamer), 3.83 (t, *J* = 2.4 Hz, 1H, major rotamer), 3.76 – 3.70 (m, 1H, major rotamer, 2H, minor rotamer), 3.43 – 3.72 (m, 1H, major and minor rotamer), 2.70 (dd, *J* = 10.1 Hz, 13.9 Hz, 1H, minor rotamer), 2.57 (dd, *J* = 10.6 Hz, 13.8 Hz, 1H, major rotamer), 2.43 (s, 3H, major rotamer), 2.17 – 2.12 (m, 1H, major rotamer, 4H, minor rotamer), 2.04 (s, 3H, major rotamer), 1.97 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, CDCl$_3$) δ 180.9, 180.7, 175.4, 175.1, 174.7, 174.6, 164.3, 164.2, 162.4, 162.2, 140.6, 138.9, 138.8, 138.3, 138.1, 138.0, 132.19, 132.15, 130.9, 130.8, 130.1, 130.06, 130.0, 129.9, 127.2, 127.1, 127.05, 127.02, 127.0, 126.98, 126.9, 125.6, 125.3, 125.2, 124.8, 120.9, 120.8, 120.6, 120.3, 118.7, 118.5, 118.4, 118.2, 114.7, 114.6, 114.5, 114.4, 68.5, 68.4, 59.0, 58.4, 51.7, 51.69, 47.9, 47.7, 38.4, 37.7, 19.0, 18.4, 16.7, 16.6; HRMS (ESI): *m/z* calculated for $C_{28}H_{21}Br_2FN_3O_3$ [M-H]$^-$ 623.9933**,** found 623.9957**;** HPLC purity: 98.2%.

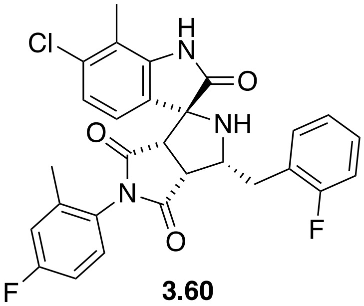
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-3'-(3-fluorobenzyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.59**):



**3.59**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(3-fluorophenyl)propanoic acid (0.19 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.59** (0.30 g, 0.58 mmol, 62%) as a white solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.19) δ 8.53 (s, 1H, minor rotamer), 8.49 (s, 1H, major rotamer), 7.25 – 7.14 (m, 1H, major rotamer, 2H, minor rotamer), 7.13 – 6.88 (m, 7H, major rotamer, 6H, minor rotamer), 6.84 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.77 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.77 – 4.68 (m, 1H, major and minor rotamer), 3.82 (d, *J* = 8.0 Hz, 1H, minor rotamer), 3.78 – 3.75 (m, 1H, major and minor rotamer), 3.71 (d, *J* = 8.1 Hz, 1H, major rotamer), 3.49 – 3.43 (m, 1H, major and minor rotamer), 2.73 (dd, *J* = 10.1 Hz, 13.9 Hz, 1H, minor rotamer), 2.61 (dd, *J* = 10.7 Hz, 13.8 Hz, 1H, major rotamer), 2.44 (s, 3H, major rotamer), 2.18 – 2.16 (m, 1H, major and minor rotamer), 2.13 (s, 3H, minor rotamer), 2.01 (s, 3H, major rotamer), 1.94 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 181.1, 180.9, 175.4, 175.2, 174.8, 174.7, 164.3, 164.25, 164.2, 162.4, 162.3, 162.2, 141.9, 141.89, 141.86, 141.8, 140.9, 138.9, 138.8, 138.1, 138.07, 136.62, 136.58, 130.7, 130.6, 130.5, 130.14, 130.07, 130.04, 129.96, 127.04, 127.02, 126.98, 125.2, 124.8, 124.82, 124.80, 124.6, 124.1, 123.8, 123.7, 118.9, 118.7, 118.6, 118.5, 118.4, 118.2, 116.2, 116.1, 116.01, 115.96, 114.7, 114.6, 114.49, 114.56, 114.08, 114.03, 113.91, 113.86, 68.6, 68.4, 58.9, 58.3, 51.8, 51.7, 47.9, 47.7, 38.8, 38.1, 19.0, 18.4, 13.8, 13.7; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}ClF_2N_3O_3Na$ $[M+Na]^+$ 544.1215**,** found 544.1213**;** HPLC purity: 98.3%.

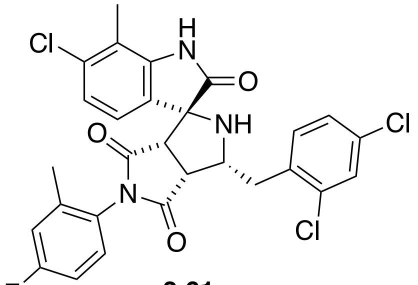
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-3'-(2-fluorobenzyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.60**):



**3.60**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.18 g, 0.93 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.20 g, 0.97 mmol, 1.05 equiv), and 2-amino-3-(2-fluorophenyl)propanoic acid (0.19 g, 1.0 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.60** (0.25 g, 0.49 mmol, 52%) as a light brown solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.26) δ 8.69 (s, 1H, minor rotamer), 8.64 (s, 1H, major rotamer), 7.29 – 6.99 (m, 8H, major and minor rotamer), 6.85 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.77 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.82 – 4.73 (m, 1H, major and minor rotamer), 3.81 – 3.76 (m, 1H, major rotamer, 2H, minor rotamer), 3.69 (d, *J* = 8.0 Hz, 1H, major rotamer), 3.54 – 3.48 (m, 1H, major and minor rotamer), 2.80 (dd, *J* = 10.0 Hz, 14.0 Hz, 1H, minor rotamer), 2.72 (dd, *J* = 10.7 Hz, 13.9 Hz, 1H, major rotamer), 2.45 (s, 3H, major rotamer), 2.19 – 2.13 (m, 1H, major rotamer, 4H, minor rotamer), 2.02 (s, 3H, major rotamer), 1.96 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 181.2, 181.1, 175.4, 175.2, 174.8, 174.7, 164.3, 164.2, 162.44, 162.40, 162.3, 162.2, 160.5, 160.4, 140.9, 138.88, 138.82, 138.3, 138.2, 136.6, 136.5, 131.5, 131.4, 131.37, 131.30, 130.2, 130.1, 130.0, 128.9, 128.8, 127.09, 127.06, 127.04, 126.4, 126.3, 126.2, 126.18, 125.2, 124.8, 124.7, 124.6, 124.58, 124.55, 124.2, 123.8, 121.6, 118.9, 118.7, 118.6, 118.5, 118.4, 118.2, 116.07, 116.05, 115.90, 115.87, 114.7, 114.6, 114.5, 114.4, 68.6, 68.5, 57.8, 57.3, 51.82, 51.79, 48.0, 47.7, 32.2, 31.8, 19.0, 18.4, 13.8, 13.7; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}ClF_2N_3O_3Na$ [M+Na]$^+$ 544.1215**,** found 544.1238**;** HPLC purity: 99.9%.

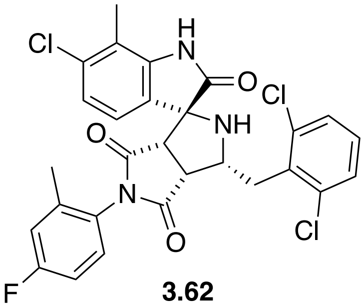
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-3'-(2,4-dichlorobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.61**):



**3.61**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.09 g, 0.46 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.10 g, 0.49 mmol, 1.05 equiv), and 2-amino-3-(2,4-dichlorophenyl)propanoic acid (0.12 g, 0.51 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.61** (0.15 g, 0.26 mmol, 55%) as a light yellow solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.23) δ 8.71 (s, 1H, minor rotamer), 8.64 (s, 1H, major rotamer), 7.37 – 7.36 (m, 1H, major and minor rotamer), 7.31 (d, *J* = 8.3 Hz, 1H, minor rotamer), 7.25 – 7.21 (m, 1H, major and minor rotamer), 7.15 – 6.99 (m, 5H, major rotamer, 4H, minor rotamer), 6.83 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.75 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.84 – 4.74 (m, 1H, major and minor rotamer), 3.83 – 3.71 (m, 2H, major and minor rotamer), 3.61 – 3.55 (m, 1H, major and minor rotamer), 2.89 – 2.78 (m, 1H, major and minor rotamer), 2.44 (s, 3H, major rotamer), 2.14 – 2.10 (m, 1H, major rotamer, 4H, minor rotamer), 2.02 (s, 3H, major rotamer), 1.96 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 181.1, 180.9, 175.4, 175.1, 174.7, 174.6, 164.3, 164.2, 162.4, 162.2, 140.95, 140.93, 138.9, 138.8, 138.1, 138.07, 136.7, 136.6, 135.5, 135.24, 135.19, 133.6, 132.2, 132.1, 130.13, 130.06, 130.02, 129.99, 129.9, 127.7, 127.6, 127.0, 126.99, 126.97, 125.1, 124.7, 124.6, 124.1, 123.8, 123.7, 119.0, 118.7, 118.5, 118.4, 118.2, 114.69, 114.65, 114.5, 114.47, 68.6, 68.5, 57.0, 56.7, 51.8, 51.7, 47.9, 47.6, 35.8, 35.4, 19.1, 18.4, 13.84, 13.76; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}Cl_3FN_3O_3$ $[M+H]^+$ 572.0711**,** found 572.0707**;** HPLC purity: 99.5%.

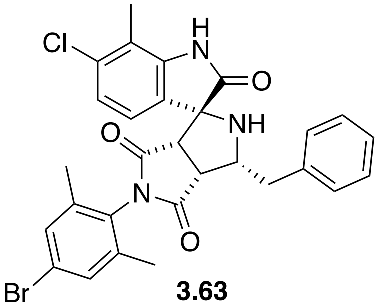
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-3'-(2,6-dichlorobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.62**):



**3.62**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.09 g, 0.46 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.10 g, 0.49 mmol, 1.05 equiv), and 2-amino-3-(2,6-dichlorophenyl)propanoic acid (0.12 g, 0.52 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.62** (0.12 g, 0.20 mmol, 43%) as a light brown solid. $R_f$ = 0.8 (3:2 EtOAc/Hex). $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.49) δ 8.83 (s, 1H, major and minor rotamer), 7.26 – 7.20 (m, 3H, major and minor rotamer), 7.12 – 6.98 (m, 4H, major and minor rotamer), 6.83 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.75 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.92 (s, 1H, major rotamer), 4.83 (s, 1H, minor rotamer), 3.89 (t, *J* = 7.8 Hz, 1H, minor rotamer), 3.83 (t, *J* = 8.0 Hz, 1H, major rotamer), 3.77 – 3.69 (m, 2H, major and minor rotamer), 3.35 – 3.23 (m, 1H, major and minor rotamer), 2.46 (s, 3H, major rotamer), 2.18 – 2.14 (m, 1H, major rotamer, 4H, minor rotamer), 2.03 (s, 3H, major rotamer), 1.99 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 181.2, 181.1, 175.5, 175.1, 174.8, 174.5, 164.3, 164.2, 162.4, 162.2, 141.0, 138.92, 138.86, 138.4, 138.3, 136.6, 136.5, 136.03, 136.02, 135.7, 135.6, 130.13, 130.06, 129.97, 129.0, 128.9, 128.8, 128.7, 127.09, 127.06, 125.0, 124.7, 124.6, 124.2, 123.8, 123.7, 118.9, 118.72, 118.67, 118.5, 118.4, 118.2, 114.7, 114.6, 114.4, 69.0, 57.2, 56.7, 51.79, 51.75, 48.6, 48.1, 33.8, 33.5, 19.1, 18.4, 13.85, 13.82; HRMS (ESI): *m/z* calculated for $C_{28}H_{21}Cl_3FN_3O_3Na$ $[M+Na]^+$ 594.0530**,** found 594.0538**;** HPLC purity: 99.9%.

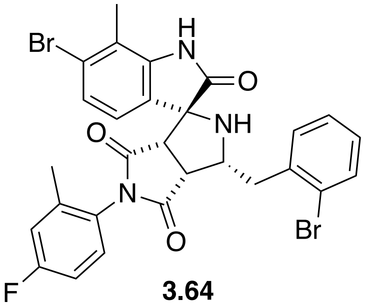
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-5'-(4-bromo-2,6-dimethylphenyl)-6-chloro-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.63**):



**3.63**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.09 g, 0.46 mmol, 1.0 equiv), 1-(4-bromo-2,6-dimethylphenyl)-1*H*-pyrrole-2,5-dione (0.14 g, 0.49 mmol, 1.05 equiv), and phenylalanine (0.09 g, 0.52 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.63** (0.13 g, 0.22 mmol, 47%) as a light yellow solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.28 (s, 1H), 7.40 (s, 1H), 7.32 (s, 1H), 7.29 – 7.21 (m, 5H), 7.01 (d, *J* = 8.2 Hz, 1H), 6.84 (d, *J* = 8.4 Hz, 1H), 4.80 (t, *J* = 9.2 Hz, 1H), 3.85 (t, *J* = 8.3 Hz, 1H), 3.62 (d, *J* = 8.0 Hz, 1H), 3.47 (d, *J* = 13.6 Hz, 1H), 2.58 (t, *J* = 13.1 Hz, 1H), 2.43 (s, 3H), 2.17 (s, 1H), 2.12 (s, 3H), 2.07 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.6, 174.8, 173.7, 140.6, 139.2, 138.1, 137.7, 136.3, 131.8, 129.6, 129.0, 128.9, 126.9, 125.5, 123.7, 123.6, 123.2, 118.0, 68.4, 58.1, 51.4, 47.6, 39.0, 18.7, 18.0, 13.7; (HRMS (ESI): *m/z* calculated for $C_{29}H_{25}BrClN_3O_3Na$ $[M+Na]^+$ 600.0665**,** found 600.0651**;** HPLC purity: 94.6%.

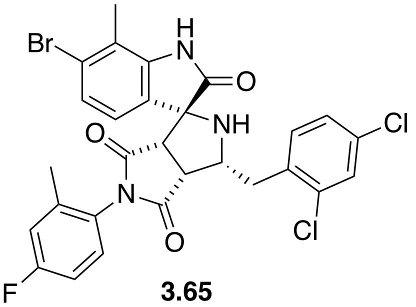
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Bromo-3'-(2-bromobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.64**):



**3.64**

Using the general procedure for spiroindolinone synthesis outlined above, 6-bromo-7-methylindoline-2,3-dione (0.11 g, 0.46 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.10 g, 0.49 mmol, 1.05 equiv), and 2-amino-3-(2-bromophenyl)propanoic acid (0.13 g, 0.52 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.64** (0.08 g, 0.12 mmol, 27%) as a light yellow solid. R$_f$ = 0.4 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.19) δ 10.64 (s, 1H, minor rotamer), 10.57 (s, 1H, major rotamer), 7.59 (t, *J* = 6.4 Hz, 1H, major and minor rotamer), 7.48 – 7.44 (m, 1H, major and minor rotamer), 7.37 (d, *J* = 7.6 Hz, 1H, major rotamer), 7.33 – 7.13 (m, 5H, major rotamer, 6H, minor rotamer), 6.85 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.60 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.70 – 4.66 (m, 1H, major rotamer), 4.52 – 4.60 (m, 1H, minor rotamer), 3.88 – 3.85 (m, 1H, major rotamer, 2H, minor rotamer), 3.70 (t, *J* = 8.1 Hz, 1H, major rotamer), 3.64 (d, *J* = 7.8 Hz, 1H, minor rotamer); 3.48 – 3.38 (m, 2H, major rotamer, 1H, minor rotamer), 2.82 (dd, *J* = 14.7 Hz, 9.6 Hz, 1H, minor rotatmer), 2.64 (dd, *J* = 14.4 Hz, 9.6 Hz, 1H, major rotatmer), 2.36 (s, 3H, major rotatmer), 2.23 (s, 3H, minor rotamer), 2.22 (s, 3H, major rotamer), 2.06 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.8, 181.2, 176.5, 176.4, 175.0, 174.6, 164.0, 163.7, 162.0, 161.8, 143.2, 143.1, 139.9, 139.8, 139.6, 139.2, 139.1, 133.39, 133.35, 132.15, 132.07, 131.74, 131.66, 131.43, 131.36, 129.3, 129.2, 128.98, 128.97, 128.7, 128.6, 127.4, 127.2, 126.3, 126.2, 126.0, 125.8, 125.5, 125.4, 125.1, 125.0, 119.5, 119.2, 118.4, 118.24, 118.20, 118.0, 114.7, 114.6, 114.5, 114.4, 69.8, 69.0, 58.5, 56.8, 53.5, 52.8, 50.2, 49.0, 39.3, 37.8, 18.9, 18.3, 17.61, 17.55; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}Br_2FN_3O_3Na$ $[M+Na]^+$ 647.9910**,** found 647.9911**;** HPLC purity: 99.5%.

(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Bromo-3'-(2,4-dichlorobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.65**):

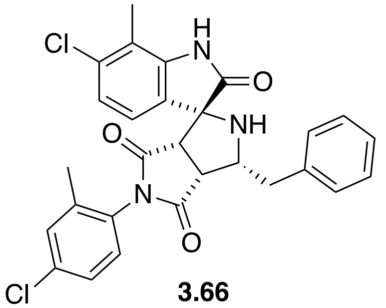


**3.65**

Using the general procedure for spiroindolinone synthesis outlined above, 6-bromo-7-methylindoline-2,3-dione (0.11 g, 0.46 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.10 g, 0.49 mmol, 1.05 equiv), and 2-amino-3-(2,4-dichlorophenyl)propanoic acid (0.12 g, 0.52 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.65** (0.11 g, 0.17 mmol, 37%) as a light yellow solid. R$_f$ = 0.4 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.32) δ 10.66 (s, 1H, minor rotamer), 10.59 (s, 1H, major rotamer), 7.58 – 7.14 (m, 7H, major and minor rotamer), 6.84 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.60 (d, *J* =

8.1 Hz, 1H, major rotamer), 4.67 – 4.64 (m, 1H, major rotamer), 4.52 – 4.46 (m, 1H, minor rotamer), 3.93 – 3.89 (m, 1H, major and minor rotamer), 3.86 (d, *J* = 7.8 Hz, 1H, minor rotamer), 3.71 (t, *J* = 8.1 Hz, 1H, major rotamer), 3.65 (d, *J* = 7.8 Hz, 1H, minor rotamer), 3.46 (d, *J* = 8.0 Hz, 1H, major rotamer), 3.42 (dd, *J* = 4.1 Hz, 14.7 Hz, 1H, minor rotamer), 3.41 – 3.34 (m, 1H, major rotamer), 2.82 (dd, *J* = 9.6 Hz, 14.7 Hz, 1H, minor rotamer), 2.64 (dd, *J* = 9.7 Hz, 14.2 Hz, 1H, major rotamer), 2.36 (s, 3H, major rotamer), 2.24 – 2.23 (m, 3H, major and minor rotamer), 2.07 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.8, 181.2, 176.5, 176.4, 175.0, 174.6, 164.0, 163.7, 162.0, 161.8, 143.2, 143.1, 139.85, 139.77, 139.2, 139.1, 137.4, 137.0, 135.0, 134.9, 133.4, 132.5, 131.7, 131.6, 131.43, 131.36, 129.49, 129.46, 129.0, 128.9, 128.60, 128.59, 128.3, 128.2, 127.3, 127.1, 126.3, 126.2, 126.0, 125.8, 125.6, 125.4, 119.5, 119.2, 118.4, 118.23, 118.19, 118.0, 114.7, 114.6, 114.5, 114.4, 69.7, 68.9, 58.1, 56.6, 53.4, 52.8, 50.0, 48.9, 36.3, 34.8, 18.9, 18.3, 17.6, 17.5; HRMS (ESI): *m/z* calculated for $C_{28}H_{21}BrCl_2FN_3O_3Na$ [M+Na]$^+$ 638.0025**,** found 638.0016**;** HPLC purity: 98.8%.

(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(4-chloro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.66**):

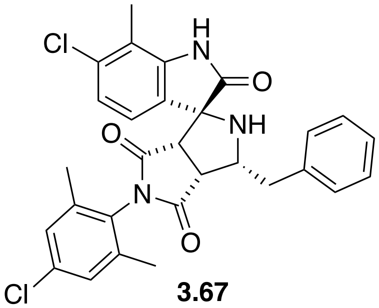


**3.66**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.10 g, 0.49 mmol, 1.0 equiv), 1-(4-chloro-2-methylphenyl)-

1*H*-pyrrole-2,5-dione (0.11 g, 0.51 mmol, 1.05 equiv), and phenylalanine (0.09 g, 0.54 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.66** (0.11 g, 0.21 mmol, 43%) as a white solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.3) δ 10.65 (s, 1H, minor rotamer), 10.59 (s, 1H, major rotamer), 7.56 (d, *J*= 2.2 Hz, 1H, major rotamer), 7.50 – 7.17 (m, 7H, major rotamer, 8H, minor rotamer), 6.99 (d, *J*= 8.1 Hz, 1H, minor rotamer), 6.95 (d, *J* = 8.1 Hz, 1H, major rotamer), 6.91 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.66 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.61 – 4.56 (m, 1H, major rotamer), 4.46 – 4.40 (m, 1H, minor rotamer), 3.86 (d, *J* = 9.5 Hz, 1H, minor rotamer), 3.83 – 3.80 (m, 1H, major and minor rotamer), 3.67 – 3.62 (m, 1H, major and minor rotamer), 3.45 (d, *J* = 7.9 Hz, major rotamer), 3.30 – 3.22 (m, 1H, major and minor rotamer), 2.74 (dd, *J* = 8.8 Hz, 14.1 Hz, minor rotamer), 2.55 – 2.52 (m, 1H, major rotamer), 2.35 (s, 3H, major rotamer), 2.21 – 2.20 (m, 3H, major and minor rotamer), 2.06 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.0, 180.5, 175.5, 175.4, 173.9, 173.6, 142.4, 142.3, 140.1, 139.7, 138.5, 137.8, 134.1, 133.9, 133.7, 133.4, 130.8, 130.6, 130.53, 130.50, 130.4, 130.2, 129.0, 128.9, 128.3, 128.2, 126.8, 126.7, 126.1, 126.0, 125.9, 125.7, 124.81, 124.80, 121.4, 121.2, 116.9, 116.7, 68.7, 67.8, 59.9, 58.0, 52.8, 52.1, 49.2, 48.1, 38.0, 36.4, 17.7, 17.1, 13.82, 13.80; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}Cl_2N_3O_3Na$ $[M+Na]^+$ 542.1014**,** found 542.1006**;** HPLC purity: 99.9%.

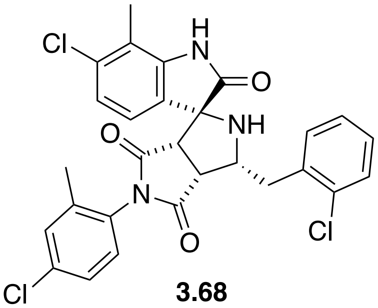
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(4-chloro-2,6-dimethylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.67**):



**3.67**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.09 g, 0.45 mmol, 1.0 equiv), 1-(4-chloro-2,6-dimethylphenyl)-1*H*-pyrrole-2,5-dione (0.11 g, 0.47 mmol, 1.05 equiv), and phenylalanine (0.08 g, 0.49 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.67** (0.10 g, 0.18 mmol, 41%) as a white solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO) δ 10.66, (s, 1H), 7.44 (s, 1H), 7.36 (s, 1H), 7.33 (d, *J* = 4.4 Hz, 4H), 7.25 (d, *J* = 4.2 Hz, 1H), 7.01 (d, *J* = 8.1 Hz, 1H), 6.74 (d, *J* = 8.1 Hz, 1H), 4.70 (t, *J* = 4.3 Hz, 1H), 3.89 (t, *J* = 4.4 Hz, 2H), 3.70 (d, *J* = 8.2 Hz, 1H), 3.27, (dd, *J* = 4.85, 13.9 Hz, 1H), 2.59 – 2.56 (m, 1H), 2.39 (s, 3H), 2.25 (s, 3H), 2.07 (s, 3H); $^{13}$C NMR (500 MHz, DMSO) δ 180.9, 175.4, 173.6, 142.5, 139.6, 138.5, 137.9, 133.8, 133.4, 129.8, 129.0, 128.3, 127.9, 126.1, 125.6, 125.1, 121.1, 116.6, 67.9, 57.7, 51.4, 47.7, 38.1, 18.0, 17.3, 13.7; HRMS (ESI): *m/z* calculated for $C_{29}H_{25}Cl_2N_3O_3Na$ $[M+Na]^+$ 556.1171**,** found 556.1176**;** HPLC purity: 99.9%.

(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-chloro-2-methylphenyl)-3'-(2-chlorobenzyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.68**):

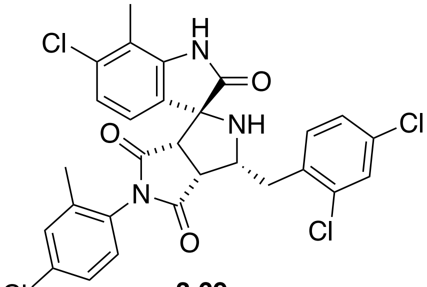


**3.68**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.10 g, 0.52 mmol, 1.0 equiv), 1-(4-chloro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.12 g, 0.55 mmol, 1.05 equiv), and 2-amino-3-(2-chlorophenyl)propanoic acid (0.11 g, 0.57 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.68** (0.16 g, 0.29 mmol, 55%) as a white solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.25) δ 10.66 (s, 1H, minor rotamer), 10.59 (s, 1H, major rotamer), 7.48 (d, *J* = 11.1 Hz, 1H, major rotamer), 7.47 – 7.21 (m, 6H, major rotamer, 7H, minor rotamer), 7.00 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.95 (d, *J* = 8.1 Hz, 1H, major rotamer), 6.91 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.66 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.71 – 4.66 (m, 1H, major rotamer), 4.53 – 4.47 (m, 1H, minor rotamer), 3.91 – 3.85 (m, 1H, major rotamer, 2H, minor rotamer), 3.71 (t, *J* = 8.0 Hz, 1H, major rotamer), 3.65 (d, *J* = 7.9 Hz, 1H, minor rotamer), 3.49 – 3.46 (m, 1H, major and minor rotamer), 3.41 – 3.34 (m, 1H, major rotamer), 2.85 – 2.81 (m, 1H, minor rotamer), 2.68 – 2.64 (m, 1H, major rotamer), 2.35 (s, 3H, major rotamer), 2.22 – 2.20 (m, 3H, major and minor rotamer), 2.08 – 2.06 (m, 3H, minor rotamer); $^{13}$C NMR (500

MHz, DMSO) δ 175.4, 175.3, 173.9, 173.5, 142.5, 142.3, 138.4, 137.8, 137.3, 137.0, 134.1, 133.9, 133.7, 133.4, 133.2, 133.1, 131.2, 131.1, 130.7, 130.5, 130.4, 130.2, 129.2, 129.1, 128.01, 127.99, 127.2, 127.1, 126.8, 126.7, 125.8, 125.5, 124.85, 124.79, 121.3, 121.2, 116.9, 116.6, 68.8, 67.9, 57.5, 55.8, 52.7, 52.0, 49.3, 48.1, 35.7, 34.2, 17.7, 17.1, 13.8, 13.7; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}Cl_3N_3O_3Na$ $[M+Na]^+$ 576.0624**,** found 576.0615**;** HPLC purity: 97.2%.

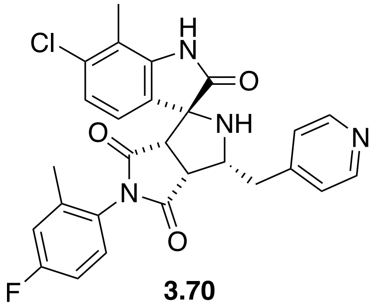
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-chloro-2-methylphenyl)-3'-(2,4-dichlorobenzyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.69**):



**3.69**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.08 g, 0.41 mmol, 1.0 equiv), 1-(4-chloro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.10 g, 0.43 mmol, 1.05 equiv), and 2-amino-3-(2,4-dichlorophenyl)propanoic acid (0.11 g, 0.46 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.69** (0.14 g, 0.24 mmol, 59%) as a white solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.35) δ 10.67 (s, 1H, minor rotamer), 10.60 (s, 1H, major rotamer), 7.58 – 7.56 (m, 1H, major rotamer, 2H, minor rotamer), 7.52 – 7.34 (m, 4H, major rotamer, 4H, minor rotamer), 7.22 (d, *J* = 8.5 Hz, 1H, major rotamer), 7.01 (d, *J* = 4.9 Hz, 1H, minor rotamer), 6.96 (d, *J* = 8.l Hz, 1H, major rotamer), 6.90 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.66 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.69 – 4.63 (m, 1H, major rotamer), 4.51 – 4.46 (m, 1H, minor rotamer), 3.93 – 3.86 (m, 1H, major rotamer, 2H, minor rotamer), 3.71 (t, *J* = 8.0 Hz, 1H, major rotamer), 3.66 (d, *J* = 7.8 Hz, 1H, minor rotamer), 3.47 (d, *J* = 7.9 Hz, 1H, major rotamer), 3.43 (dd, *J* = 4.1 Hz, 14.7 Hz, 1H, minor rotamer), 3.36 (d, *J* = 3.8 Hz, 1H, major rotamer), 2.82 (dd, *J* = 9.7 Hz, 14.7 Hz, 1H, minor rotamer), 2.65 (dd, *J* = 9.8 Hz, 14.2 Hz, 1H, major rotamer), 2.35 (s, 3H, major rotamer), 2.22 – 2.21 (m, 3H, major and minor rotamer), 2.07 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.8, 181.2, 176.3, 176.2, 174.8, 174.4, 143.4, 143.3, 139.4, 138.7, 137.3, 137.0, 135.05, 134.99, 134.9, 134.8, 134.7, 134.4, 133.4, 132.5, 131.7, 131.5, 131.4, 131.33, 131.31, 131.1, 129.49, 129. 45, 128.3, 128.2, 127.8, 127.6, 126.6, 126.4, 125.8, 125.7, 122.3, 122.1, 117.8, 117.6, 69.7, 68.9, 58.1, 56.6, 53.5, 52.9, 50.2, 49.0, 36.3, 34.7, 18.7, 18.0, 14.74, 14.68; HRMS (ESI): *m/z* calculated for $C_{28}H_{21}Cl_4N_3O_3Na$ [M+Na]$^+$ 610.0235**,** found 610.0245**;** HPLC purity: 99.9%.

(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-3'-(pyridin-4-ylmethyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.70**):

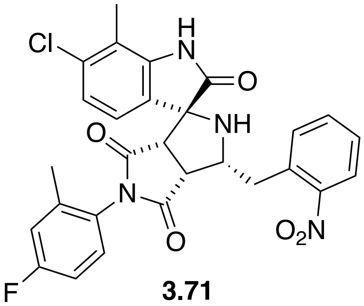


**3.70**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.09 g, 0.46 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-

1*H*-pyrrole-2,5-dione (0.10 g, 0.49 mmol, 1.05 equiv), and 2-amino-3-(pyridin-4-yl)propanoic acid (0.09 g, 0.52 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.70** (0.12 g, 0.23 mmol, 51%) as a white solid. $R_f$ = 0.2 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.17) δ 10.69 (s, 1H, minor rotamer), 10.63 (s, 1H, major rotamer), 8.50 – 8.45 (m, 2H, major rotamer and minor rotamer), 7.48 – 7.45 (m, 1H, major rotamer), 7.35 – 7.17 (m, 4H, major rotatmer, 5H minor rotamer), 7.02 – 6.97 (m, 1H, major and minor rotamer), 6.91 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.67 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.67 – 4.61 (m, 1H, major rotamer), 4.51 – 4.45 (m, 1H, minor rotamer), 3.96 – 3.95 (m, 1H, major and minor rotamer), 3.85 (t, *J* = 7.7 Hz, 1H, minor rotamer), 3.70 (t, *J* = 7.9 Hz, 1H, major rotamer), 3.65 (d, *J* = 7.9 Hz, 1H, minor rotamer), 3.46 (d, *J* = 8.0 Hz, 1H, major rotamer), 3.32 – 3.23 (m, 1H, major and minor rotamer), 2.78 (dd, *J* = 9.2 Hz, 14.2 Hz, 1H, minor rotamer), 2.55 (dd, *J* = 8.8 Hz, 13.9 Hz, 1H, major rotamer), 2.35 (s, 3H, major rotamer), 2.22 – 2.21 (m, 3H, major and minor rotamer), 2.07 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.9, 181.3, 176.5, 176.4, 175.0, 174.6, 163.9, 163.7, 162.0, 161.8, 150.34, 150.30, 149.8, 149.3, 143.4, 143.2, 139.84, 139.77, 139.2, 139.1, 135.0, 134.8, 131.73, 131.66, 131.43, 131.35, 129.0, 128.9, 128.61, 128.59, 126.6, 126.5, 125.8, 125.7, 125.43, 125.37, 122.3, 122.2, 118.4, 118.2, 118.0, 117.8, 117.6, 114.7, 114.6, 114.5, 114.4, 69.6, 68.8, 59.6, 57.9, 53.5, 52.8, 50.0, 48.9, 38.4, 36.7, 18.9, 18.3, 14.74, 14.69; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}ClFN_3O_3Na$ [M+Na]$^+$ 527.1262**,** found 527.1266**;** HPLC purity: 99.9%.

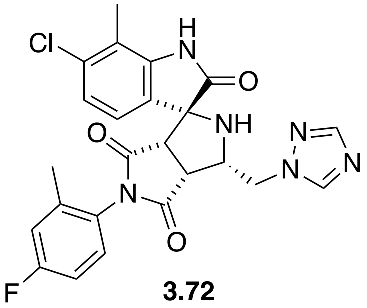
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-3'-(2-nitrobenzyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.71**):



**3.71**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.09 g, 0.46 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.10 g, 0.49 mmol, 1.05 equiv), and 2-amino-3-(2-nitrophenyl)propanoic acid (0.11 g, 0.52 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.71** (0.15 g, 0.28 mmol, 61%) as a white solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.09) δ 8.55 (s, 1H minor rotamer), 8.51 (s, 1H major rotamer), 7.93 – 7.90 (m, 1H, major and minor rotamer), 7.57 – 7.50 (m, 2H, major and minor rotamer), 7.39 – 7.36 (m, 1H, major and minor rotamer), 7.25 – 6.99 (m, 4H, major and minor rotamer), 6.84 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.76 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.85 – 4.80 (m, 1H, major rotamer), 4.78 – 4.73 (m, 1H, minor rotamer), 3.84 – 3.74 (m, 3H, major and minor rotamer), 3.12 (dd, *J* = 8.6 Hz, 13.9 Hz, 1H, minor rotamer), 3.01 (dd, *J* = 8.9 Hz, 13.9 Hz, 1H, major rotamer), 2.43 (s, 3H, major rotamer), 2.34 – 2.30 (m, 1H, major and minor rotamer), 2.13 (s, 3H, minor rotamer), 1.97 (s, 3H, major rotamer), 1.92 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.84, 180.76, 175.5, 175.2, 174.8, 174.5, 164.4, 164.2, 162.4, 162.2, 149.9, 149.8, 140.9, 138.9, 138.8, 138.24, 138.17, 136.7, 136.6, 134.4, 134.3, 133.64, 133.56, 132.7, 132.6, 130.11, 130.09, 130.04, 130.02, 128.3, 127.00, 126.97, 126.95, 125.6, 125.5, 125.0, 124.6, 124.5, 124.1, 123.8, 123.7, 119.0, 118.74, 118.67, 118.5, 118.4, 118.2, 114.7, 114.60, 114.56, 114.42, 68.71, 68.68, 58.7, 58.2, 51.9, 51.8, 48.1, 47.8, 35.2, 34.7, 19.1, 18.4, 13.8, 13.7; HRMS (ESI): *m/z* calculated for $C_{29}H_{23}ClFN_3O_5Na$ $[M+Na]^+$ 571.1160**,** found 571.1157**;** HPLC purity: 99.9%.

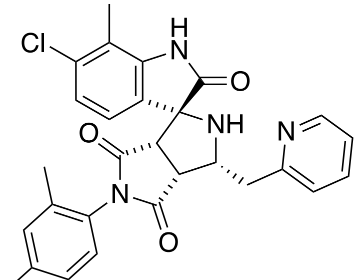
(3*R*,3'*S*,3a'*R*,6a'*S*)-3'-((1*H*-1,2,4-Triazol-1-yl)methyl)-6-chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.72**):



**3.72**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.09 g, 0.46 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.10 g, 0.49 mmol, 1.05 equiv), and 2-amino-3-(1*H*-1,2,4-triazol-1-yl)propanoic acid (0.08 g, 0.52 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.72** (0.13 g, 0.25 mmol, 55%) as a white solid. $R_f$ = 0.4 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.18) δ 10.73 (s, 1H, minor rotamer), 10.71 (s, 1H, major rotamer), 8.55 – 8.52 (m, 1H, major and minor rotamer), 8.01 – 8.00 (m, 1H, major and minor rotamer), 7.44 (dd, *J* = 5.5 Hz, 8.6 Hz, 1H, minor rotamer), 7.36 (dd, *J* = 2.5 Hz, 9.6 Hz, 1H, major rotamer), 7.30 – 7.12 (m, 2H, major and minor rotamer), 7.04 – 7.00 (m, 1H, major and minor), 6.88 (d, *J* = 8.1 Hz, 1H, minor rotamer), 8.68 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.88 – 4.84 (m, 1H, major rotamer), 4.80 – 4.71 (m, 2H, minor rotamer, 1H, major rotamer), 4.31 (dd, *J* = 8.0 Hz, 13.5 Hz, 1H, minor rotamer), 4.20 – 4.15 (m, 1H, major and minor rotamer), 4.10 (dd, *J* = 8.2 Hz, 14.0 Hz, 1H, major rotamer), 3.95 (t, *J* = 7.6 Hz, 1H, minor rotamer), 3.78 (t, *J* = 8.0 Hz, 1H, major rotamer), 3.70 (d, *J* = 7.9 Hz, 1H, minor rotamer) 3.52 (d, *J* = 7.9 Hz, 1H, major rotamer), 2.35 (s, 3H, major rotamer), 2.24 (s, 3H, major and minor rotamer), 2.09 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 180.6, 180.5, 175.2, 175.0, 174.2, 173.8, 164.3, 164.2, 162.3, 162.2, 152.7, 144.1, 144.0, 140.9, 140.8, 138.7, 138.6, 138.02, 137.95, 136.75, 136.71, 130.0, 129.9, 129.83, 129.76, 126.6, 125.2, 124.8, 124.0, 123.8, 123.7, 123.5, 118.7, 118.5, 118.4, 118.2, 114.7, 114.5, 68.6, 68.5, 56.9, 56.6, 51.9, 51.5, 51.14, 51.07, 46.7, 46.5, 19.0, 18.3, 14.0, 13.9; HRMS (ESI): *m/z* calculated for $C_{25}H_{21}ClFN_5O_3Na$ [M+Na]$^+$ 517.1167**,** found 517.1157**;** HPLC purity: 93.7%.

(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-3'-(pyridin-2-ylmethyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.73**):

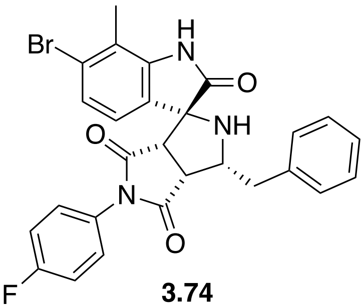


**3.73**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.09 g, 0.46 mmol, 1.0 equiv), 1-(4-fluoro-2-methylphenyl)-

1*H*-pyrrole-2,5-dione (0.10 g, 0.49 mmol, 1.05 equiv), and 2-amino-3-(pyridin-2-yl)propanoic acid (0.08 g, 0.52 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.73** (0.08 g, 0.16 mmol, 35%) as a white solid. $R_f$ = 0.2 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.16) δ 10.67 (s, 1H, minor rotamer), 10.64 (s, 1H, major rotamer), 8.50 (s, 1H, major and minor rotamer), 7.69 – 7.67 (m, 1H, major and minor rotamer), 7.44 (dd, *J* = 5.6 Hz, 7.9 Hz, 1H, minor rotamer), 7.36 – 7.32 (m, 2H, major rotamer, 1H, minor rotamer), 7.27 – 7.16 (m, 3H, major and minor rotamer), 7.01 – 6.97 (m, 1H, major and minor rotamer), 6.92 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.68 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.90 (q, *J* = 4.3 Hz, 12.7 Hz, 1H, major rotamer), 4.76 (q, *J* = 6.8 Hz, 14.2 Hz, 1H, minor rotamer), 3.96 – 3.95 (m, 1H, major and minor rotamer), 3.84 (t, *J* = 7.7 Hz, 1H, minor rotamer), 3.69 (t, *J* = 8.0 Hz, 1H, major rotamer), 3.64 (d, *J* = 7.8 Hz, 1H, minor rotamer), 3.47 (d, *J* = 7.9 Hz, 1H, major rotamer), 3.39 – 3.30 (m, 1H, major and minor rotamer), 2.96 (dd, *J* = 8.2 Hz, 14.7 Hz, 1H, minor rotamer), 2.79 (dd, *J* = 8.3 Hz, 14.7 Hz, 1H, major rotamer), 2.34 (s, 3H, major rotamer), 2.23 (s, 3H, major and minor rotamer), 2.05 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 180.8, 180.4, 175.55, 175.58, 174.0, 173.7, 162.9, 162.7, 161.0, 160.8, 159.3, 159.1, 148.79, 148.77, 142.3, 142.2, 138.8, 138.7, 138.13, 138.06, 136.20, 136.16, 134.0, 133.9, 130.7, 130.6, 130.4, 130.3, 128.0, 127.6, 125.73, 125.69, 124.8, 124.7, 123.5, 123.4, 121.3, 121.24, 121.19, 117.3, 117.2, 117.1, 117.0, 116.8, 116.7, 113.7, 113.54, 113.47, 113.4, 68.4, 67.7, 57.5, 55.7, 52.5, 51.8, 48.7, 47.7, 38.6, 17.9, 17.2, 13.71, 13.68; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}ClFN_3O_3Na$ $[M+Na]^+$ 527.1262**,** found 527.1261**;** HPLC purity: 99.9%.

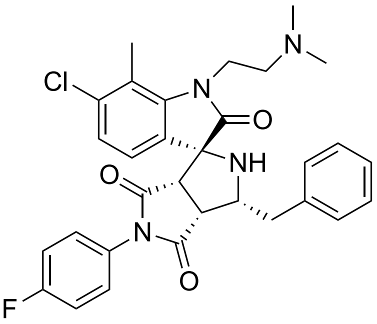
(3R,3'R,3a'R,6a'S)-3'-Benzyl-6-bromo-5'-(4-fluorophenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'H-spiro[indoline-3,1'-pyrrolo[3,4-c]pyrrole]-2,4',6'(5'H)-trione (**3.74**):



**3.74**

Using the general procedure for spiroindolinone synthesis outlined above, 6-bromo-7-methylindoline-2,3-dione (0.30 g, 1.2 mmol, 1 equiv), 1-(4-fluorophenyl)-1H-pyrrole-2,5-dione (0.25 g, 1.31 mmol, 1.05 equiv) and phenylalanine (0.23 g, 1.4 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.74** (0.47 g, 0.87 mmol, 70%) as a white solid. R*f* = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$) δ 8.54 (s, 1H), 7.39 (t, *J* = 7.9 Hz, 2H), 7.24 – 7.21 (m, 8H), 6.74 (d, *J* = 8.1 Hz, 1H), 4.71 (s, 1H), 3.84 (d, *J* = 7.9 Hz, 1H), 3.70 (t, *J* = 7.5 Hz, 1H), 3.46 (dd, *J* = 13.8 Hz, 3.4 Hz, 1H), 2.76 (dd, *J* = 13.5 Hz, 10.5 Hz, 1H), 2.18 (s, 1H), 1.94 (s, 3H); $^{13}$C NMR (500 MHz, CDCl$_3$) δ 180.8, 175.2, 175.0, 163.5, 161.5, 140.5, 139.2, 129.0, 128.9, 128.4, 128.3, 127.62, 127.59, 126.9, 126.8, 126.76, 125.6, 124.8, 120.4, 116.7, 116.5, 68.3, 59.2, 51.7, 47.8, 37.8, 16.4; HRMS (ESI): *m/z* calculated for $C_{27}H_{21}BrFN_3O_3Na$ [M+Na]$^+$ 556.0648, found 556.0668; HPLC purity: 99.9%.

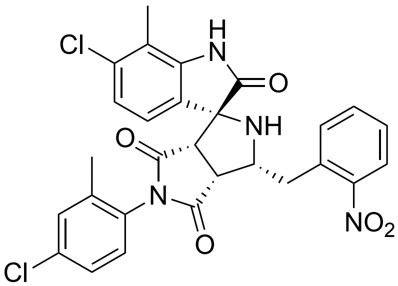
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-1-(2-(dimethylamino)ethyl)-5'-(4-fluorophenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.75**):



**3.75**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-1-(2-(dimethylamino)ethyl)-7-methylindoline-2,3-dione (0.13 g, 0.49 mmol, 1 equiv), 1-(4-fluorophenyl)-1H-pyrrole-2,5-dione (0.098 g, 0.51 mmol, 1.05 equiv), and phenylalanine (0.089 g, 0.54 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.75** (0.14 g, 0.25 mmol, 50%) as a white solid. $R_f$ = 0.4 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, CDCl$_3$) δ 7.37 (dd, *J* = 2.5 Hz, 9.0 Hz, 2H), 7.26 – 7.25 (m, 4H), 7.21 – 7.18 (m, 3H), 7.07 (d, *J* = 8.1 Hz, 1H), 6.84 (d, *J* = 8.1, 1H), 4.75 – 4.71 (m, 1 H), 4.06 – 4.00 (m, 1H), 3.90 – 3.85 (m, 1H), 3.70 (t, *J* = 7.8 Hz, 1H), 3.50 – 3.44 (m, 2H), 2.68 (dd, *J* = 10.5 Hz, 13.7 Hz, 1H), 2.45 (s, 3H), 2.45 – 2.38 (m, 1H), 2.33 – 2.28 (m, 1H), 2.21 (s, 1H), 2.00 (s, 6H); $^{13}$C NMR (500 MHz, CDCl$_3$) *δ* 181.3, 175.3, 173.8, 163.4, 161.4, 142.3, 139.6, 137.4, 129.1, 128.8, 128.4, 128.3, 127.9, 127.8, 126.6, 126.0, 124.6, 123.8, 118.9, 116.5, 116.3, 66.9, 58.9, 57.5, 51.9, 47.8, 45.5, 41.0, 38.5, 15.2; HRMS (ESI): *m/z* calculated for $C_{31}H_{30}ClFN_4O_3H$ [M+H]$^+$ 561.2068, found 561.2062; HPLC purity: 99.7%.

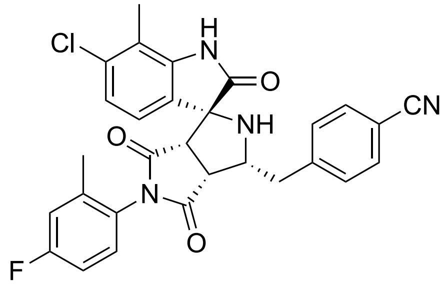
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-chloro-2-methylphenyl)-7-methyl-3'-(2-nitrobenzyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.76**):



**3.76**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.096 g, 0.49 mmol, 1 equiv), 1-(4-chloro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.11 g, 0.51 mmol, 1.05 equiv), and 2-amino-3-(2-nitrophenyl)propanoic acid (0.13 g, 0.54 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.76** (0.13 g, 0.22 mmol, 46%) as a tan solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.11) δ 8.52 (s, 1H, minor rotamer), 8.48 (s, 1H, major rotamer), 7.93 – 7.89 (m, 1H, major and minor rotamer), 7.57 – 7.35 (m, 4H, major and minor rotamer), 7.29 – 6.98 (m, 3H, major and minor rotamer), 6.83 (d, *J* = 8.0 Hz, 1H, minor rotamer), 6.74 (d, *J* = 7.9 Hz, 1H, major rotamer), 4.82 – 4.74 (m, 1H, major and minor rotamer), 3.83 – 3.73 (m, 3H, major and minor rotamer), 3.12 (dd, *J* = 8.6 Hz, 14.0 Hz, 1H, minor rotamer), 3.00 (dd, *J* = 8.9 Hz, 14.1 Hz, 1H, major rotamer), 2.42 (s, 3H, major rotamer), 2.33 – 2.31 (m, 1H, major and minor rotamer), 2.11 (s, 3H, minor rotamer), 1.96 – 1.92 (m, 3H, major and minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.6, 180.5, 175.1, 174.8, 174.3, 174.1, 149.7, 149.6, 140.7, 137.9, 137.3, 136.5, 136.4, 135.9, 135.6, 134.2, 134.1, 133.4, 133.3, 132.5, 132.4, 131.6, 131.4, 129.5, 129.43, 129.36, 128.1, 127.6, 127.4, 125.4, 125.3, 124.7, 124.4, 124.3, 123.9, 123.6, 123.5, 118.7, 118.5, 68.52, 68.49, 58.5, 58.0, 51.8, 51.7, 48.0, 47.7, 34.9, 34.5, 18.7, 18.0, 13.6, 13.5; HRMS (ESI): *m/z* calculated for $C_{28}H_{22}Cl_2N_4O_5Na$ $[M+Na]^+$ 587.0865, found 587.0839; HPLC purity: 99.9%.

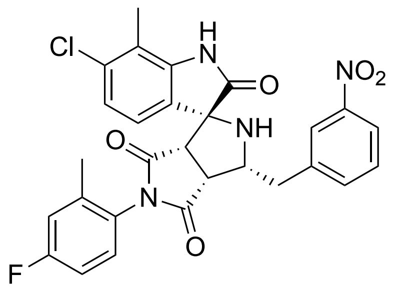
4-(((3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-2,4',6'-trioxo-3',3a',4',5',6',6a'-hexahydro-2'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrol]-3'-yl)methyl)benzonitrile (**3.77**):



**3.77**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.044 g, 0.225 mmol, 1 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.049 g, 0.236 mmol, 1.05 equiv), and 2-amino-3-(4-cyanophenyl)propanoic acid (0.047 g, 0.248 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.77** (0.0499 g, 0.094 mmol, 42%) as a white solid. $R_f$ = 0.5 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.19) δ 10.66 (s, 1H, 1 minor rotamer), 10.60 (s, 1H, 1 major rotamer), 7.76 – 7.74 (m, 2H, major and minor rotamer), 7.54 – 7.18 (m, 5H, major and minor rotamer), 7.02 – 6.96 (m, 1H, major and minor rotamer), 6.90 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.68 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.63 – 4.58 (m, 1H, major rotamer), 4.48 – 4.42 (m, 1H, minor rotamer), 3.91 – 3.84 (m, 2H, minor rotamers, 1H, major rotamer), 3.69 – 3.64 (m, 1H, major and minor rotamers), 3.46 (d, *J* = 7.9 Hz, 1H, major rotamer), 3.39 – 3.31 (m, 1H, major and minor rotamer), 2.83 (dd, *J* = 9.2 Hz, *J* = 13.6 Hz, 1H, minor rotamer), 2.61 (dd, *J* = 9.0 Hz, *J* = 13.7 Hz, 1H, major rotamer), 2.35 (s, 3H, major rotamers), 2.22 – 2.21 (m, 3H, major and minor rotamer), 2.07 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.2, 180.7, 175.9, 175.8, 174.4, 174.0, 163.4, 163.2, 161.5, 161.3, 146.5, 146.1, 142.8, 142.7, 139.3, 139.2, 138.6, 138.5, 134.5, 134.3, 132.54, 132.48, 131.2, 131.1, 130.8, 130.5, 130.4, 128.43, 128.40, 128.09, 128.07, 126.1, 125.9, 125.3, 125.2, 121.7, 121.6, 119.44, 119.39, 117.8, 117.7, 117.6, 117.5, 117.3, 117.0, 114.1, 114.0, 113.94, 113.88, 109.33, 109.26, 69.1, 68.2, 59.6, 57.8, 52.9, 52.3, 49.5, 48.4, 38.6, 37.0, 18.3, 17.7, 14.2, 14.1; HRMS (ESI): *m/z* calculated for $C_{29}H_{22}ClFN_4O_3Na$ [M+Na]$^+$ 551.1262, found 551.1259; HPLC purity: 99.9%.

(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-5'-(4-fluoro-2-methylphenyl)-7-methyl-3'-(3-nitrobenzyl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.78**):

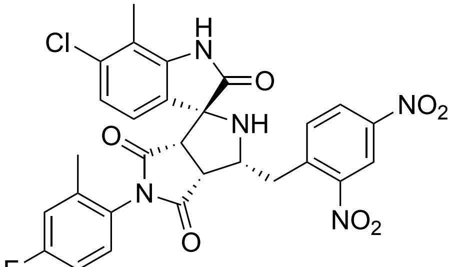


**3.78**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.034 g, 0.173 mmol, 1 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.037 g, 0.182 mmol, 1.05 equiv), and 2-amino-3-(3-nitrophenyl)propanoic acid (0.040 g, 0.190 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.78** (0.019 g, 0.036 mmol, 21%) as a white solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio =

1:1.05) δ 8.36 (s, 1H, minor rotamer), 8.30 (s, 1H, major rotamer), 8.16 – 8.05 (m, 2H, major and minor rotamer), 7.66 – 7.61 (m, 1H, major and minor rotamer), 7.48 – 7.44 (m, 1H, major and minor rotamer), 7.23 (t, *J* = 3.4 Hz, 1H, major rotamer), 7.15 – 6.99 (m, 4H, minor rotamer, 3H, major rotamer), 6.85 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.77 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.80 – 4.74 (m, 1H, major and minor rotamer), 3.84 – 3.72 (m, 2H, major and minor rotamer), 3.59 – 3.53 (m, 1H, major and minor rotamer), 2.88 (dd, *J* = 9.4 Hz, 14.1 Hz, 1H, minor rotamer), 2.76 (dd, *J* = 9.8 Hz, 13.9 Hz, 1H, major rotamer), 2.45 (s, 3H, major rotamer), 2.18 (s, 1H, major and minor rotamer), 2.13 (s, 3H, minor rotamer,), 2.01 (s, 3H, major rotamer), 1.94 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.8, 180.7, 175.3, 175.0, 174.6, 174.5, 164.4, 164.2, 162.4, 162.2, 148.85, 148.83, 141.3, 140.8, 138.9, 138.8, 138.1, 138.0, 136.8, 136.7, 135.54, 135.51, 130.13, 130.07, 130.03, 129.95, 127.0, 126.97, 126.95, 126.92, 125.2, 124.8, 124.4, 124.1, 124.0, 123.9, 123.8, 122.3, 122.2, 118.9, 118.7, 118.6, 118.5, 118.4, 118.3, 114.72, 114.68, 114.54, 114.51, 68.6, 68.5, 58.9, 58.4, 51.7, 51.6, 47.9, 47.6, 38.6, 37.9, 19.1, 18.4, 13.8, 13.7. HRMS (ESI): *m/z* calculated for $C_{28}H_{22}ClFN_4O_5Na$ $[M+Na]^+$ 571.1160, found 571.1151; HPLC purity: 99.9%

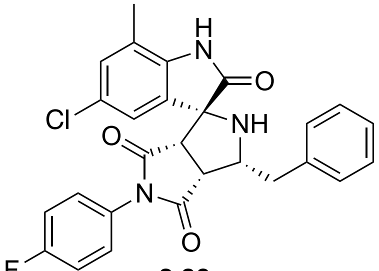
(3*R*,3'*R*,3a'*R*,6a'*S*)-6-Chloro-3'-(2,4-dinitrobenzyl)-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.79**):



**3.79**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.099 g, 0.50 mmol, 0.91 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.12 g, 0.53 mmol, 0.95 equiv), and 2-amino-3-(2,4-dinitrophenyl)propanoic acid (0.14 g, 0.55 mmol, 1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.79** (0.18 g, 0.30 mmol, 60%) as a light brown solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.26) δ 10.67 (s, 1H, minor rotamer), 10.61 (s, 1H, major rotamer), 8.71 – 8.68 (m, 1H, major and minor rotamer), 8.50 – 8.46 (m, 1H, major and minor rotamer), 7.94 – 7.85 (m, 1H, major and minor rotamer), 7.42 (t, *J* = 5.6 Hz, 1H, minor rotamer), 7.33 (t, *J* = 7.1 Hz, 1H, major rotamer), 7.28 – 7.16 (m, 2H, major and minor rotamer), 7.03 – 6.98 (m, 1H, major and minor rotamer), 6.87 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.65 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.66 (s, 1H, major rotamer), 4.51 (s, 1H, minor rotamer), 3.90 – 3.60 (m, 4H, minor rotamer, 3H, major rotamer), 3.48 (d, *J* = 8.0 Hz, 1H, major rotamer), 3.13 (dd, *J* = 9.6 Hz, 14.4 Hz, 1H, minor rotamer), 2.95 (dd, *J* = 9.6, Hz, 14.1 Hz, 1H, major rotamer), 2.33 (s, 3H, major rotamer), 2.22 – 2.21 (m , 3H, minor and major rotamer), 2.07 (s, 3H, minor rotamer). $^{13}$C NMR (500 MHz, DMSO) δ 181.5, 181.0, 176.3, 176.2, 174.8, 174.4, 162.0, 161.8, 150.3, 150.1, 147.0, 146.9, 143.3, 143.2, 142.2, 141.9, 139.9, 139.8, 139.2, 139.1, 135.1, 134.9, 134.7, 134.6, 131.5, 131.4, 131.3, 131.2, 128.85, 128.83, 128.51, 128.49, 128.0, 126.4, 126.2, 125.83, 125.78, 122.3, 122.2, 120.8, 120.7, 118.2, 118.0, 117.8, 117.7, 114.7, 114.6, 114.5, 114.4, 69.6, 68.8, 68.4, 57.2, 53.2, 52.6, 49.9, 48.9, 35.6, 34.4, 18.8, 18.2, 14.7, 14.6. HRMS (ESI): *m/z* calculated for $C_{28}H_{21}ClFN_5O_7Na$ [M+Na]$^+$ 616.1011, found 616.1005; HPLC purity: 99.6%.

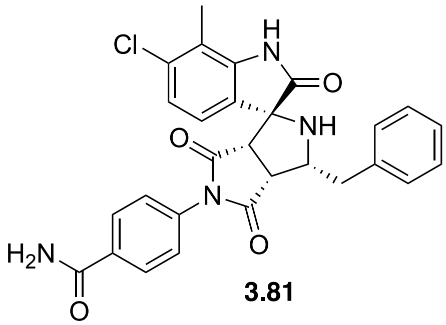
(3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(4-fluorophenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.80**):



**3.80**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.25 g, 1.3 mmol, 1 equiv), 1-(4-fluorophenyl)-1*H*-pyrrole-2,5-dione (0.27 g, 1.4 mmol, 1.1 equiv), and phenylalanine (0.23 g, 1.4 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.80** (0.77 g, 0.75 mmol, 59%) as a white solid. $R_f$ = 0.3 (9:1 $CH_2Cl_2$/Acetone). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.60 (s, 1H), 7.41 – 7.38 (m, 2H), 7.27 – 7.17 (m, 7H), 7.00 (s, 1H), 6.89 (d, *J* = 1.6 Hz, 1H), 4.70 – 4.65 (m, 1H), 3.84 (d, *J* = 7.9 Hz, 1H), 3.69 (t, *J* = 7.4 Hz, 1H), 3.45 (dd, *J* = 13.9 Hz, 4.1 Hz, 1H), 2.79 (dd, *J* = 13.9 Hz, 10.1 Hz, 1H), 2.19 – 2.18 (m, 1H), 1.87 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.7, 175.2, 174.9, 163.5, 161.5, 139.1, 138.1, 131.1, 129.0, 128.9, 128.33, 128.26, 128.1, 127.57, 127.55, 126.7, 123.9, 121.6, 116.7, 116.5, 68.2, 59.4, 51.9, 47.9, 37.7, 15.9; HRMS (ESI): *m/z* calculated for $C_{27}H_{21}ClFN_3O_3$ $[M+Na]^+$ 512.1153, found 512.1152; HPLC purity: 99.9%.

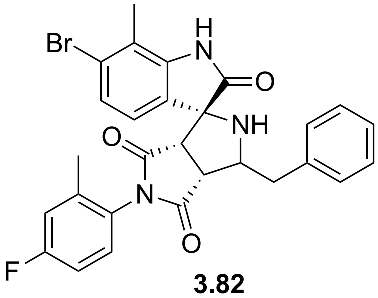
4-((3*R*,3'*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-7-methyl-2,4',6'-trioxo-2',3',3a',4',6',6a'-hexahydro-5'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrol]-5'-yl)benzamide (**3.81**):



**3.81**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.060 g, 0.309 mmol, 1 equiv), 4-(2,5-dioxo-2,5-dihydro-1*H*-pyrrol-1-yl)benzamide (0.070 g, 0.324 mmol, 1.05 equiv), and phenylalanine (0.056 g, 0.34 mmol, 1.1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.81** (0.10 g, 0.20 mmol, 64%) as a white solid. R$_f$ = 0.1 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO) δ 10.64 (s, 1H), 8.08 (s, 1H), 8.02 (d, *J* = 8.4 Hz, 2H), 7.48 (d, *J* = 8.3 Hz, 3H), 7.34 (d, *J* = 7.4 Hz, 2H), 7.29 (t, *J* = 7.5 Hz, 2H), 7.20 (t, *J* = 7.7 Hz, 1H), 7.01 (d, *J* = 8.1 Hz, 1H), 6.90 (d, *J* = 8.1 Hz, 1H), 4.46 – 4.40 (m, 1H), 3.83 (d, *J* = 7.2 Hz, 1H), 3.70 (t, *J* = 7.5 Hz, 1H), 3.50 (d, *J* = 7.8 Hz, 1H), 3.33 – 3.29 (m, 1H), 2.76 (dd, *J* = 8.7 Hz, 14.0 Hz, 1H), 2.23 (s, 3H); $^{13}$C NMR (500 MHz, DMSO) δ 181.2, 176.0, 174.3, 167.8, 142.8, 140.6, 135.3, 134.8, 134.6, 129.5, 128.74, 128.70, 127.4, 126.6, 126.5, 125.1, 122.0, 117.4, 69.2, 60.5, 53.4, 49.8, 36.9, 14.3; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}ClN_4O_4$ [M+Na]$^+$ 537.1306, found 537.1306; HPLC purity: 99.8%.

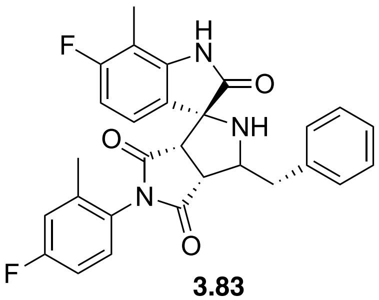
(3*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-bromo-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.82**):



**3.82**

Using the general procedure for spiroindolinone synthesis outlined above, 6-bromo-7-methylindoline-2,3-dione (0.14 g, 0.63 mmol, 1 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.14 g, 0.69 mmol, 1.1 equiv), and phenylalanine (0.10 g, 0.63 mmol, 1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.82** (0.10 g, 0.18 mmol, 29%) as a light brown solid. $R_f$ = 0.7 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.11) δ 8.24 (s, 1H, minor rotamer), 8.17 (s, 1H, major rotamer), 7.28 – 7.00 (m, 9H, major and minor rotamer), 6.78 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.71 (d, *J* = 8.2 Hz, 1H, major rotamer), 4.78 – 4.75 (m, 1H, major and minor rotamer), 3.79 – 3.77 (m, 1H, major rotamer, 2H, minor rotamer), 3.66 (d, *J* = 8.3 Hz, 1H, major rotamer), 3.49 – 3.44 (m, 1H, major and minor rotamer), 2.71 (dd, *J* = 10.4 Hz, 13.9 Hz, 1H, minor rotamer), 2.59 (dd, *J* = 10.9 Hz, 13.7 Hz, 1H, major rotamer), 2.45 (s, 3H, major rotamer), 2.17 – 2.16 (m, 1H, major rotamer, 4H, minor rotamer), 2.09 (s, 3H, major rotamer), 2.03 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.7, 180,5, 175.2, 175.1, 174.4, 174.3, 164.1, 164.0, 162.2, 162.0, 140.39, 140.38, 139.2, 139.1, 138.7, 138.6, 138.0, 137.9, 130.0, 129.9, 129.88, 129.81, 129.0, 128.96, 128.92, 128.89, 127.0, 126.94, 126.90, 126.86, 126.80, 126.76, 126.7, 125.6, 125.5, 125.2, 125.1, 124.7, 120.1, 119.8, 118.5, 118.3, 118.2, 118.0, 114.5, 114.4, 114.3, 114.2, 68.4, 68.3, 58.9, 58.3, 51.7, 51.6, 47.8, 47.5, 38.9, 38.3, 18.8, 18.2, 16.6, 16.5; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}BrFN_3O_3$ [M+Na]$^+$ 570.0804, found 570.0804; HPLC purity: 92.7%.

(3*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-fluoro-5'-(4-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.83**):

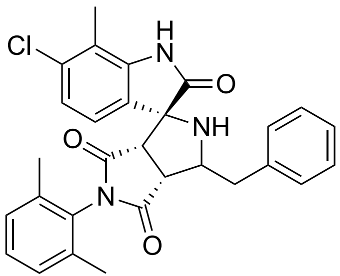


**3.83**

Using the general procedure for spiroindolinone synthesis outlined above, 6-fluoro-7-methylindoline-2,3-dione (0.150 g, 0.837 mmol, 1 equiv), 1-(4-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.189 g, 0.921 mmol, 1.1 equiv), and phenylalanine (0.138 g, 0.837 mmol, 1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.83** (0.17 g, 0.35 mmol, 42%) as a white solid. $R_f$ = 0.6 (3:2 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.10) δ 10.65 (s, 1H, minor rotamer), 10.59 (s, 1H, major rotamer), 7.47 (dd, *J* = 5.7 Hz, 8.5 Hz, 1H, minor rotamer), 7.36 – 7.16 (m, 7H, minor rotamer, 8H, major rotamer), 6.91 (dd, *J* = 5.4 Hz, 8.3 Hz, 1H, minor rotamer), 6.72 – 6.65 (m, 1H, minor rotamer, 2H, major rotamer), 4.63 – 4.58 (m, 1H, major rotamer), 4.45 (q, *J* = 7.8 Hz, 13.1 Hz, 1H, minor rotamer), 3.82 – 3.74 (m, 2H, minor rotamer, 1H, major rotamer), 3.68 – 3.61 (m, 1H, major and minor rotamer), 3.44 (d, *J* = 7.9 Hz, 1H, major rotamer), 3.32 – 3.23 (m, 1H, major and minor rotamer), 2.76 (dd, *J* = 8.8 Hz, 14.1 Hz, 1H, minor rotamer), 2.55 (dd, *J* = 8.6 Hz, 13.9 Hz, 1H, major rotamer), 2.36 (s, 3H, major rotamer), 2.12 – 2.07 (m, 6H, minor rotamer, 3H, major rotamer); $^{13}$C NMR (500

MHz, DMSO) δ 181.5, 180.9, 175.98, 175.93, 174.5, 174.1, 163.5, 163.1, 161.2, 143.1, 143.0, 142.9, 142.8, 140.5, 140.1, 139.3, 139.2, 138.6, 138.5, 131.2, 131.1, 130.9, 130.8, 129.33, 129.29, 128.6, 128.5, 128.4, 128.2, 128.1, 126.4, 126.3, 125.2, 125.0, 122.9, 122.6, 117.8, 117.6, 117.4, 114.1, 114.0, 113.9, 113.8, 107.5, 107.4, 107.3, 107.2, 107.1, 106.9, 106.8, 106.3, 69.0, 68.1, 60.1, 58.2, 53.0, 52.3, 50.0, 48.4, 38.3, 36.8, 18.3, 17.7; 9.2 HRMS (ESI): *m/z* calculated for $C_{28}H_{23}BrFN_3O_3$ $[M+Na]^+$ 510.1605, found 510.1625; HPLC purity: 97.5%.

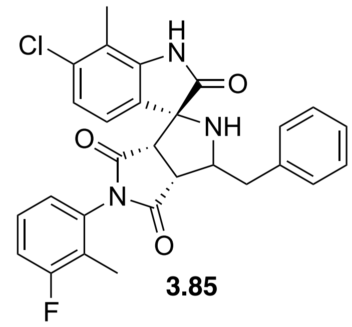
(3*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(2,6-dimethylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.84**):



**3.84**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.20 g, 1.02 mmol, 1 equiv), 1-(2,6-dimethylphenyl)-1*H*-pyrrole-2,5-dione (0.23 g, 1.13 mmol, 1.1 equiv), and phenylalanine (0.17 g, 1.02 mmol, 1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.84** (0.51 g, 1.02 mmol, 99.9%) as an off white solid. $R_f$ = 0.4 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.26 (s, 1H), 7.29 – 7.15 (m, 8H), 6.99 (d, *J* = 8.0 Hz, 1H), 6.88 (d, *J* = 8.0 Hz, 1H), 4.80 (t, *J* = 10.0 Hz, 1H), 3.86 (t, *J* = 8.0 Hz, 1H), 3.62 (d, *J* = 8.0, 1H), 3.48 (dd, *J* = 10.5 Hz, 2.6 Hz, 1H), 2.61 (*J* = 2.7 Hz, 11.0 Hz, 1H), 2.45 (s, 3H), 2.16 (s, 1H), 2.11 (s, 3H), 2.09 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.8, 175.2, 174.0, 140.8, 139.4, 136.3, 136.1, 135.6, 130.5, 129.9, 129.1, 129.0, 128.95, 128.93, 126.9, 125.7, 123.9, 123.3, 118.1, 68.6, 58.2, 51.4, 47.7, 39.2, 18.9, 18.2, 13.8; HRMS (ESI): *m/z* calculated for $C_{29}H_{26}ClN_3O_3$ [M+Na]$^+$ 522.1561, found 522.1573; HPLC purity: 95.6%.

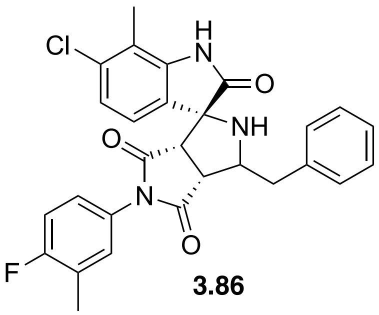
(3*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(3-fluoro-2-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.85**):



**3.85**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.075 g, 0.383 mmol, 1 equiv), 1-(3-fluoro-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.086 g, 0.421 mmol, 1.1 equiv), and phenylalanine (0.063 g, 0.383 mmol, 1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.85** (0.105 g, 0.209 mmol, 55%) as a white solid. $R_f$ = 0.2 (3:7 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$, rotamer ratio = 1:1.36) δ 8.52 (s, 1H, minor rotamer), 8.47 (s, 1H, major rotamer), 7.36 (t, *J* = 6.2 Hz, 1H, minor rotamer), 7.29 – 7.14 (m, 6H, minor rotamer, 7H, major rotamer), 7.08 (d, *J* = 10.0 Hz, 1H, minor rotamer), 7.03 – 6.95 (m, 1H, minor rotamer, 2H, major rotamer), 6.85 (d, *J* = 8.1 Hz, 1H, minor rotamer), 6.78 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.78 – 4.74 (m, 1H, major and minor rotamer), 3.82 – 3.77 (m, 2H, minor rotamer, 1H, major rotamer), 3.70 (d, *J* = 8.0 Hz, 1H, major rotamer), 3.48 – 3.45 (m, 1H, major and minor rotamer), 2.73 (t, *J* = 13.7 Hz, 1H, minor rotamer), 2.62 (t, *J* = 13.3 Hz, 1H, major rotamer), 2.37 (s, 3H, major rotamer), 2.17 (s, 1H, major and minor rotamer), 2.04 – 2.02 (m, 3H, major and minor rotamers), 1.97 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 180.9, 180.8, 175.0, 174.9, 174.3, 174.2, 162.9, 160.9, 140.7, 139.2, 139.1, 136.3, 136.2, 132.5, 132.4, 129.0, 128.9, 128.8, 127.7, 127.6, 127.5, 126.9, 126.8, 125.1, 124.7, 124.5, 124.1, 124.0, 123.86, 123.84, 123.80, 123.77, 123.76, 123.7, 123.6, 123.5, 123.4, 118.5, 118.3, 116.8, 116.6, 116.5, 116.3, 68.41, 68.39, 68.36, 68.30, 58.9, 58.3, 51.7, 47.9, 47.3, 38.8, 38.2, 13.6, 13.5, 11.2, 10.4; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}ClFN_3O_3$ $[M+Na]^+$ 526.1310, found 526.1302; HPLC purity: 99.3%.

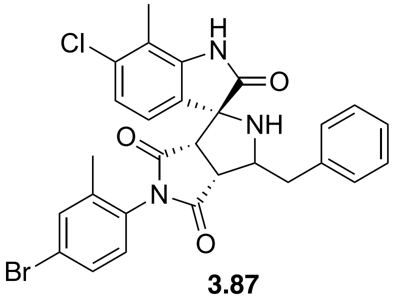
(3*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-5'-(4-fluoro-3-methylphenyl)-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.86**):



**3.86**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.15 g, 0.77 mmol, 1 equiv), 1-(4-fluoro-3-methylphenyl)-1*H*-pyrrole-2,5-dione (0.17 g, 0.84 mmol, 1.1 equiv), and phenylalanine (0.13 g, 0.77 mmol, 1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.86** (0.30 g, 0.60 mmol, 78%) as a white solid. $R_f$ = 0.3 (1:1 EtOAc/Hex). $^1$H NMR (500 MHz, $CDCl_3$) δ 8.41 (s, 1H), 7.26 – 7.14 (m, 8H), 7.01 (d, *J* = 8.2 Hz, 1H), 6.81 (d, *J* = 10.0 Hz, 1H), 4.70 (q, *J* = 12.5 Hz, 6.0 Hz, 1H), 3.80 (d, *J* = 7.5 Hz, 1H), 3.69 (t, *J* = 7.5 Hz, 1H), 3.45 (dd, *J* = 4.0 Hz, 10.0, 1H), 2.75 (dd, *J* = 4.0 Hz, 10.0 Hz, 1H), 2.34 (s, 3H), 2.17 – 2.15 (m, 1H), 1.92 (s, 3H); $^{13}$C NMR (500 MHz, $CDCl_3$) δ 181.0, 175.5, 175.1, 162.3, 160.4, 140.9, 139.4, 136.5, 129.8, 129.8, 129.2, 129.1, 127.5, 127.4, 126.9, 126.8, 126.7, 125.92, 125.85, 125.0, 124.7, 123.7, 118.8, 116.4, 116.2, 68.4, 59.3, 51.9, 48.0, 38.1, 15.08, 15.05, 13.7; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}ClFN_3O_3$ $[M+Na]^+$ 526.1310, found 526.1311; HPLC purity: 99.2%.

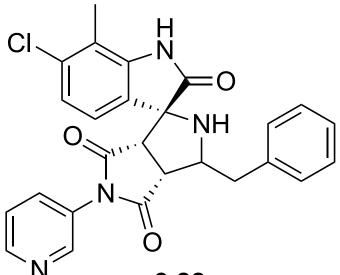
(3*R*,3a'*R*,6a'*S*)-3'-Benzyl-5'-(4-bromo-2-methylphenyl)-6-chloro-7-methyl-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.87**):



**3.87**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.070 g, 0.36 mmol, 1 equiv), 1-(4-bromo-2-methylphenyl)-1*H*-pyrrole-2,5-dione (0.10 g, 0.39 mmol, 1.1 equiv), and phenylalanine (0.59 g, 0.36 mmol, 1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.87** (0.055g, 0.097mmol, 27%) as a light brown solid. $R_f$ = 0.5 (20:1 $CH_2Cl_2$/Acetone). $^1$H NMR (500 MHz, DMSO, rotamer ratio = 1:1.12), (DMSO calibrated to 2.69) δ 10.80 (s, 1H, minor rotamer), 10.74 (s, 1H, major rotamer), 7.86 (s, 1H, major rotamer), 7.79 (s, 1H, minor rotamer), 7.77 (d, *J* = 5.0 Hz, 1H, minor rotamer), 7.70 (dd, *J* = 1.7 Hz, 8.4 Hz, 1H, major rotamer), 7.54 (d, *J* = 8.4 Hz, 1H, minor rotamer), 7.50 – 7.49 (m, 1H, major and minor rotamer), 7.46 – 7.43 (m, 3H, major and minor rotamers), 7.36 – 7.30 (m, 1H, minor rotamer, 2H, major rotamer), 7.16 – 7.06 (m, 2H, minor rotamer, 1H, major rotamer), 6.82 (d, *J* = 8.1 Hz, 1H, major rotamer), 4.79 – 4.74 (m, 1H, major rotamer), 4.60 (q, *J* = 7.9 Hz, 21.5 Hz, 1H, minor rotamer), 4.03 – 3.96 (m, 2H, minor rotamer, 1H, major rotamer), 3.84 – 3.78 (m, 1H, major and minor rotamer), 3.61 (d, *J* = 7.9 Hz, 1H, major rotamer), 3.47 – 3.39 (m, 1H, major and minor rotamer), 2.90 (dd, *J* = 8.8 Hz, 14.1 Hz, 1H, minor rotamer), 2.72 – 2.69 (m, 1H, major rotamer), 2.51 (s, 3H, major rotamer), 2.38 – 2.37 (m, 3H, major and minor rotamer), 2.22 (s, 3H, minor rotamer); $^{13}$C NMR (500 MHz, DMSO) δ 181.4, 180.8, 175.8, 175.7, 174.3, 173.4, 142.8, 142.7, 140.4, 140.1, 139.2, 138.5, 134.5, 134.3, 133.8, 133.7, 131.6, 131.3, 131.2, 130.9, 130.2, 130.0, 129.4, 129.3, 128.7, 128.6, 126.4, 126.3, 126.2, 126.1, 125.2, 122.7, 122.4, 121.7, 121.6, 117.3, 117.1, 69.1, 68.2, 60.2, 58.4, 53.2, 52.5, 49.6, 48.5, 38.4, 36.8, 18.0, 17.4, 14.2, 14.1; HRMS (ESI): *m/z* calculated for $C_{28}H_{23}BrClN_3O_3$ [M+Na]$^+$ 586.0509, found 586.0529; HPLC purity: 98.9%.

(3*R*,3a'*R*,6a'*S*)-3'-Benzyl-6-chloro-7-methyl-5'-(pyridin-3-yl)-2',3',3a',6a'-tetrahydro-4'*H*-spiro[indoline-3,1'-pyrrolo[3,4-*c*]pyrrole]-2,4',6'(5'*H*)-trione (**3.88**):



**3.88**

Using the general procedure for spiroindolinone synthesis outlined above, 6-chloro-7-methylindoline-2,3-dione (0.10 g, 0.57 mmol, 1.1 equiv), 1-(pyridin-3-yl)-1*H*-pyrrole-2,5-dione (0.10 g, 0.52 mmol, 1 equiv), and phenylalanine (0.086 g, 0.52 mmol, 1 equiv) were used. The crude material was purified by flash chromatography to afford spiroindolinone **3.88** (0.11g, 0.23 mmol, 45%) as a white solid. R$_f$ = 0.5 (7:3 EtOAc/Hex). $^1$H NMR (500 MHz, DMSO) δ 10.69 (s, 1H), 8.68 (dd, *J* = 1.5 Hz, 4.8 Hz, 1H), 8.66 (d, *J* = 2.1 Hz, 1H), 7.91 – 7.89 (m, 1H), 7.67 – 7.64 (m, 1H), 7.37 (d, *J* = 7.1 Hz, 2H), 7.32 (t, *J* = 7.5 Hz, 2H), 7.23 (t, *J* = 7.3 Hz, 1H), 7.06 (d, *J* = 8.1 Hz, 1H), 6.98 (d, *J* = 8.1 Hz, 1H), 4.50 – 4.44 (m, 1H), 3.86 (d, *J* = 7.6

Hz, 1H), 3.75 (t, *J* = 7.6 Hz, 1H), 3.56 (d, *J* = 7.8 Hz, 1H), 3.35 – 3.32 (m, 1H), 2.81 (dd, *J* = 14.1 Hz, 8.8 Hz, 1H), 2.26 (s, 3H); $^{13}$C NMR (500 MHz, DMSO) δ 181.4, 176.3, 174.7, 150.2, 148.6, 143.2, 141.0, 135.7, 134.9, 130.1, 129.8, 129.1, 126.8, 126.7, 125.5, 124.9, 122.4, 117.8, 69.6, 60.8, 53.9, 50.4, 37.2, 14.7; HRMS (ESI): *m/z* calculated for $C_{26}H_{21}ClN_4O_3$ $[M+Na]^+$ 495.1200, found 495.1209; HPLC purity: 99.7%.

**Biological evaluations:**

Procedures for biological evaluations are the same as described in chapter 2.

# Chapter 4: Deep Learning for Chemical Reaction Prediction: Reaction Predictor

## Introduction

Few organic reactions work as intended or as well as intended and it is challenging to identify undesired by-products of reactions or the mechanisms by which they form. Identifying those by-products and the competing pathways is usually essential for rational selection of more efficient reaction conditions. Another useful and necessary application of product identification is drug degradation. Every drug that is approved in the United States as well as many other countries must be approved by the Food and Drug Administration (FDA).[168] The 2010 FDA guidance for new drug applications, issued to comply with the 2006 International Conference on Harmonization QB3(R),[169] recommends that specifications include a list of degradation products.[170] Degradants are usually identified through forced degradation conditions including: acid and base hydrolysis, thermal, photolytic, and oxidation conditions. Toxic degradation products or degradation products above threshold levels (e.g., 0.1% for $\leq 1$ g daily dose) should be identified. Due to the current challenges associated with identification of reaction products, the FDA allows specified degradation products (e.g., specified degradants) to go “unidentified”.

Mass spectrometry can be used to identify the exact mass of most reaction products, and ion traps and related techniques allow analysis of fragments generated in the spectrometer. Still screening of reaction conditions is usually preferred over rational choice of conditions based on the laborious identification of competing pathways and by-products.

Since the emergence programmable computers based on integrated circuits in the 1960s, they have become increasingly valuable in prediction and forecasting. Achieving human-level or above human-level performance at predicting chemical reactions remains an unsolved problem with broad potential applications. Corey's LHASA program represented an early application of computers to the problem of planning out multi-step synthetic strategies.[171] Ideally computers would be able to more accurately and efficiently predict the outcomes of reactions than experts in the field. This will lead to more discoveries. Historically there have been three major categories of approaches to reaction prediction: quantum-mechanical simulations, rule-based expert systems, and machine learning-based systems.

Quantum-mechanical (QM) approaches to prediction of transition states can yield highly accurate results based on physical first principles, but only when the components of the reactants, transition state, and/or products are known; accurate calculations on large organic molecules are computationally expensive. Many recent studies involving QM-based prediction of reaction pathways are narrowly limited to a single chemical system.[172,173,174,175,176] A clear benefit of these methods, when successful, is their ability to quantitatively predict important reaction parameters such as free energies, energy barriers, transition states, and reaction rates. Still, they require considerable human intervention and are not suitable for making high-throughput predictions.

Rule-based approaches to reaction prediction can be fast, but the requisite systems of manually implemented rules and exceptions require painstaking maintenance. While they may provide good results within a limited chemical domain, rule-based systems are constrained by the extent to which a human expert has defined the underlying rules, and no comprehensive system of rules covering all of chemistry currently exists. Rule-based systems do not scale well over the long term as new areas of chemistry are added. Furthermore, these systems typically make predictions at the level of overall chemical transformations. Multi-step reactions are condensed into a single transformation, and information about the elementary arrow-pushing steps comprising the multi-step reaction is not available. Yet these elementary steps are the building blocks for predicting novel multi-step global reactions and identifying side products.

Machine learning (ML) approaches are fast and scalable, but require large data sets to create algorithms that can make predictions with high levels of accuracy. Two major proprietary collections of reaction recipes are available, REAXYS/Beilstein-Gmelin and SCIFINDER/CAS, but these are essentially lists of ingredients. Atmospheric chemists have compiled lists of atmospheric reactions that include both elementary and composite reaction mechanisms with rate constants, but those reactions are centered around the gas-phase chemistry of volatile organics.[177,178,179,180,181] The suitability of these databases as sources of training data is limited because the few reactions are balanced and atom-mapped. Furthermore, publications describing synthetic methods frequently tabulate only the reactants that work and omit the reactants that don't work. It is usually left to the expertise of the reader to use a combination of careful reading and guesswork to figure out which classes of reactants are likely to fail under the reaction conditions.

This chapter summarizes a rule-based and machine learning-based software called Reaction Predictor that has been developed for the prediction of chemical reaction mechanisms and identification of products and side-products. The current development of Reaction Predictor, a machine learning system I worked on, is discussed in detail. Eugene Gutman, Frances Liu, Nancy Huynh, Patrick Lam, Steven Snow and I in the Van Vranken lab greatly expanded, curated, and managed the pedagogical training set of elementary reactions, carried out testing and performance analysis, and ran experimental test reactions in the lab. I did the majority of the chemistry and chemoinformatics work for the current development of Reaction Predictor. David Fooshee and Amin Tavakoli in the Baldi group worked on the deep learning and computer programming side of the project.

**Rules Based Methods for Reaction Prediction**

As discussed previously rule-based systems can be quick at predicting reaction outcomes but are limited to the rules that have been programmed. Programs that utilize rules can also contain QM or other forms of calculations as discussed below.

One of the first rule-based systems developed for prediction of reaction outcomes was CAMEO[182] (Computer-Assisted Mechanistic Evaluation of Organic Reactions) from 1975 to 1995 in the Jorgenson lab.[183] CAMEO was designed to predict the most likely reaction outcome based upon many different criteria. CAMEO was comprised of six independent modules, each focused on a different type of chemistry: a basic/nucleophilic module, an acidic/electrophilic module, a pericyclic module, an oxidation-reduction module, a free radical module, and a carbene module. Most modules were based upon elementary reaction steps. For instance, in the basic/nucleophilic module the system would first try to identify the most nucleophilic atom through using a combination of parameters including $\mathrm{p}K_\mathrm{a}$ and steric hindrance. The CAMEO basic/nucleophilic module would also rank electrophilic sites utilizing $\mathrm{p}K_\mathrm{a}$ values. The module would then try to determine if a reaction was likely based on the difference in the $\mathrm{p}K_\mathrm{a}$ of the reactant and product. The CAMEO pericyclic module could look at estimates of HOMO and LUMO energies for the reactants. The oxidation-reduction module would make judgements if a reaction was viable based upon overall transformations instead of elementary reaction steps. Part of the reason for this approach is that many mechanisms of oxidation reactions are not well known or understood. CAMEO was a promising program, but work on CAMEO ended in 1995.

EROS[184] (Elaboration of Reactions for Organic Synthesis) was developed by Gasteiger and co-workers in 1987. EROS gives the user a set of possible structures of products given starting materials and reaction conditions. EROS does not depend on a database of chemical reactions, so the number of potential reactions addressable by EROS is quite large. The system generates plausible product structures based upon "bond and electron-shifting processes." EROS determines if reactions are plausible based upon rules developed by the EROS team and using available physicochemical properties such bond dissociation energies and heats of reactions. Reaction trees could be generated if EROS was applied to successive intermediates and products.

Beppe[185] (developed in 1992) is a knowledge-based reaction prediction system. The system first identifies reactive sites on molecules. The reactive sites are determined by calculating various atomic and molecular properties on each atom. The program then groups the labeled reactive sites into ordered pairs (i.e., nucleophiles and electrophiles) and ranks the pairings based on their reactivity. The ranking of reactive pairings is achieved by calculating pairing energies. Finally, Beppe combines the pairings to generate a list of resulting reaction intermediates and assesses the viability based using a simple thermodynamic criterion; the reaction step is viable if the "reaction activity" for the forward step is greater than half the "reaction activity" for the reverse step (activity is an artificial score given to each pairing combination). Beppe ranks reactive sites and pairings based on molecular property calculations. The biggest limitation to this approach is the large number of intermediate structures generated and the computational cost associated with their evaluation.

SOPHIA[186] (System for Organic reaction Prediction by Heuristic Approach) is capable of predicting reactive sites on molecules and proposing plausible products. The system does not evaluate the mechanistic feasibility of each transformation; instead it compares results to a reaction database (AIPHOS). The system is capable of perceiving reactive sites and does not require user specification of reaction conditions. Products are ranked based on similarity to the knowledge base and are the result of multi-step transformations.

ROBIA[187] (Reaction Outcomes By Informatics Analysis) uses a mechanistic approach to predict individual reaction steps as well as overall transformations. ROBIA uses molecular modeling as well as selected organic transformation rules to predict reaction outcomes. ROBIA is a rule-based program based upon a library of chemical knowledge. The program works by first looking at reactive site blocks and then uses a chemical transformation block to determine probably reaction. The results are filtered to discard results that are improbable and were formed in the same step. Monte Carlo conformational searches (MacroModel), AM1 calculations (MOPAC), and ab initio calculations (Jaguar) are used to find structures that have the lowest energies. ROBIA allows the user to view any intermediate formed during the reaction process. ROBIA could be used to predict unknown products in biosynthetic and metabolic pathways.

METEOR,[188] described in 2005, is an expert knowledge system used for predicting the metabolic fate of xenobiotic compounds. METEOR features the ability to import data from MS experiments such as molecular formula, exact mass, or relative mass. Given a starting molecule, METEOR can generate a list of plausible product structures and tree paths leading to the proposed metabolic product. METEOR's relative reasoning engine assigns the likelihood of one product over the other based on information contained in the knowledge base.

DELPHI[189] (Degradant Expert Leading to Pharmaceutical Insight) was a program designed at Pfizer to predict the degradation products of pharmaceuticals. As mentioned above, identification of degradants is essential for pharmaceutical safety and regulatory approval. DELPHI is an expert system that uses a knowledge database of known degradation pathways and reactions to decide on the most likely drug degradant molecules. DELPHI is programmed with known transformations of different functional groups and functional group reactivity with each other. For instance, DELPHI was programmed that esters would easily be converted to carboxylic acids under acidic or basic hydrolysis conditions. DELPHI did not think on a mechanistic step level but was able to predict intermediates and products of degradation pathways. For instance, carboxylic acids produced from esters could then be converted into the decarboxylated product.

DELPHI was retired at Pfizer due to the large effort needed to update the software and knowledge base, and was resurrected as Zeneth in the 2010's, a commercial software package that is still being developed by Lhasa Limited for drug degradation prediction.[190,191] Zeneth is the only commercially available software that can predict drug degradation products. Zeneth also relies on a knowledge base and rules like DELPHI. The Zeneth knowledge base comes from a variety of sources including the open research literature and proprietary pharmaceutical data. Users also have the option of adding their own reactions to the database if they purchase Zeneth. Zeneth works by using a "reasoning engine" that uses rules from the knowledge base to estimate the likelihood of predicted products under various conditions such as pH. Zeneth tested their software against 27 known drugs and for which 191 drug degradant products had aready been identified. The Zeneth team predicted 104 (54%) of the correct products. Zeneth is still under development and this includes updating the knowledge as well as rules.

Expert systems based upon rules and databases of transformations tend to fare poorly when applied to unknown processes. This is a problem that could potentially be solved by machine learning and deep learning. In theory, machine learning should be a to learn and propose products it hasn't exactly seen before. Deep learning is a type of machine learning that has multiple layers in a neural network.

## Machine Learning Methods for Reaction Prediction

The general difference between a rule-based system and a machine learning system lays in who makes the rules: a rule-based system uses rules created by a human expert in the field; a machine-learning system uses rules created by a computer by correlating a dataset and a set of correct predictions. Hybrid systems use a combination of expert rules and machine learning.

DENDRAL[192,193,194] was one of the earliest uses of machine learning in chemistry prediction and was developed in the late 1960s. The purpose of DENDRAL was to determine the structure of unknown compounds taken in an EI mass spectrum. Interpretation of mass spectra has practical applications that are still relevant today. DENDRAL worked through two different programs: Heuristic DENDRAL and Meta DENDRAL. Heuristic DENDRAL was a machine learning program designed to give possible structures based upon atomic masses and bonding rules. Meta DENDRAL was a machine learning program designed to give fragmentation patterns of unimolecular reactions in the gas phase. It was trained with EI mass spectra. These two programs, Heuristic DENDRAL and Meta DENDRAL, would work in concert to determine the structures of molecules in an EI mass spectrum. Since the development of DENDRAL many programs have been designed using machine learning to predict reaction outcomes. Select programs are described below although they mostly look at reaction recipes instead of individual mechanistic steps.

SYNCHEM[195,196] was developed in the 1990s as a tool to develop synthetic routes for organic synthesis. It was one of earliest efforts to apply machine learning to organic reaction prediction. SYNCHEM tried to predict reactions by using reaction clustering to group similar reactions and anticipate the type of chemistry based upon the functional groups present in the reactants. This system had two different machine learning modules named ISOLDE and TRISTAN. Large training sets of organic transformations were needed for both of these modules. ISOLDE primarily uses inductive generalization to arrive at its answer whereas TRISTAN uses deductive generalization that is commonly referred to as "explanation base learning".

In 2005, Fic and Nowak developed the CSB system (Chemical Sense Builder). CSB was comprised of two different modules that can be used alone or in conjugation. The first module is comprised of four logic-based and knowledge-based models that generate and discover reactions. The second module used machine learning tools to predict reaction outcomes. The system also used thermodynamic properties such as enthalpy and common reactive sites. The system searched for similar reactions in the reaction database to predict the most likely reaction outcome.

Over the past decade, the successful application of machine learning has been demonstrated in many areas (self driving cars, facial recognition, medical diagnostics, etc.) as well as a tool to predict the outcome of organic chemistry reactions. In 2009 Carrera and workers proposed a machine learning system that could predict chemical reactivity from organic reaction databases.[197] They looked at reactions involving $BuNH_2$ as well as $NaCNBH_3$. They used databases that had either one of these molecules in a reaction. Depending on whether a reaction occurred or did not occur the machine learning algorithm was able to predict the reactivity of molecules in a database. The system also used physicochemical properties that were calculated from atoms and bonds.

In 2016 Wei and co-workers designed a system for the prediction of organic chemistry reactions.[198] Wei utilized neural "molecule fingerprints" and graph convolutional neural networks to compare the fingerprints of the reactants to the outcomes of overall reactions. The system predicts the most likely reaction products based upon reactions in the training set. Wei used the SMARTS functional group descriptors to encode their reactions in the computer. The system was able to predict 85% of reactions based upon a test set and 80% of selected textbooks questions from a Wade organic chemistry textbook. While these results sound promising, the system only used 16 different types of reactions that involved alkenes and alkyl halides. These reactions include epoxidation, halogenation, and hydrogenation. In addition, the test set and training sets were generated by the computer using very simple molecules and carbon chains.

Between 2017 and 2019 Segler and coworkers published three separate papers on ways to predict the outcome of chemical reactions using machine learning. The first paper is entitled "Neural-Symbolic Machine Learning for Retrosynthesis and Reaction

Prediction."[199] This paper focused on retrosynthetic routes instead of proposing products in a forward direction. Segler was interested in predicting reactants from products instead of visa versa. The data set for this paper was 3.5 million reactions extracted from REAXYS. The authors were able to achieve a top-10 accuracy of 95% for the correct retrosynthesis. The system uses machine learning to identify what rules and reactions classes lead to each product. The second paper is entitled "Planning chemical syntheses with deep neural networks and symbolic AI"[200] This paper builds upon their work in their previous paper. The authors used Monte Carlo Tree Searches and symbolic artificial intelligence to predict retrosynthetic routes. The authors claim that their program solves for twice as many reactants and up to thirty times faster than traditional computer programs that use rules and expert heuristics. They noted that graduate students in synthetic chemistry, on average, could not differentiate between synthetic routes designed by their system and synthetic routes designed by an expert. Segler's third paper is entitled "A Generative Model for Electron Paths."[201] Although this paper tries to predict the flow of electron paths it essentially is another program that predicts products using reaction recipes. The system uses machine learning to try to map the flow of electrons in one step. The authors used the USPTO database to train and test their system. The system was able to predict the correct product from a test set with a top-5 accuracy of 95.9%. This system is potentially useful, but it is not able to predict mechanisms and intermediates in a mechanism.

Between 2017 and 2019 Coley and coworkers published two separate papers on ways to predict the outcome of chemical reactions using machine learning. The first paper is entitled "Prediction of Organic Reaction Outcomes Using Machine Learning."[202] This paper by Coley and coworkers uses reaction templates (such as hydrolysis), machine learning and neural networks to predict the outcomes of reaction from a given set of starting materials. The system first generated a plausible set of reactions using reaction rules and then ranked the subsequent products. Using a dataset of 15,000 reactions from the USPTO database for training, the system was able to produce a top-5 accuracy of 90.8% in the determination of the product. Coley's second paper, entitled "A graph-convolutional neural network model for the prediction of chemical reactivity",[203] uses more data than their previous paper. They trained their system with about 500,000 reactions from the USPTO database. Coley and coworkers use a graph convolutional neural network to predict the most likely outcome of a reaction given a certain set of starting materials. The system first decides what reactive sites are most likely to change their connectivity. The system then gives a list of plausible products based upon those reactive sites. Finally the system ranks the plausible products it produced. This updated system was able to produce a top accuracy of 93.4%. All the systems described above are focused on mainly predicting products from a given set of reactants without regard to the stepwise reaction mechanism or potential side reactions arising from mechanistic intermediates.

## Reaction Predictor

While all of the machine learning systems described above focus on overall transformations, predicting reaction mechanisms, reactive intermediates, and reaction products using elementary steps presents a unique chemistry problem as well as a unique computer science problem. Predicting reaction mechanisms is much harder than predicting the products of known or desired synthetic transformations. For instance, reactions in the REAXYS or USPTO database usually only report the desired product with no information on the side reactions. Some reactions can have 2, 3, or more plausible mechanistic steps from the same intermediate. For example, attempts to sulfonate of an 1,2-aminoalcohol can lead to aziridines, alkylpyridinium salts, sulfonamides, and sulfonates from a common intermediate.[204] Also, some viable mechanistic steps may not lead to a product because the equilibrium does not favor that product (i. e. addition to an amide). Finally, even expert chemists can disagree on the correct mechanisms of a reaction even if the product made is entirely known. All of these reasons showcase the challenge of designing a system that predicts mechanism, intermediates and products of chemical reactions.

In spite of these challenges, predicting reactivity on a mechanistic level offers benefits. First, Jorgensen showed that the process of predicting reactions at the level of elementary steps can offer deep insight into chemical reactivity. Furthermore, a computer system that is trained to predict at the level of elementary reactions is more likely to predict side products than a system that is only trained to predict the desired products of reactions. As mentioned at the beginning of this chapter, the prediction of side products has great use in experimental organic chemistry as well as drug degradation.

Driven by the need for a program that predicts reactions at the level of elementary reaction steps, Reaction Predictor was developed in the Baldi Group at UCI in the early 2010s.[205,206] The initial development of Reaction Predictor was driven by Jonathan Chen, a graduate student in the Baldi group who took the first-year Organic Reaction Mechanism sequence in the Department of Chemistry at UCI. Work on Reaction Predictor was subsequently taken over by a series of students in the Baldi group: Matthew Kayala, David Fooshee, and most recently Amin Tavakoli. Reaction Predictor is the only machine learning reaction prediction system based on elementary reactions and should, in theory, be capable of predicting all possible reaction pathways – known and unknown - for both unimolecular and bimolecular processes. Using elementary reaction steps is a fundamental design choice that reflects how human experts think about chemical reactions. Each elementary step involves the movement of electrons from an electron source to an electron sink. In summary, given a set of input reactants, the Reaction Predictor pipeline operates in the following multi-step fashion: (1) enumerate all possible electron sources and electron sinks within the input reactant molecules; (2) filter the list of candidate sources and sinks, predicting a smaller list containing only the most reactive sources and sinks; (3) propose reactions by enumerating all combinations of source-sink pairings; (4) rank the proposed reactions by favorability; and (5) iterate the above process to identify global reactions, or search for unidentified products using analytical data like mass spectrometry. The last part of this chapter describes the work we have done to improve Reaction Predictor since its original implementation. I describe the machine learning (ML) design, methodology, and chemistry under-pinning Reaction Predictor's ML-based predictions.

To train our models, we carefully expanded and curated a training data set to consist of over 11,000 pedagogically elementary reactions, covering a broad range of advanced organic chemistry. We tested Reaction Predictor's performance on a benchmark data set of challenging experimental results, and demonstrated a high degree of accuracy. These results are compared with the performance of an early prototype system (described above) that was developed in the Baldi lab. We wrote six more simple chemistry rules that increase the performance of Reaction Predictor on an expanded test set. We also demonstrate that an alternative approach to predicting electron sources and sinks simply by examining SMILES strings, using a long short-term memory (LSTM) architecture,[207,208] shows promising results. Finally, we show experimental results on how Reaction Predictor can be used to predict products of reactions.

## Reaction Predictor Development

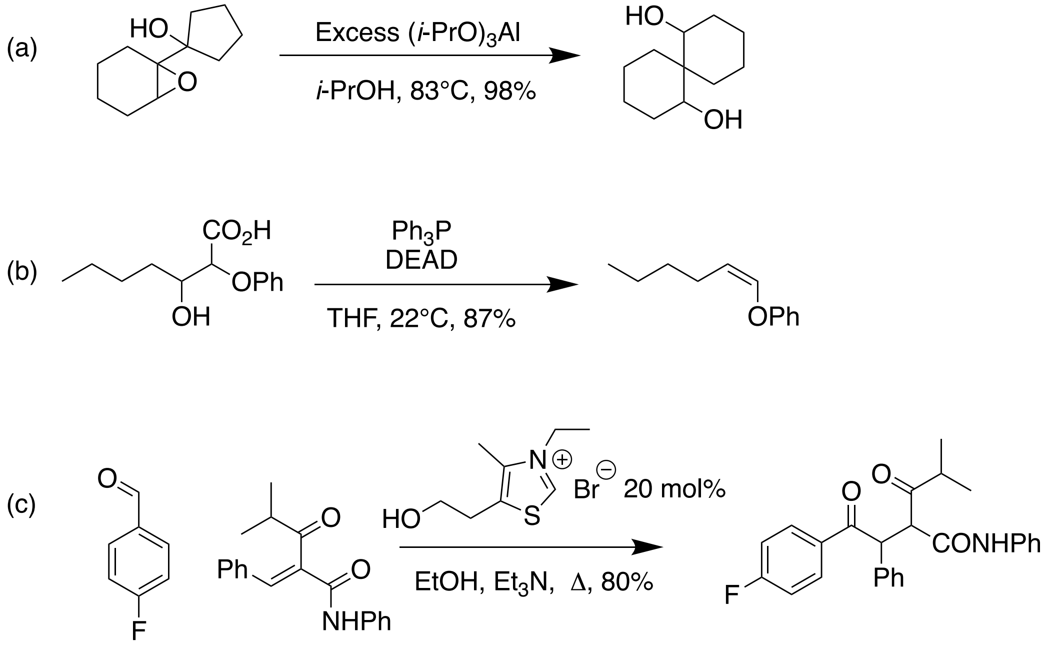
**Chemical software interface**. Molecules were represented using SMILES strings and and reactions were represented as SMIRKS strings according to the Daylight formalism,[209] and the OEChem toolkit[210] was used for chemical computation.

**Data**. The unit of our data set is an "elementary reaction". Each elementary reaction represents an energetically favorable mechanistic step with one transition state, with a single labeled electron source and a single labeled electron sink. An earlier version of the data set was primarily composed of undergraduate organic reactions extracted from Reaction Explorer rules,[211] plus a set of 368 reactions from graduate level organic chemistry texts.[212,213] In total, there were 5551 elementary reactions in the original data set. We note that, internally, Reaction Predictor has three distinct chemical prediction modes: one for polar, one for radical, and one for pericyclic reactions. Each of these uses its own separate underlying data set and trained predictive models. Here we will discuss the polar data set and models, as they represent the most important type of reactions for Reaction Predictor. We used a benchmark data set of 289 elementary reactions taken from challenging multi-step transformations to test the performance of our system. These reactions were chosen from reactions in the literature and inferred from reactions in Strategic Applications of Named Reactions in Organic Synthesis[214] to cover a broad range of advanced organic chemistry intended to test the system's ability to generalize on real-world reactions. They are not a subset of the training data. Later we used a challenging expanded training set of 600 reactions to test new chemistry rules. The expanded training set included the 289 elementary reactions mentioned above as well as roughly 300 additional reactions taken from various named reactions in organic chemistry.

**Data set development**. One significant limitation of using Reaction Explorer rules to generate the bulk of the prototype's original training reactions is the inherent bias towards undergraduate chemistry. These training reactions were mostly limited to first, second, and third-row elements. Undergraduate texts often make simplifying assumptions or omit complicating details in order to more clearly present fundamental concepts. A more accurate understanding of the chemical reality is left to be clarified during advanced study. This presents a problem for learning algorithms, which can only learn and generalize based on what they are shown during training. To address this, we reviewed the existing data set in its entirety. Manual inspection of all elementary reactions led to the removal of 884 problematic reactions. Reactions were removed for any of several reasons. First, up to 10% of the elementary reactions were duplicates. Second, some reactions were removed because the arrow-pushing mechanism was depicted incorrectly. Third, some of the training reactions contained products or reactants that were implausible. After removing these problematic reactions, we were left with a cleaned data set of 4,667 polar elementary reactions.

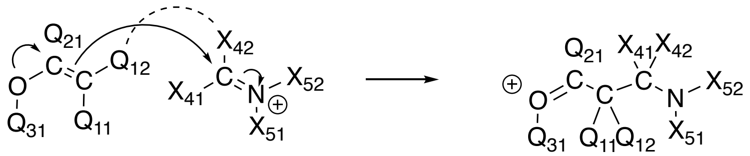
Using this cleaned data set as our starting point, we have added 6,361 high quality hand-curated reactions: (1) we added about two thousand additional elementary training reactions to cover gaps in various areas of chemistry: phosphorus functional groups, sulfur functional groups, silicon functional groups, tetrahedral intermediates, proton transfers, and migratory displacements. (2) About 1500 additional polar elementary reaction steps were chosen from reaction pathways covered in a first-year graduate course in organic reaction mechanisms including, for example: carbonyl chemistry, enolates, enols, enamines, phosphorus chemistry, sulfurchemistry, allylsilanes, vinylsilanes, strained rings, non-classical carbocations, and others. (3) About a thousand (1004) polar mechanistic steps were sampled from multi-step reaction mechanisms in a well-known book on named reactions.[214] (4) About two thousand additional reactions were drawn randomly from the literature and organic chemistry research presentations in an attempt to further complement the data set. Some examples of notable new reaction types added to the data set are shown in Figure 4-1. Figure 4-1a shows an MPV reduction involving 12 mechanistic steps.[215] Figure 4-1b represents a Mitsunobu reaction that has seven mechanistic steps.[216] Figure 4-1c shows an eight-step Stetter reaction.[217] For each of these examples, critical steps in the reaction mechanism required elementary reactions that were not originally represented in the data set, but have since been added. At time of writing, the total number of elementary reactions in our data set is 11,028. We have observed that the system improves as we grow the data set.

**Figure 4-1:** Examples of complex transformations requiring chemistry that was not represented in the original data set. Hand-curated elementary reactions were added to the training data to address these reaction types, and many more, greatly improving predictive capability. Reaction (a) is a 12-step MPV reduction; (b) is a seven-step Mitsunobu reaction; and (c) is an eight-step Stetter reaction.



**Combinatorial reaction generation**. I created a set of Python scripts to automatically generate hundreds of thousands of combinatorial variants of the elementary training reactions, using the following methodology. For a given elementary reaction type (l.p., pi, and sigma donors adding to empty p orbitals, pi* or sigma* orbitals) we first created an atom-mapped SMIRKS string for the core reaction with the appropriate arrow-pushing representations. Next, we created a list of SMILES strings for spectator substituents deemed unreactive towards either the nucleophilic or electrophilic functional groups (e.g., $CH_3$, $C_6H_5$, $CO_2CH_3$, $SO_2Ph$, etc.). We then systematically generated combinatorial variants of each class of reaction. In this way we gained access to a training set with a potential diversity of 18,399,899 reactions, far too large for timely training with a large feature set. Instead, we randomly selected members of each class of combinatorial training reactions, on the order of a thousand reactions for each mechanism. Figure 4-2 illustrates this process.

**Figure 4-2**: Illustration of combinatorial reaction generation, including reaction template (top) and substitution constraints (bottom). Thousands of reactions are produced by generating all combinations of allowed substitutions at the Q## and X## sites.



Q31 = ['[Na]','[K]']

Q21 = ['[H]','C','CC','C9=CC=CC=C9','OC','OCC','N(C)C','SC']

Q11 = ['[H]','C','CC','C7=CC=CC=C7','C(=O)C','C(=O)OC','C(=O)N(C)C']
Q12 = ['[H]','C','CC']

X41 = ['[H]','C','C8=CC=CC=C8','OC','OCC','SC','C#N','C(=O)C']
X42 = ['[H]','C','CC']

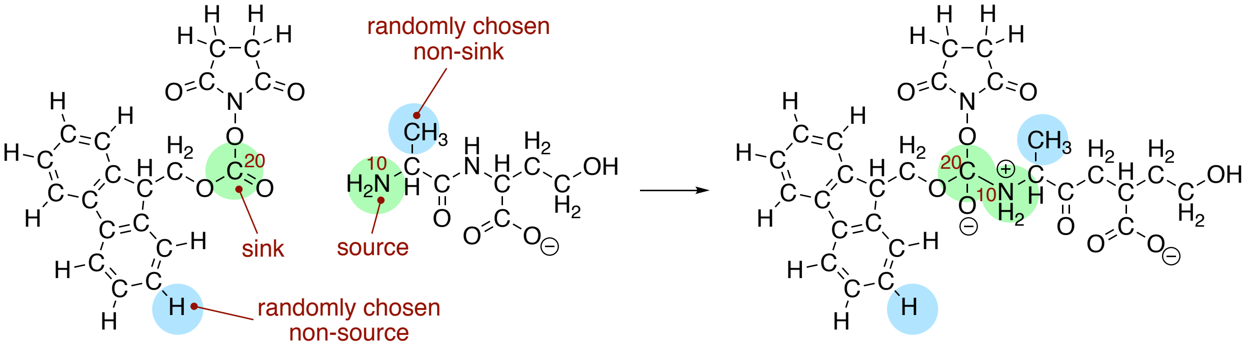
X51 = ['C','CC']
X52 = ['C','CC']

**Applying deep learning**. Predicting reactive electron sources and sinks is a crucial step in the Reaction Predictor pipeline. If the best source or best sink is rejected during the source/sink filtering step, the desired reaction cannot be reproduced. The early prototype of Reaction Predictor placed great emphasis on recall, with little consideration for precision. That is, the system was biased towards predicting many potential sources and sinks, to avoid missing any, even if most were false positives. Yet false positives have negative performance implications: they significantly increase computation time, which quickly adds up for pathway searches, wherein multiple single-step predictions are chained together to predict products of multi-step reactions. We developed source/sink filtering models focused on both precision and recall, as described below.

For source/sink filtering, the Baldi group experimented with a variety of architectures, and obtained best results using a single fully-connected feed forward neural network (also called a multilayer perceptron, or MLP) with 1500 inputs, three hidden layers of 200 rectified linear units, and two independent sigmoid output units corresponding to a source prediction and a sink prediction. To avoid overfitting, we use a number of methods including 50% dropout applied to each hidden layer,[218,219] and early stopping. To train the model, weights were initialized as described in Glorot and Bengio,[220] and updated using the Adam optimizer[221] on mini-batches of 64 examples. An exponentially decaying learning rate, and early stopping based on a validation set of 10% of the training set were used. Models were implemented using Keras and TensorFlow, and training was performed on an NVIDIA Titan X GPU.

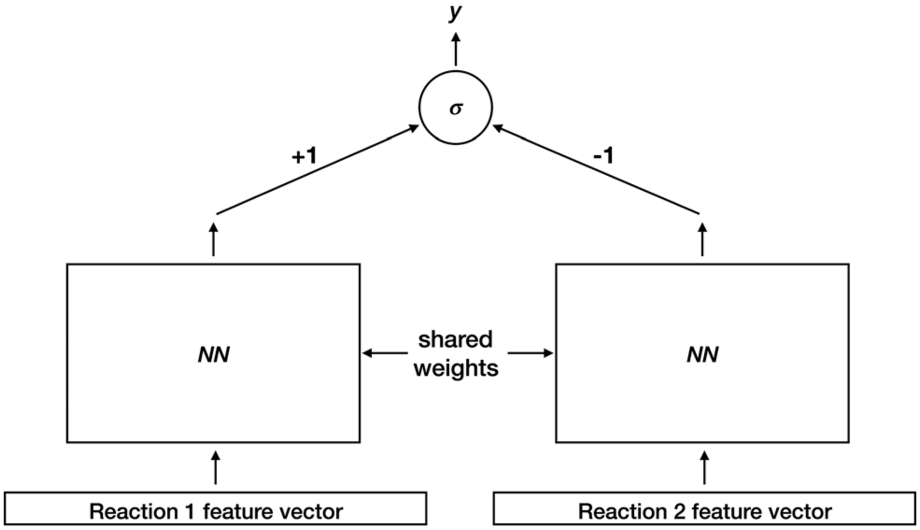
David Fooshee in the Baldi group built the training data for our source/sink filtering network as follows. For each elementary reaction in the database, we extracted four training examples of atom reactivity: (1) the labeled source, (2) the labeled sink, and (3, 4) two randomly sampled non-source, non-sink examples. This is illustrated in Figure 4-3. There are two advantages to this method compared with the original method of extracting two positively labeled examples (true source and true sink), plus all remaining negative examples. First, we avoid the significant imbalance inherent in the data, as we observe approximately 22-times more negative examples than positive examples. Previously this was addressed by oversampling the positive examples. The second advantage is we avoid adding potentially misleading examples to our training data. Specifically, we avoid negatively labeled examples that should actually be considered secondary sources or sinks. For a given elementary reaction, the set of atoms not explicitly labeled source or sink contains mostly poor sources and poor sinks. However, some could be considered "second-tier" sources/sinks, either on their own or within a different molecular context. By randomly selecting from these atoms to generate our negative examples, we gain a representative sample of the non-source, non-sink examples in our data, while also avoiding labeling all potential second-tier sources/sinks as negative examples. Extracting the data as described above, our training set for source/sink filtering consisted of 23,850 examples, half of which were positive examples.

**Figure 4-3**: Training examples of atom reactivity extracted for the source/sink filtering network.



After identifying sources and sinks, and pairing them together, we had to rank the resulting set of proposed reactions. To do so, the Baldi group trained a deep Siamese architecture neural network[222,223] to compute a reaction favorability score. Figure 4-4 illustrates this architecture. Training examples consist of ordered reaction pairs ($R_{favorable}$, $R_{unfavorable}$), where the favorable reaction is always presented to the left instance of the shared-weight neural network. Fixed weights of +1 and−1 for left and right outputs are connected to a final sigmoid unit. Thus the final output y approaches 1 if the left reaction was scored higher than the right reaction, and 0 otherwise. After model training, we use one instance of the shared-weight network to compute favorability scores for all reactions, and rank them based on those scores.

**Figure 4-4**: Siamese architecture for reaction ranking. Outputs from the left and right instances of the neural network NN have fixed weights of+1 and−1 into a final sigmoid unit. Thus the final output y approaches 1 if reaction 1 scores higher than reaction 2, and 0 otherwise. We can think of NN as computing a reaction favorability score that is learned by training on many examples of ($R_{favorable}$, $R_{unfavorable}$) reaction pairs.



For the shared-weight network, we used two hidden layers of 300 tanh units, and a sigmoid output. Initialization and training proceeded as described above for the source/sink models. We generated training examples ($R_{favorable}$, $R_{unfavorable}$) as follows. For each elementary reaction in the data set, we have one reaction, $R_{favorable}$, formed by pairing the labeled electron source with the labeled electron sink. We can propose many additional unfavorable reactions, by pairing the labeled source with all non-sinks, and all non-sources with the labeled sink, within the constraints of chemical feasibility. We use this set of unfavorable reactions to create additional training pairs ($R_{favorable}$, $R_{unfavorable}$), yielding 387,744 total training examples.

**Feature representation & selection**. To make accurate source/sink predictions, we must extract relevant chemical information about each potential source/sink site within a reactant molecule. The features we use to capture this information fall into two categories: physico-chemical, and graph-topological. Physicochemical properties are extracted at the atom level. Examples include partial charge, formal charge, presence and type of filled/unfilled orbitals, presence of lone pairs, and a steric coefficient. Graph-topological features capture properties about the atom and bond connectivity of the molecular graph. These are based on a variation of chemical fingerprints[224] and are extracted by enumerating paths and trees over a small neighborhood around a particular atom. Specifically, we allow paths up to depth 6 if the atoms along that path are heteroatoms or are part of a conjugated pi system, otherwise the maximum depth is 3.

Then, to accurately rank reactions by favorability, we must extract reaction-level information that captures both the source/sink interaction and the overall molecular change(s) occurring in the elementary reaction. These reaction-level features include (1) a combination of concatenated source and sink atom-level features, (2) features describing the type of orbitals involved, and (3) net change features, which are created by computing molecular fingerprints for both the reactants and products, then subtracting the reactants fingerprints from the products fingerprint to capture the net changes that occurred during the reaction, e.g. which functional groups and motifs were formed or destroyed.

Extracting the features described above for all examples in our data set yields 293,046 atom-level features, and 62,560 reaction-level features. We select the top 1,500 atom-level and top 2,000 reaction-level features with the highest mutual information and use those features as the input representations for our source/sink filtering and ranking models.[225,226]

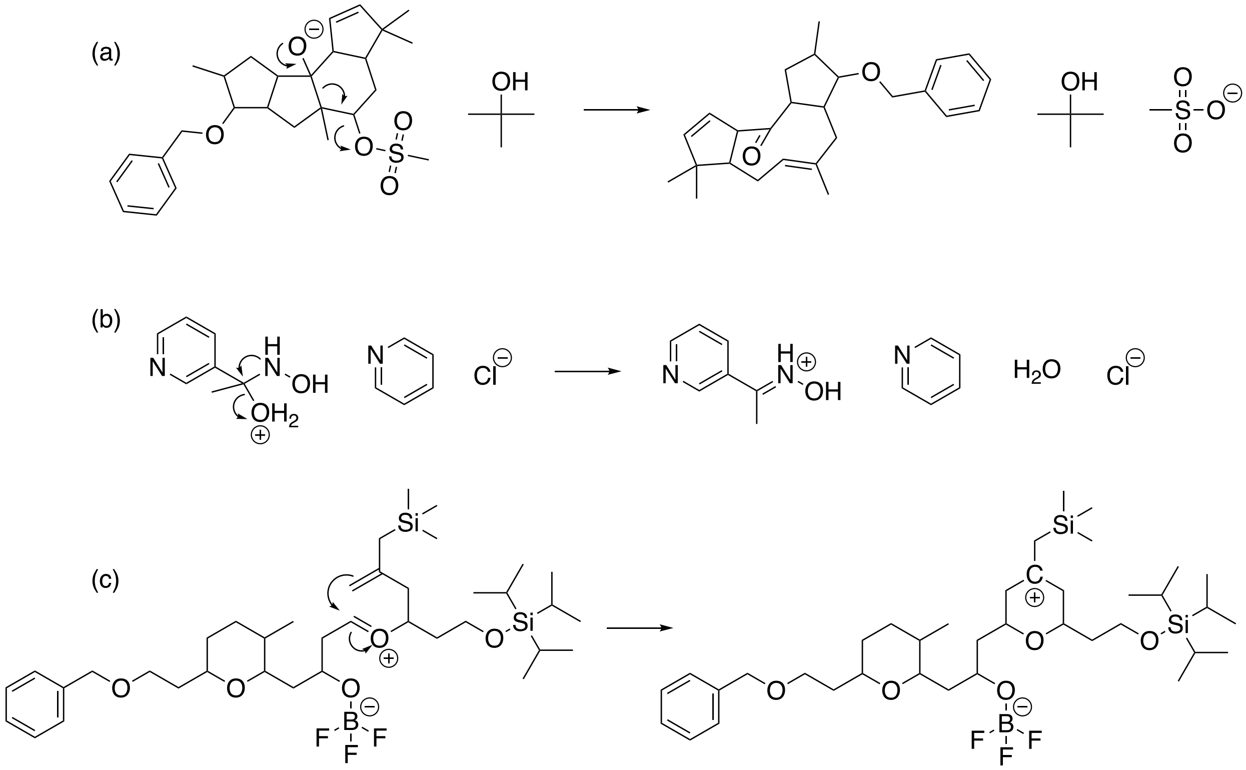
**Spectator molecules**. There is information to be gleaned, however, from the non-reacting spectators in the training reactions. Each spectator molecule can provide negative source/sink training examples for the filtering model, and unproductive elementary reaction examples for the ranking model. We added the ability to capture and consider these spectator molecules in our training data.

**Offline pathway search**. Reaction Predictor's pathway search feature allows the user to input starting materials and a set of targets molecule to search for multi-step reaction pathways that yield one or more of the targets. Targets can be chemical structures, exact masses, or a mixture of both. Users can enter as many search targets as desired for a given set of reactants and the system will search relentlessly until a match is found. Users simply input their email and wait for their result. This makes pathway search a powerful tool for suggesting alternative reaction pathways and identifying unknown products observed in mass spectrometry data.

**Additional features**. While implementing the major features described above, many other improvements were made, including new features and improved chemical capabilities. We describe a non-exhaustive selection of these additions below.

**Intramolecular reactions**. Reaction Predictor considers intramolecular reactions in cases where more than a single reactant molecule is present. In the earlier prototype, if two or more reactants were present, only intermolecular reactions were considered. This change is especially important for pathway search, where multiple reactants will either be directly entered or inevitably formed during the course of the search, and to prevent intramolecular reactions at all subsequent steps is to omit a broad swath of potential reactions. Multi-step reaction mechanisms frequently have steps involving intramolecular reactions, and they must be considered, even in the presence of many reactant molecules, in order to achieve high-quality multi-step predictions. Some examples of intramolecular reactions, including a Grob fragmentation, a Neber rearrangement, and an intramolecular Prins reaction, are shown in Figure 4-5.[227,228,229]

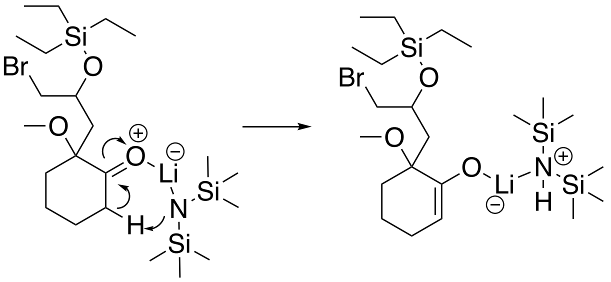
**Figure 4-5**: Examples of intramolecular reactions that can be predicted by the system. A Grob fragmentation (a), Neber rearrangement (b), and intramolecular Prins reaction (c) are shown. Enabling the prediction of intramolecular reactions when multiple reactants are present significantly increases the number of proposed reactions, but is necessary for the prediction of many reaction pathways including these.



**"Continue reacting" button for single-step predictions**. Users can manually explore a multi-step reaction pathway in a guided stepwise fashion. After submitting reactants and generating a list of predicted products, users can click a button next to any of the results to use those products as the reactants for a new single-step prediction.

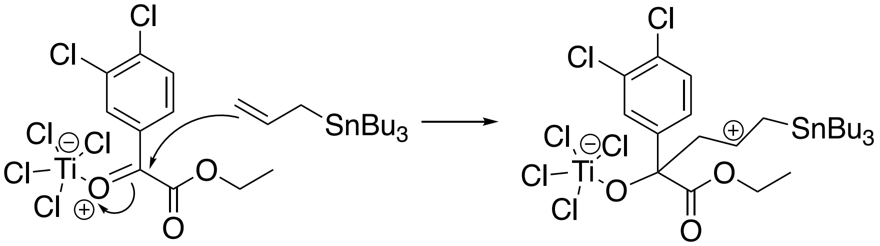
**Improved modeling of alkali metals**. The alkali metals Li, Na, and K, are now modeled with a more sophisticated understanding of their bonding potential. Originally, these metals were only allowed to form a single bond, while in reality they can form up to four or more. This is now reflected in reaction predictions involving these atoms. An example involving lithium is shown in Figure 4-6.

**Figure 4-6**: Initially, Reaction Predictor only modeled lithium to include at most one bond. Now the system is capable of correctly predicting this LDA deprotonation to make an enolate via an Ireland transition state.[230]



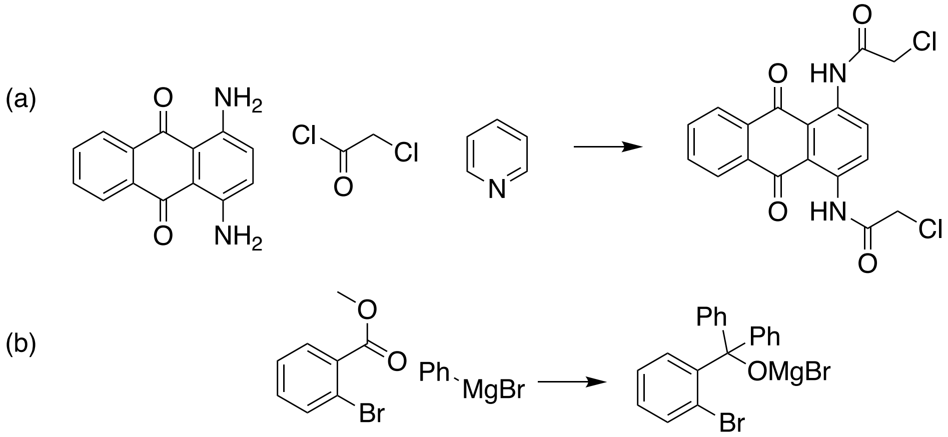
**Additional atom types**. Reactants containing Sc, Ti, Zn, As, or Se atoms were not accepted in the early prototype. We have improved the underlying chemical model to be capable of handling these elements. Figure. 4-7 shows an intermolecular Prins mechanistic step that can be predicted because of the system's ability to model Ti in $TiCl_4$.[231]

**Figure 4-7**: Reaction predictor can predict this intermolecular Prins mechanistic step because it can model the Ti atom in $TiCl_4$.



**Multiple equivalents for reaction pathways.** Some pathways require the presence of additional species that can serve as, for example, proton transfer agents or engage in oligomerization reactions. Reaction predictor can automatically consider an additional equivalent of the reactants at each step of the pathway search before identifying sources and sinks and ranking the resulting combinations. At the early stages of most chemical reactions, the starting materials are present in high concentration relative to other reactive intermediates. Considering additional equivalents of the query reactants allows Reaction Predictor to anticipate oligomeric products that can be difficult to identify in complex product mixtures. The additional equivalents of the query reactants can also serve in additional mechanistic roles beyond that of substrate, such as catalytic acids or catalytic bases. Addition of the query reactants at each and every step of a pathway search greatly increases the number of potential pathways to be searched and can lead to implausible oligomers. Instead of simply considering the reactants to be present at each and every step, we let the user choose how many equivalents to include. Two examples of reactions requiring multiple equivalents are shown in Figure 4-8.[232,233]

**Figure 4-8**: Examples of complex transformations requiring multiple reactant equivalents. In (a), two equivalents of chloroacetyl chloride and pyridine are necessary to complete the double acylation reaction involving six mechanistic steps. In (b), one equivalent of a Grignard reagent adds to the ester, and a second equivalent is needed to add tot he ketone that is generated *in situ*. Reaction predictor is able to predict both of these products from the literature by adding additional reactant equivalents.



**ML features**. We carefully evaluated the physico-chemical and graph-topological features used by our ML algorithms. Some were identified that were either irrelevant or counterproductive for making source/sink predictions. For example, we observed instances where increasing the molecular mass of a molecule, by adding a side-chain to a distant part of the molecule, would cause a source or sink that had at first been predicted correctly, to suddenly be misclassified. We removed this feature, as the reactivity of a candidate source or sink should not be a function of the mass of its parent molecule. We also removed a feature designed to capture whether a source/sink was located centrally or peripherally within the molecular graph, as it too was chemically irrelevant for determining the quality of a source or sink.

## Results and Discussion

**Single-step performance**. We assessed single-step reaction prediction performance using the benchmark data set of 289 reactions described above. Table 4-1 shows the results achieved by Reaction Predictor.

**Table 4-1**: Single-step reaction prediction performance for Reaction Predictor (RP), compared with the early prototype, using a benchmark data set of 289 reactions.

| Metric | RP | Prototype |
|---|---|---|
| Products recovered | 83.0% | 58.1% |
| Products ranked in top-5 | 80.0% | 76.8% |
| Mean time per reaction (s) | 8.3 | 91.8 |
| Total reactions proposed | 20,812 | 92,158 |

First we note that the early prototype failed while attempting to run the benchmark data set, due to its inability to handle certain atom types, as described above. We incorporated the necessary updated library into that version, so that it could complete the test.

We observe that Reaction Predictor recovers 83.0% of the expected products anywhere in the ranked list, vs. 58.1% for the prototype. This difference is particularly striking when we consider that the prototype version is biased towards predicting more false positive sources/sinks, in exchange for, ideally, improved recall. We see this reflected in the total number of reactions proposed by each version, with the prototype proposing

92,158 reactions, while our current version proposes 20,812. Yet, even though the prototype predicted far more reactions, it still only recovered 58.1% of the expected products. That Reaction Predictor can predict nearly 72,000 fewer reactions while recovering significantly more of the products (83.0%) indicates a dramatic improvement in source/sink filtering capability. We believe this is a result of two factors: the improved breadth and quality of the expanded training data, and the application of deep learning to better learn from that data.

The improved version of Reaction Predictor also performed well in terms of how many correct products are ranked within the top-5 of the ordered reaction list, with 80.0% of correct reactions ranked within the top-5. We have observed that the ranking performance was slower to improve as we grew the training data, compared with source/sink accuracy. Being able to generate hundreds of thousands of training examples for the ranking model, even with only several thousand elementary reactions in the training set, seems to convey enough information to yield a highly accurate trained ranking model. Our observation that doubling the number of elementary reactions in the training set led to a dramatic improvement in source/sink identification, but a relatively minor improvement in ranking performance, seems to imply that the task of source/sink prediction is more difficult than the ranking task. How much of this apparent imbalance is a reflection of chemical reality, versus how much may be an artifact of our particular computational approach and ML design, is unclear. From the perspective of a human chemist, it seems surprising that the source/sink prediction task should be significantly more challenging. We suspect that ultimately the problem is the scarcity of available training data. Using additional data on source/sink reactivity, we expect the source/sink predictions to become increasingly accurate.

We also note the significant improvement in average runtime per reaction. For the early prototype, each prediction took 91.8 seconds on average; the new version of Reaction Predictor is more than ten times faster, averaging 8.3 seconds per reaction. This is a major boon for offline pathway searches, which benefit greatly from faster prediction speed. Results that would have previously taken 10 days can now be processed overnight.

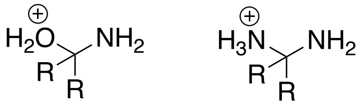
**Combinatorial data**. We tested the effect of including combinatorially-generated reactions in our training set by running a direct comparison between a version trained on the standard training set and a version trained on a combinatorially-augmented training set. For this test, the standard training set contained 10,052 elementary reactions, while the combinatorial version contained 36,902 elementary reactions. Decision thresholds were tuned to achieve an equivalent false positive rate for each version, and performance was measured on our benchmark data set of 289 reactions. Surprisingly, the results indicated decreased accuracy for the version trained with combinatorial data. Specifically, only 70.2% of the correct products were recovered, and only 70.9% of those recovered were ranked in the top-5, compared with 80.3% and 77.6%, respectively, for the non-combinatorial version. Thus we did not include combinatorial the combinatorially-generated training reactions in the latest Reaction Predictor training set.

We hypothesize that the homogeneity of the combinatorially-generated reactions introduced biases that degraded predictive performance. We attempted to counter-act this by randomly sampling a small fraction of the total reactions generated from each of our combinatorial reaction templates and including only those in the training set. Nonetheless, we observed degraded performance even when the smaller samples of reactions were used in the training set. We believe there is likely value in using combinatorial reaction generation, if done in such a way as to closely mimic the molecular variety observed in real-world reactions. However, the time required to carefully design and validate the necessary templates and constraints, while also aiming to simulate a realistic variety of molecular contexts, is by our estimation better spent simply writing high-quality elementary reactions by hand. For now, we leave combinatorial reaction generation aside for potential future work.

**Additional chemistry rules.** A number of systematic failures were observed in the results that were difficult to address by expansion of the training set. We hypothesized that expert rules could improve the performance of the machine learning system described above. Six additional rules, applicable via user toggle buttons, were added to the system. Some of the rules below are general rules that may have exceptions in special circumstances.

**(i) Tetrahedral intermediate rule**. In order to favor $S_N1$ type ionization over $S_N2$ displacement, we created a setting to favor displacement of leaving groups by adjacent lone pairs over intermolecular displacement by lone pairs on other molecules (Figure 4-9).

**Figure 4-9**: Tetrahedral intermediates



**(ii) Hydrogen sink transition state rule**. When this setting is applied, proton transfers are included in the hit set only if the proton acts as the acceptor and intramolecular proton transfers are allowed only if the cyclic transition state is five- or six-atoms. We did this to lower the total number of possible proton transfer that occur while maintaining the most likely intramolecular proton transfers. It should be noted that intermolecular as well as intramolecular proton transfers can both lead to the same products.

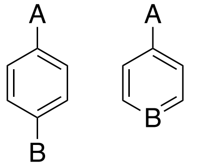
**(iii) Source orbital rule**. For functional groups such as C=O, C=N, and C≡N, the following preference was enforced: l.p. > pi > sigma. We restricted atoms with lone pairs (e.g., oxygen and nitrogen) from using their pi and sigma orbitals if their lone pairs were available for attack. For example, the lone pair of an imine (C=N-H) nitrogen is always used instead of the C=N pi bond or the N-H sigma bond. This rule reduces the presence of implausible reactions and degenerate processes in the list of ranked reactions.

**(iv) Baldwin's rules**. We anticipate that implausible reactions can be penalized to varying degrees by application of Baldwin's rules for ring closures.[234] To test this idea, we restricted the cyclic transition states be fewer than 8 atoms. While making molecules with a transition state of 8 or more atoms is possible, the removal of implausible reactions is often more important than inclusion of intramolecular process involving medium or macrocyclic rings.

**(v) p$K_a$ and p$K_b$ rule**. The training set includes many species acting as proton transfer agents making it difficult for the system to rank them. We gave the system a list of 172 p$K_a$ and p$K_b$ values for common molecules such as water, ammonia, and methanol. When this rule is turned on, then only the molecule with the lowest p$K_b$ is considered as a base and only the molecule with the lowest p$K_a$ is considered as an acid. For proton transfer events where one of the species did not appear in the p$K_a$ or p$K_b$ list then no restrictions would be placed on it. For example, if a complex amine that did not appear in the list was in the presence of hydronium and pyridinium, the complex amine could only pull the proton off of the hydronium.

**(vi) Geometry rule**. This rule simply restricts sources and sinks from reacting that could not reach each other in space. For example, cyclic transition states less than 8 atoms involving trans double bonds (Figure 4-10). This rule was generated by giving the system templates of atoms that could not reach each other geometrically.

**Figure 4-10**: Geometry Restrictions



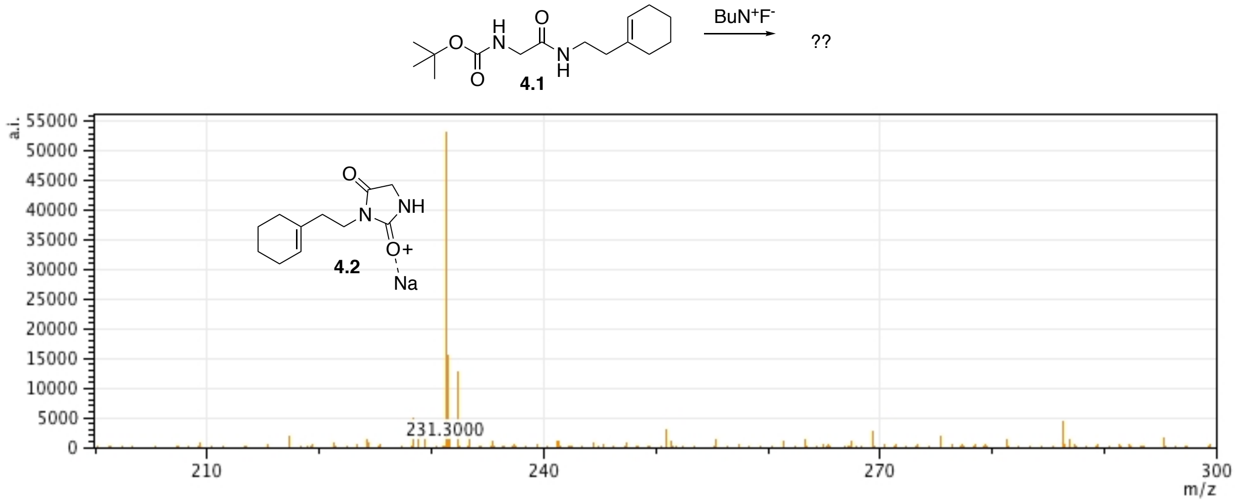
**Additional rules results**. We tested how the rules improved the system on the expanded training set of 600 challenging reactions described above. The rules improved the percentage of recovered reactions from 67% to 80% in the top 5. In addition to machine learning improvements and dataset development we expect that a hybrid system incorporating these types of user-selectable expert rules can improve the performance of Reaction Predictor.

**Pathway search results**. Pathway searches can take hours or days depending on the complexity of the reactants. Offline pathway search allows chemists to submit many jobs at once, each one searching for arbitrarily many targets, and have them run in parallel in the background, until results are found and returned via email. The improved performance of our single-step predictions, both in terms of accuracy and speed, make pathway search a powerful tool for understanding unknown masses observed by mass spectrometry, proposing alternative synthesis pathways, or identifying side products. We have added a feature to pathway search that removes products that it has previously seen in previous levels of a search tree. This allows the pathway search to go faster.

We submitted a number of pathway search jobs based on actual mass spectrometry data to test the feature's ability to identify unknown masses identified the mass spectrum. Typically, these offline searches generate a number of potential structures that match the target mass, and all but one are readily excluded.

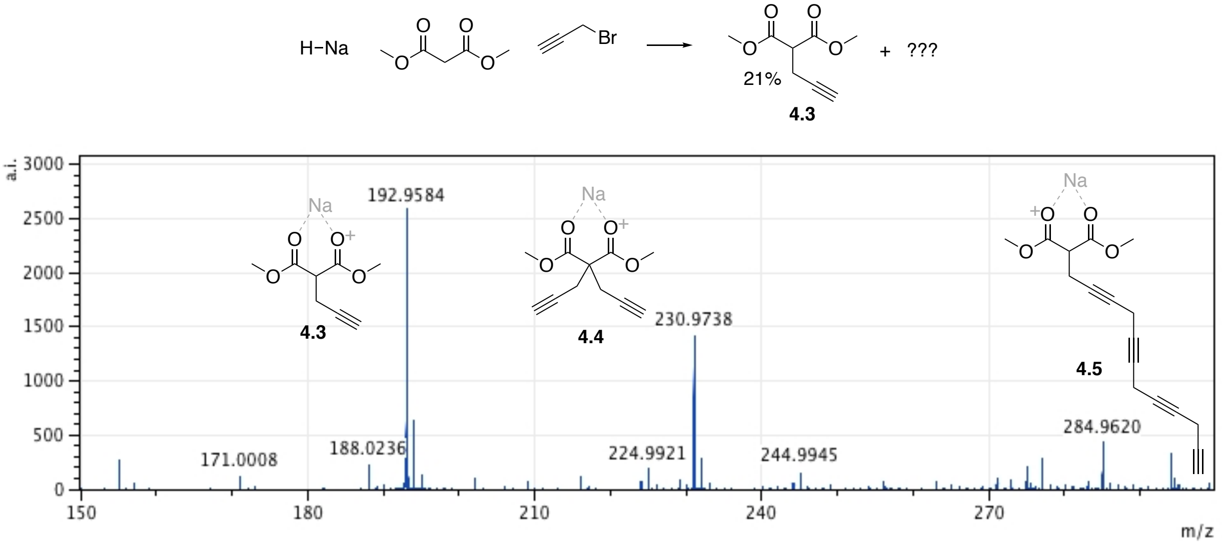
The first reaction we looked at is demonstrated in Figure 4-11. As described in Chapter 2, I was interested in finding an efficient way to deprotect BOC groups in the absence of acid because of tertiary carbocations that formed in the presence of acid but were disappointed when traditional TBAF deprotection gave an unidentified product. When Reaction Predictor was challenged with to identify targets with mass [m/*z* - H$^+$] or [m/*z* - Na+], the system gave back the highly plausible imidazolidine-2,4-dione **4.2**; the imidazolone was later confirmed to be the product by NMR spectroscopy.

**Figure 4-11**: Fluoride Deprotection of a BOC Protecting Group.



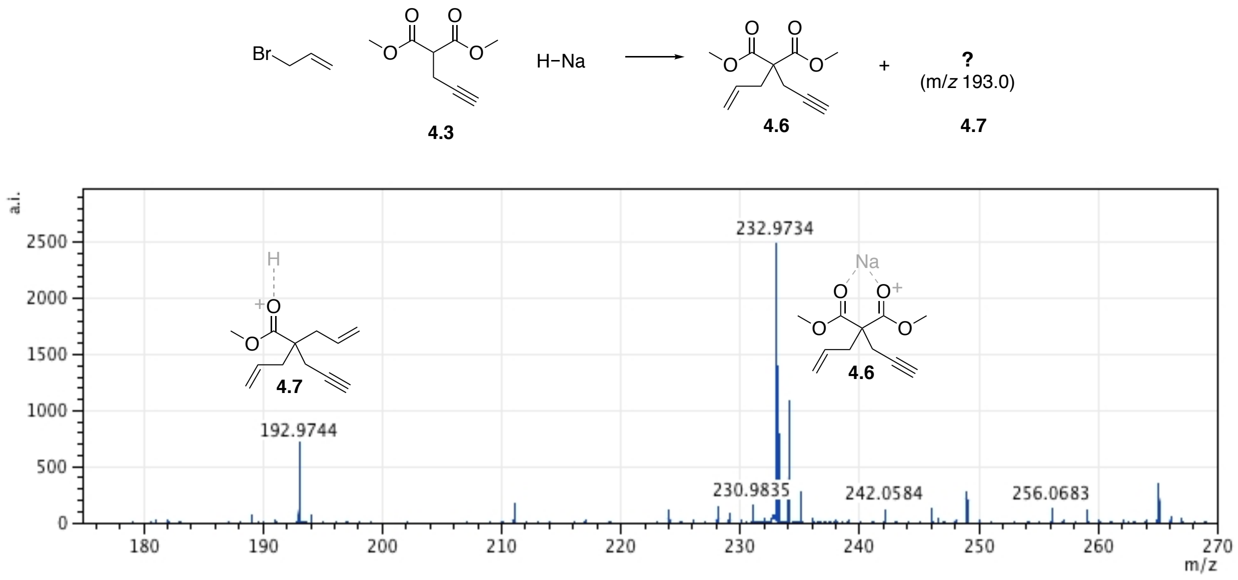
An undergraduate researcher Marlon Rhea attempted to synthesize a substrate for palladium-catalyzed carbenylative cyclizations through a seemingly simply alkylation of dimethyl malonate but the reaction proceeded with low efficiency (Figure 4-12). The desired alkylation product **4.3** was generated in a 21% yield. The reactants were introduced to Reaction Predictor and challenged to identify targets with mass [m/z - H+] or [m/z - Na+] and the starting materials described in Figure 4-12 into pathway search on Reaction Predictor. In addition to returning the expected product **4.3** and the expected double-alkylation product **4.4** the system proposed an overalkylation product **4.5** which could arise if the sodiomalonate starting material was highly insoluble and the initial product generated reactive alkynyl anions.

**Figure 4-12**: Malonate Alkylation in Low Yield



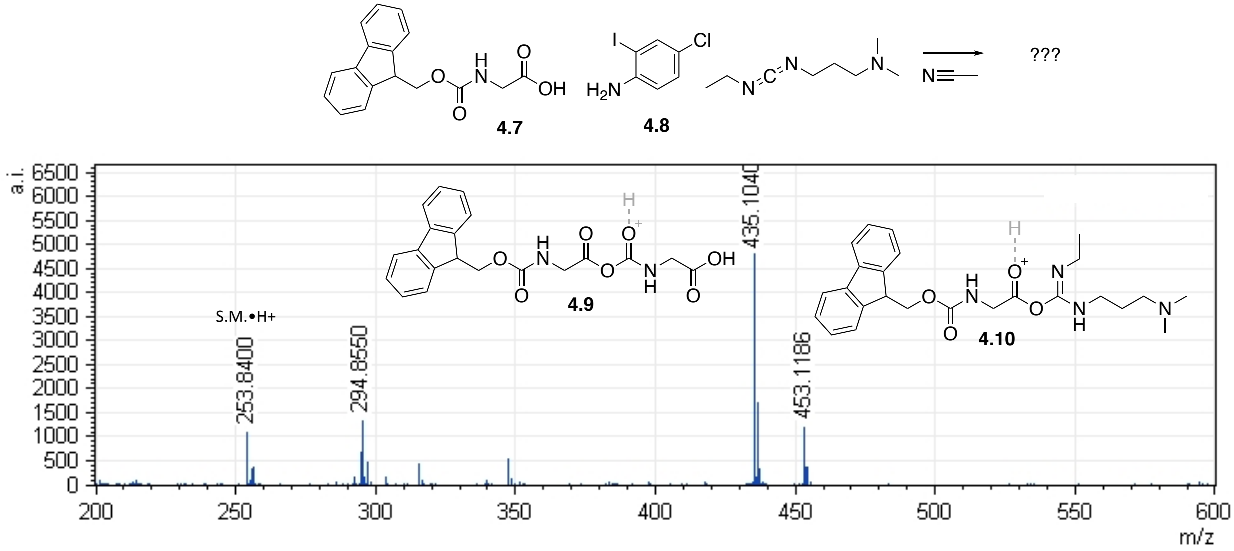
When Marlon allylated the propargyl malonate **4.3** (Figure 4-13) the malonate **4.6** was isolated in a 26% yield and unidentified side products were present in the product mixture. The reactants were entered into Pathway Predictor and the system was challenged to identify plausible products with mass [m/z - H+] or [m/z - Na+]. The system returned the expected allylation product **4.6** as well as a plausible decarboxylation/alkylation side product arising from a Krapcho decarboxylation pathway.

**Figure 4-13**: Malonate Alkylation Plus Something Else



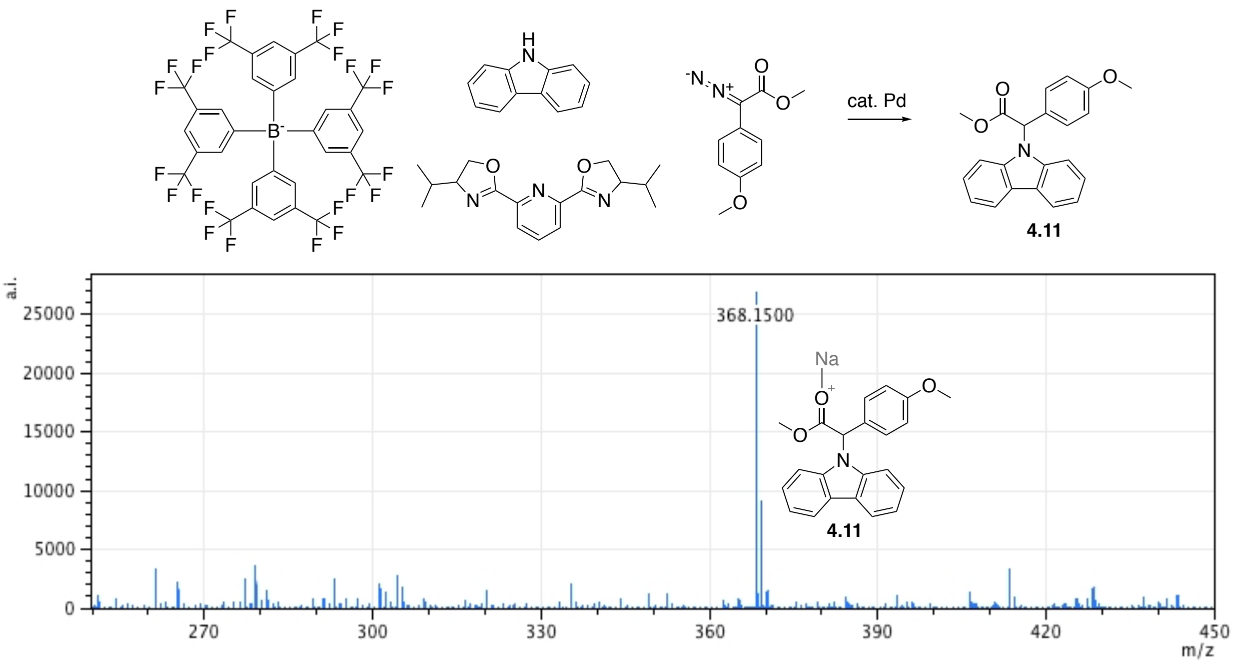
An attempt to carry out an EDC coupling of carboxylic acid **4.7** with aniline **4.8** was unsuccessful and none of the desired product was observed. Reaction Predictor generated implausible products for both masses: an isourea for product **4.10** (which is more likely the *N*-acylurea), and an anhydride **4.9**, which isn't expected to be stable enough for workup.

**Figure 4-14**: Carbodiimide Coupling

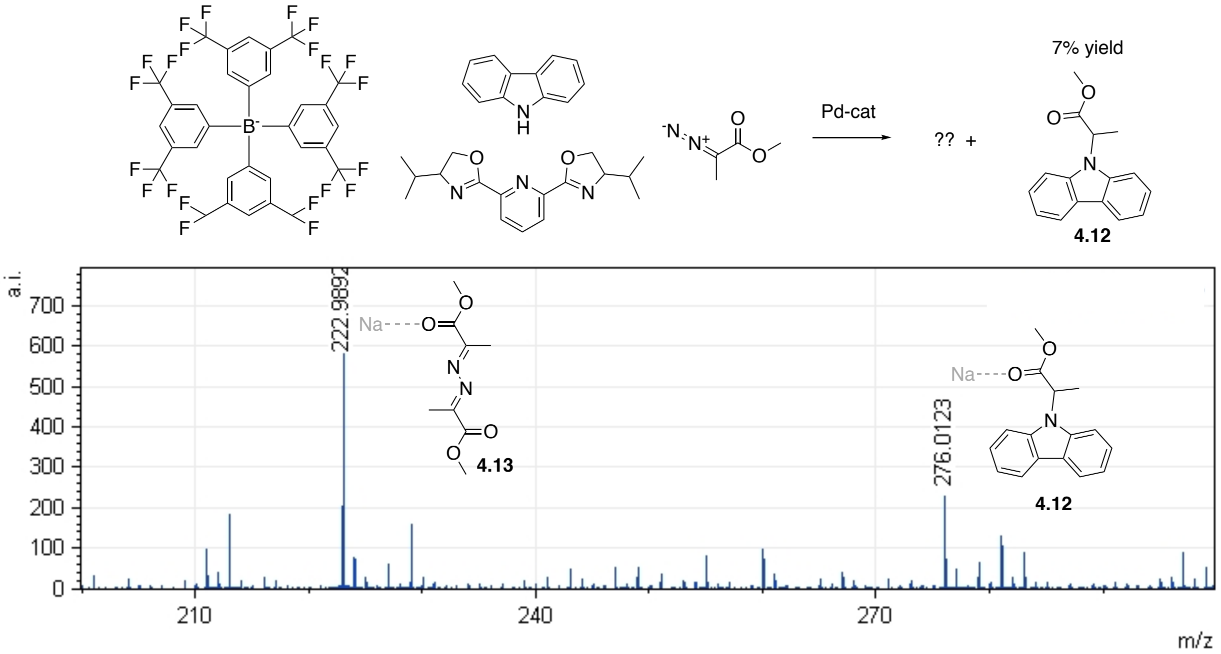


Our lab has been interested in the N-H insertion of carbazoles into diazo compounds using palladium but[235] the reaction in Figure 4-16 gave a very low yield of 7% of the desired product, **4.12**. Two of these reactions are shown in Figures 4-15 and 4-16. Although Reaction Predictor has not been trained in palladium reactions, we anticipated that the system might useful for generating plausible structures for reaction chemistry in which the system has not yet been trained Figure 4-15. When the reactants were entered into Pathway Predictor and the system was challenged to identify the products with mass [m/z - H+] or [m/z - Na+]. The system generated a plausible structure matching the mass of the desired insertion product **4.11** as well as a plausible structure for the known azine dimer, **4.13**.

## **Figure 4-15**: N-H Insertion Product



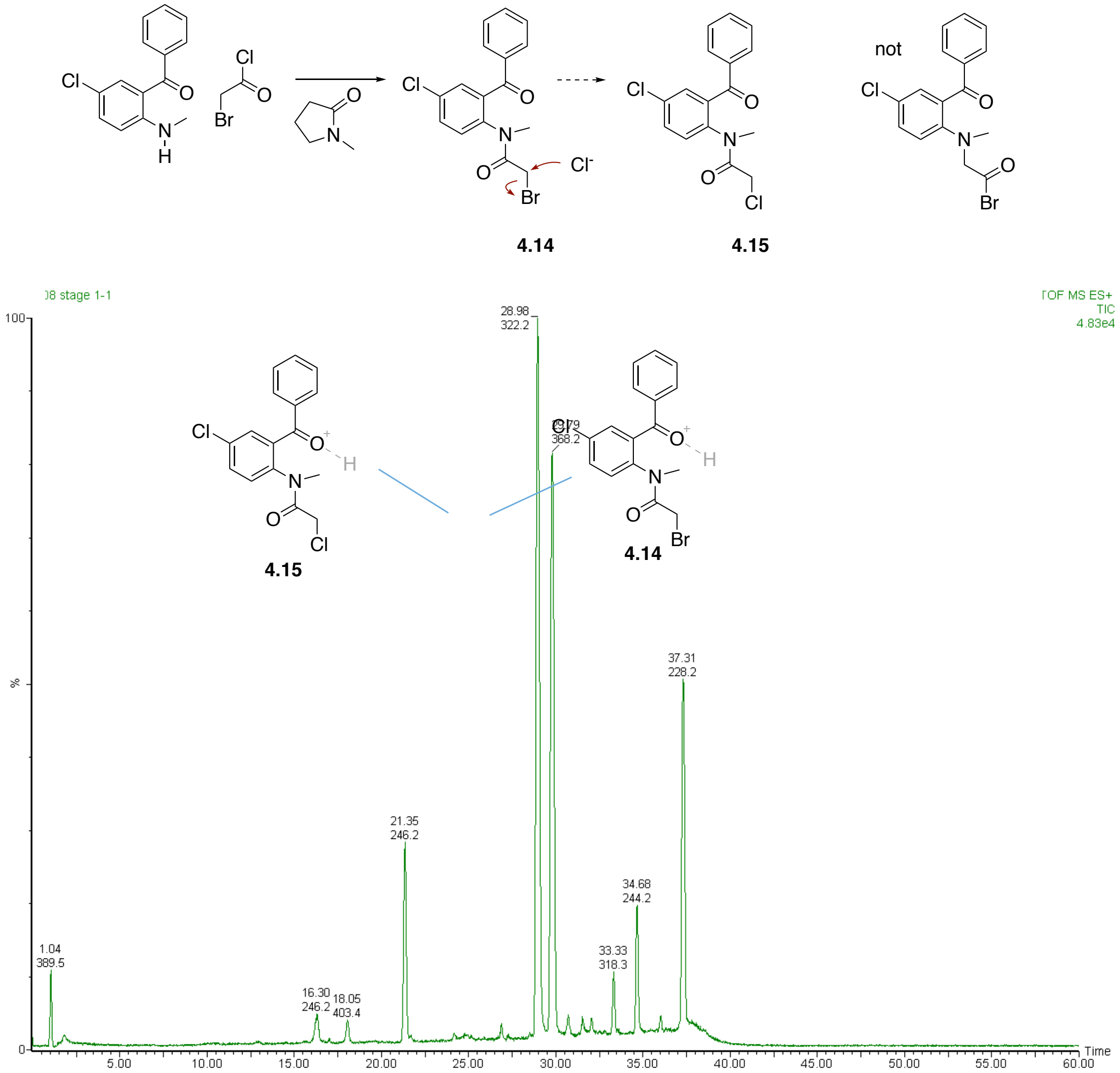
## **Figure 4-16**: Azine Formation



As seen above, Reaction Predictor is a tool that can give chemists plausible structures matching masses generated by ESI mass spectra. How does Reaction Predictor compare with other systems for identification products using mass spectrometry data? Thompson and coworkers observed a major side product in the first step of a flow synthesis of diazepam;[236] they used their mass spectrometry expertise to assign the structure of the product as an acyl bromide, resulting from undesired attack on the alkyl chloride functionality.

We observed the same by-product in an LCMS of a batch version of the same reaction,[237] conditions under which the acyl bromide should not be stable. In addition to the desired amide product **4.14**, Reaction Predictor could also identify a halide exchange product **4.15** as an highly plausible explanation for a product with mass 368 (t= 29.8 min).

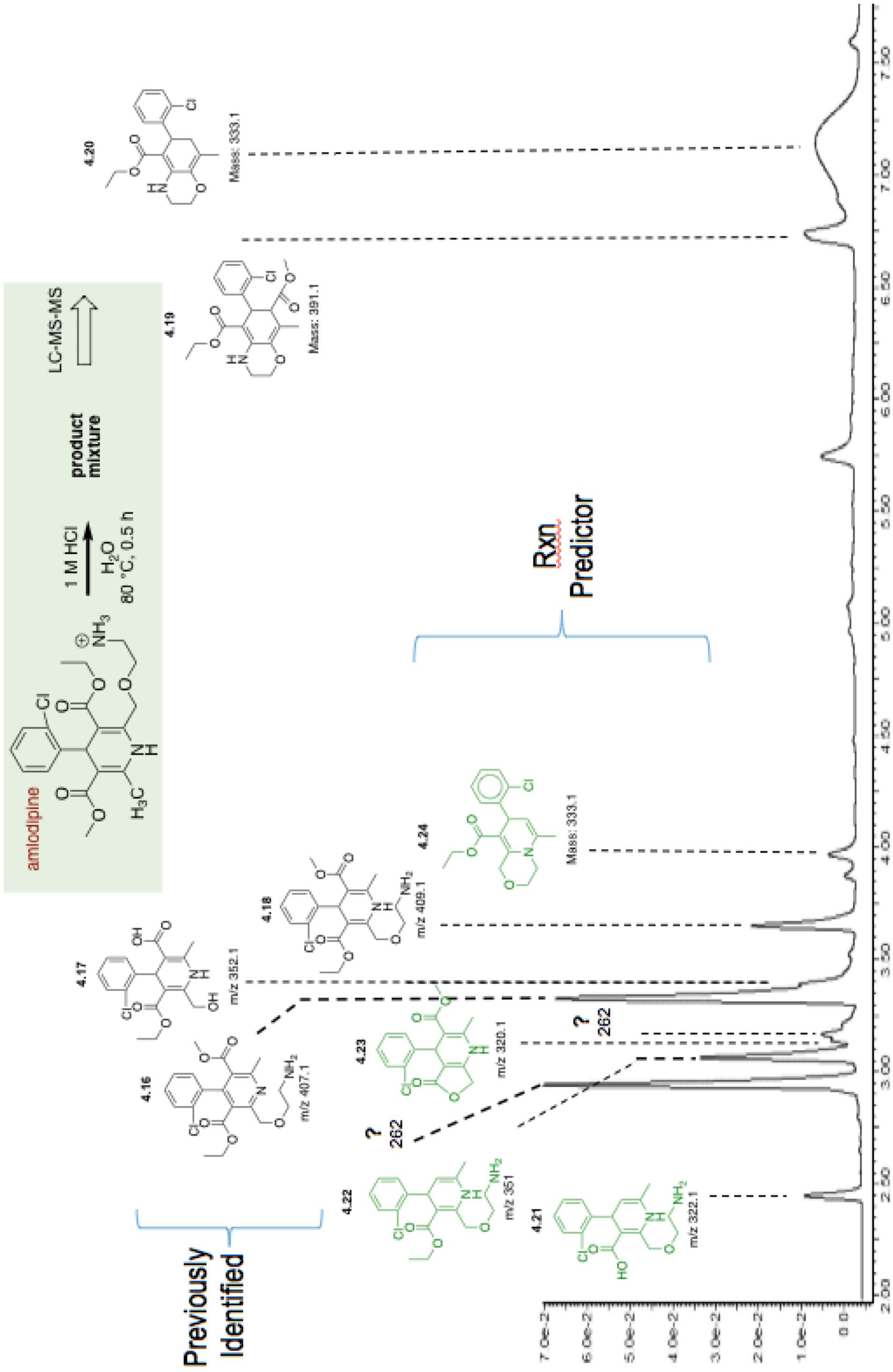
**Figure 4-17**: Diazepam Products in an LCMS chromatogram



As mentioned at the beginning of this chapter, forced drug degradation studies would greatly benefit from methods for identification of degradant structure. Forced degradation under acidic conditions, e.g., 1 M aq HCl, 30 min, is a common test for stability on the shelf (in the presence of excipients) and in the human stomach. We set out to test challenge Reaction Predictor to predict the acid degradation products of the drug amlodipine because it is relatively complex and some of the degradants were yet to be identified.[238,239,240,241,242,243] We heated amlodipine in 1 M HCl for 30 min and took a LC-MS of the product mixture.

The chromatogram for amlodipine degradation is shown in Figure 4-18 and is more complete than any previously published chromatogram. The reactants were entered into Pathway Predictor along with target masses corresponding to [m/$z$ - H+] or [m/$z$ - Na+] under the default search conditions. As seen in the labeled chromatogram there is still a small amount of amlodipine, **4.18**, left. Four known degradants were generated in our forced degradation reaction, **4.16**, **4.17**, **4.19**, and **4.20**. Reaction Predictor was not able to find any of the known products. The oxidation product, pyridine **4.16**, presumably was not found because Pathway Predictor was working in polar chemistry mode. Although Reaction Predictor was not able to find any of the known products, it proposed plausible structures for four of the unknown products: compounds **4.21** and **4.22** produced from hydrolysis and decarboxylation; **4.23** produced from cyclization; and **4.24** produced from cyclization and decarboxylation. Even though Reaction Predictor is still in its development stage, it can still give plausible products of drug degradation on a relatively complex drug.

**Figure 4-18**: Amlodipine Degradation



Reaction Predictor is beginning to demonstrate potential utility. Even implausible structures matching a target mass may spark ideas or suggest paths to identifying plausible alternatives. Continued improvements to source/sink prediction and ranking accuracy are ultimately the most important factors contributing to pathway search efficacy.

**LSTMs for source and sink prediction**. Deep learning and its architectures can be used in many ways. Recurrent neural networks (RNNs), and specifically LSTMs, are deep learning architectures well suited to the translation of variable-length sequences. They are commonly used to translate the written or spoken word from one language to another. We can naturally view chemical reactions as translations from reactants to products. These translations can be considered at the level of elementary reactions, or global transformations, and can be applied in the forward or reverse direction. Thus the "language" being translated is SMILES representations of molecules transforming from reactants into products, or vice versa. Using the inner and outer approach described by P. Baldi,[244] we applied bi-directional LSTMs to the problem of translating SMILES strings into source/sink predictions.

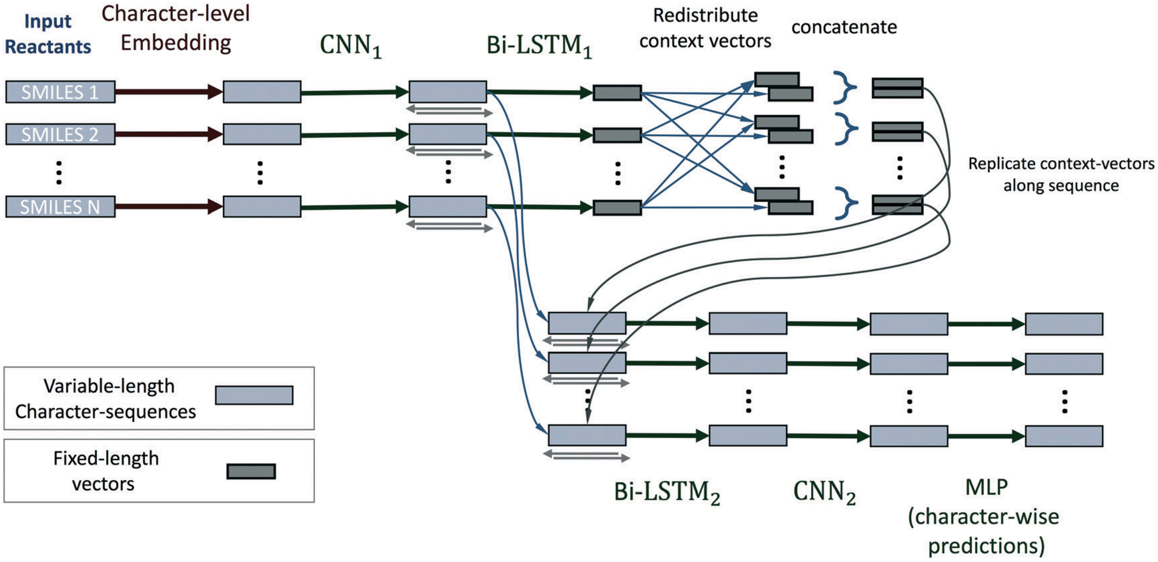
Our MLP-based source and sink predictor has some inherent limitations. The input features only cover a limited amount of context for any given molecule, *e.g.* neighborhoods of atoms within six bonds. Furthermore, these features do not contain any information about other reactants in a given reaction, which could render the prediction task virtually impossible in some cases, where a part of a molecule could act as a sink or a source depending on which other reactants are present.

We therefore explore a fundamentally different model to overcome these limitations. On a high level, this model is based on recurrent neural networks that operate on the canonicalized SMILES strings of all reactants. It is able to learn and use features that encode the context of the entire reaction when making predictions for locations of sinks or sources. This model is able to operate on an arbitrary number of reactants of arbitrary size/length (However, we expect that the accuracy of predictions will degrade for reactions with very large molecules) and is invariant to the ordering of reactants as presented. We achieve this invariance by operating on reactants in parallel, and extracting fixed-length feature vectors for all reactants, which are merged into groups of reaction-level features by averaging. A different part of our network uses these reaction-level, and order-invariant, features as context when it predicts sources and sinks for a given molecule.

A more technical description of the model and operating procedure is as follows: SMILES representations of reactants are canonicalized using an implicit representation of hydrogen atoms. We then remove all information that could trivialize the source/sink prediction task. For example, in our dataset all potential hydrogen sinks (or sources) appear as the first element in the SMILES string. Thus we remove these and add a 'start-of-sequence' character to every SMILES string. The training objective of our model is to predict, for every character in the input SMILES strings of all reactants, whether it corresponds to an atom (or bond) that will act as as ink, source, or both. We further replace multi-letter atoms (e.g. 'Cu', 'Al') with new unique single characters.

The neural network model conceptually consists of eight elements, shown in Figure 4-19. The layers of this model operate on all reactants in parallel, and receive information about the operations on other reactants of the reaction only at the reaction-level-feature merging step (see step 4). The input consists of a variable number (≈ number of reactants) of character strings of variable length (≈ length of individual reactant SMILES). We therefore use zero-padding for minibatches to speed up training. Descriptions of the layers are as follows:

**Figure 4-19**: Schematic of the LSTM architecture used for source/sink prediction. This approach operates directly on SMILES strings representing all reactant molecules, and is able to make source/sink predictions using context from the entire set of reactants.



1. The first layer of the neural network maps the input characters into a learned set of vectors (also called embedding), where the number of vectors equals the number of unique characters in all SMILES.

2. This layer is followed by a one-dimensional convolutional neural network (CNN),[245] and then further by a recurrent bi-directional LSTM.

3. The layers of the bi-directional LSTM traverse the sequences that correspond to a processed version of the original SMILES strings in the forwards and backwards directions. By doing so they accumulate and compute a fixed-length vector representation of the individual reactants, i.e. learned fingerprint vectors for reactions.

4. These representation vectors are then redistributed across all processing streams of all reactants: a given stream receives the fingerprint of its own molecule and the average

of fingerprints of the other molecules/reactants. This way we achieve commutativity of reactants while not mixing contexts of “this” and “other” reactants.

5. These two context vectors are concatenated and replicated across the output of the convolutional layer (2). We thereby re-use the character-level representations that are produced by the convolutional network (for efficiency and to promote weight sharing), while also augmenting them with reaction-level information about all reactants.

6. A bi-directional LSTM, separate from and unrelated to (3), then operates on this augmented stream of vectors and produces one output for each vector. These vectors have a one-to-one correspondence to characters in the input SMILES.

7. The LSTM outputs are then (optionally) processed by a CNN that can refine and sharpen predictions on a local level.

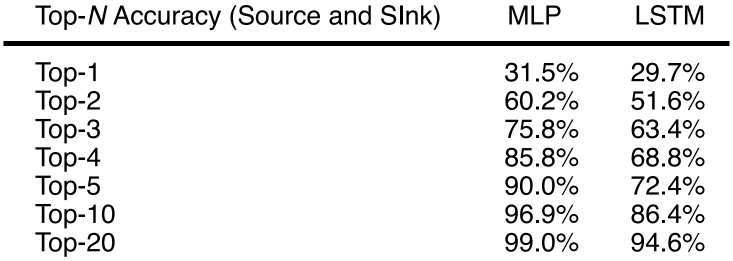
8. A final sequence-distributed MLP then computes the class-probability predictions for each element of a given reactant. These are the character-level predictions of sources/sinks for every atom (or non-atom symbol) in the input SMILES strings, computed for all reactants in parallel.

This model can predict multiple sources/sinks for one reaction or even reactant. We therefore post-process the model's predictions for all reactions by ranking the predicted probabilities, and only using the single most confident source and sink prediction for any given reaction.

The LSTM architecture uses rectified linear units for its hid-den layers, and sigmoid outputs. It was trained for 60 epochs on a set of 10,052 labeled SMILES strings. Weights were initialized according to Glorot and Bengio, and updated using the Adam optimizer, with an exponentially decaying learning rate. Training was performed on an NVIDIA Titan X GPU.

To gauge the performance of the LSTM on challenging re-actions, we checked its source/sink prediction accuracy on the benchmark data set of 289 reactions, and compared those results with the MLP-based predictor's performance. Table 4-2 summarizes these results. When we considered only the top-1 highest-scored source and sink, the MLP recovered both correctly in 31.5% of the reactions, while the LSTM re-covered both correctly for 29.7% of the reactions. If we con-sider the top-5 predictions, the MLP recovers both the correct source and the correct sink for 90.0% of the reactions, and the LSTM for 72.4% of them. Similarly, top-10 accuracy for the MLP was 96.9%, and 86.4% for the LSTM. Finally, top-20 accuracy for the MLP was 99.0%, versus 94.6% for the LSTM.

**Table 4-2**: MLP and LSTM source/sink prediction accuracy on the benchmark data set of 289 reactions. Predictions were considered correct only if both the true source and the true sink were identified within the top-N ranked source/sink predictions.



| Top-*N* Accuracy (Source and SInk) | MLP | LSTM |
|---|---|---|
| Top-1 | 31.5% | 29.7% |
| Top-2 | 60.2% | 51.6% |
| Top-3 | 75.8% | 63.4% |
| Top-4 | 85.8% | 68.8% |
| Top-5 | 90.0% | 72.4% |
| Top-10 | 96.9% | 86.4% |
| Top-20 | 99.0% | 94.6% |

The top-1 score of 29.7% for the LSTM is a promising result, and is particularly impressive as it is comparable to the MLP's top-1 performance of 31.5%. But this result is tempered by the LSTM's lower performance at recovering the labeled sources/sinks within top-5 and top-10 constraints. The crucial job of the source/sink filtering model is to recover all reactive electron sources and sinks, while minimizing the prediction of false positives. Table 4-2 shows that while the MLP is comparably accurate at predicting a single best source and sink, it is considerably better at recovering the correct sources/sinks, with fewer false positives, when multiple source/sink predictions are allowed. Specifically, the top-2 through top-5 scores are 60.2%, 75.8%, 85.8%, and 90.0% for the MLP, vs. 51.6%, 63.4%, 68.8%, and 72.4% for the LSTM. In reality, we expect that a complex chemical reactant will have multiple potentially-reactive source sand sinks, and the MLP recovers those more efficiently than the LSTM. In fact, even if we allow the LSTM to pick its top-10 proposed sources and sinks, its reaction-level accuracy of 86.4% is still lower than the top-5 MLP result of 90.0%. Nonetheless, these results are very promising and indicate potential for using an LSTM architecture for effective source/sink prediction. We emphasize that one advantage of our LSTM approach is its ability to consider the entire context of the reactants when making its source/sink predictions. This capability fundamentally shifts our expectations of what a good source/sink filter should do. Whereas the MLP predicts a set of potentially many reactive sources and sinks, but is necessarily less accurate in choosing the single best ones because it lacks contextual information, the LSTM can see the entire reaction context, and, at least in theory, predict the best source/sink pair given that complete information.

## Conclusion

Reaction Predictor is a unique and powerful tool for predicting chemical reactions at the level of elementary mechanistic steps. Deep learning coupled with a curated and expanded set of training data has yielded significant advances in both speed and predictive accuracy. Importantly, as the data set grows, Reaction Predictor continues to improve. Pathway search takes advantage of these performance gains to aid in the identification of unknown products by searching in the background and emailing results to the user.

The design of Reaction Predictor significantly mitigates the “black box” problem of deep learning systems. This refers to the observation that predictions from these systems can be difficult to interpret, if not inscrutable. A hypothetical LSTM making global reaction predictions, for example, has the problem that the “logic” behind any given prediction is obscured, and mistakes are opaque. In contrast, because Reaction Predictor's design is modular and operates at the level of elementary reactions, we can tell how it has made a prediction, and why, simply by following the sequence of elementary reaction steps involved. In our experience, even if Reaction Predictor mis-identifies the final target using elementary reaction steps, the structures frequently provide sufficient insight to propose plausible pathways and products.

Finally, we demonstrate a promising LSTM-based approach to predicting reactive sites based solely on SMILES strings. This could be used in future work to complement and improve the existing MLP-based source/sink filters. Ultimately we expect Reaction Predictor will continue to improve over time as new opportunities for refinement are identified, and as more training data becomes available.

## CHAPTER 5: Prediction of Nucleophilicity and Electrophilicity using Methyl Cation Affinity and Methyl Anion Affinity

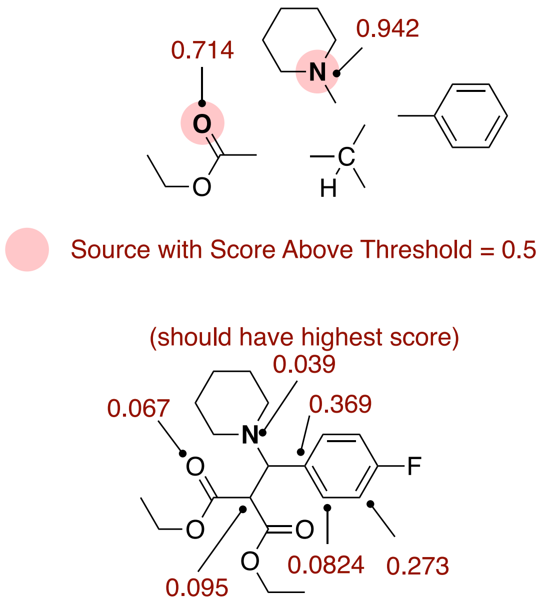
### Introduction

As described in chapter 4, reaction predictor works through a system of 4 steps as follows: 1. Enumerate all possible electron sources and electron sinks within the input reactant molecules. 2. Filter the list of candidate sources and sinks, predicting a smaller list containing only the most reactive sources and sinks. 3. Propose reactions by enumerating all combinations of source-sink pairings. 4. Rank the proposed reactions by favorability. Reaction predictor can reiterate through these steps to string multiple mechanisms together.

The first two parts of the system deal with ranking sources and sinks. The system learns what is a good source and what is a good sink through the training reactions. Each training reaction is an individual mechanistic step. The system essentially learns what is a good source or sink through pattern matching. One limitation of using this method is that the system is not able to pick up on the relative nucleophilcity and electrophilicity of sources and sinks because it learns only if a source and sink has been seen before. For instance, if the system has seen many electrophilic aromatic substitutions and many amine nucleophiles, it will give both of these reactants similar source scores. Toluene and piperdine would be ranked similarly, even though these molecules have drastically different reactivities.

The system ranks sources and sinks from a scale of 0 to 1. Generally any source or sink above 0.5 is considered a source or sink respectively. Another issue is that sometimes the system will rank sources or sinks lower than they are supposed to based upon varying substitution patterns. As seen in Figure 5-1, a simple tertiary amine gives a source ranking of 0.942, which is a very good. When more substitution is added to the molecule a similar amine now has a source ranking of 0.039 even though it should have the highest source ranking.

**Figure 5-1**: Source Rankings



Because of the two issues describe above, having a method to easily rank and quantify the reactivity of sources and sinks would be of great use for reaction predictor. In addition, having a complete and quantitative scale of electrophilicities and nucleophilicities would greatly empower new students of organic chemistry as well as experienced practitioners in the field. Organic chemistry is taught using a canonical set of functional groups. To a first order approximation, prediction of polar chemical reactivity rests on the deceptively simple act of quantifying the nucleophilicity and electrophilicity of every functional group that is present in the reactants. After over almost century of study,[246] we still lack the ability to quantify and rank the nucleophilicity and electrophilicity of all the canonical organic functional groups, ranging from C-C bonds to naked alkyl anions, in any reference environment (gas phase or solvent system).

This chapter describes two simple computational methods, methyl cation affinity and methyl anion affinity, to estimate the nucleophilicity and electrophilicity of the canonical organic functional groups. The work in this chapter was almost exclusively done by Dr. Van Vranken and I with help from Dora Kadish and Amin Tavakoli.

## Reactivity Scales

Countless researchers over the years have taken kinetic measurements but few have tried to development reactivity scales to quantify the nucleophilicity and electrophilicity of molecules.[247] The first researchers to quantify reactivity on a scale were Swain and Scott in 1953.[248] They became famous for developing the Swain-Scott equation, $\log(k/k_o) = sn$, where k is the reaction rate of the interested nucleophile, $k_o$ is the reaction rate of the reference nucleophile, $s$ is a sensitivity term specific to each electrophile, and $n$ is the nucleophilicity of the interested nucleophile. Typically $CH_3Br$ in water was used as the reference electrophile ($s = 1$), so the equation was used to compare the rates of reactions of $S_n2$ reactions. From the form of the equation it can be seen that nucleophilicity can change depending on the reference electrophile used.

Since p$K_a$ data is measured easily for many molecules, Edwards came up with a four-parameter equation, $\log(k/k_{H2O}) = \beta H + \alpha E$, based upon the basicity (H) and polarizability (E) of the nucleophile in 1954.[249,250] $\alpha$ and $\beta$ change with respect to each electrophile. This equation did not find widespread application possibility because of the tedious method of introducing multiple parameters. Although it may seem obvious, Parker demonstrated that solvation can increase the rates of nucleophilicity by up to $10^8$.[251] For instance, the hydrogen bonding of a polar solvent like water can have drastically different effects than an aprotic solvent.

Ritchie developed the Richie equation, $\log(k/k_o) = N_+$, in 1972.[252] It is notable because it is a constant selectivity relationship. This means that relative nucleophilicity did not change based upon the electrophile. It should be noted that Ritchie only measured nucleophiles against trityl, diazonium, and tropylium cations. Ritchie later showed that there is slightly better correlations when each electrophile is treated separately but over the 13 orders of magnitude he measured nucleophilicity, the equation still gave good first approximations.[253]

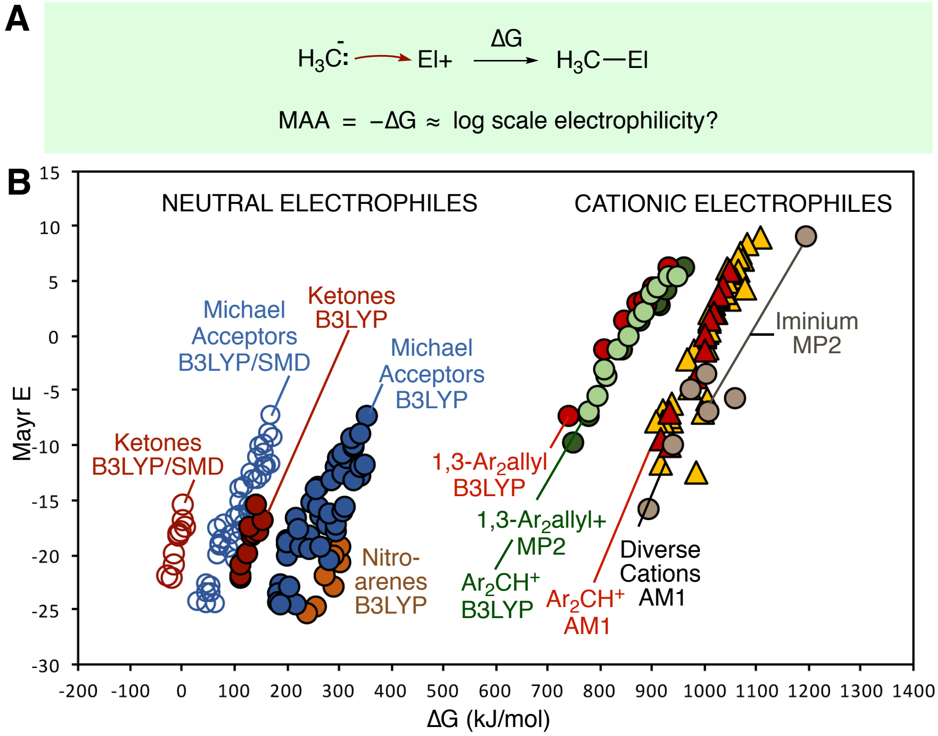
In 1994, Herbert Mayr introduced the Mayr equation, which has become the gold standard in reactivity scales. Mayr and coworkers developed independent scales of nucleophilicity and electrophilicity for a wide range of polar compounds and a powerful equation for prediction of reaction rate constants: $\log \boldsymbol{k}_{20°} = s_N\, s_E\, (E + N)$, where E and N are log-scale electrophilicity and log-scale nucleophilicity parameters, respectively, which can be plotted on a useful scale of reactivity order.[254,255] Mayr and his team determined Mayr $E$ parameters for over 300 electrophiles and within that range $s_E$ is sufficiently close to unity that it could be neglected. Mayr $N$ parameters and nucleophile-specific parameters $s_N$ have been reported for over 1100 nucleophile/solvent combinations, with far more diversity than the electrophilic functional groups. In addition to being the most expansive and accurate set of kinetic measurements, these parameters are readily available and organized online in one place.[256]

### Electrophilicty and Methyl Anion Affinity

As long as the $s_E$ parameter is at unity, the mayr equation states that electrophilicity is independent of nucleophilicity. The success of the Mayr equation centers around a focus on reactions that form bonds to carbon atoms, not, for example, Cs—O or F—Ge bonds; but a focus on carbon is not a significant limitation in the field of organic chemistry. The current set of electrophilicity parameters spans about 33 orders of magnitude and does not encompass highly reactive nor unreactive groups that serve as the pedagogical foundation for the field of organic chemistry: for example, *t*-butyl carbocation, ester carbonyls, amide carbonyls, acid chlorides, imines, alkyl halides, and carbon-carbon bonds.

The methyl anion is unhindered and supremely nucleophilic making it an ideal reference nucleophile for quantifying electrophilicity. It combines the negative charge of a hard nucleophile with the modest electronegativity of a carbon atom. Methyl anion affinity (figure 5-2A) should is related to the Mayr E parameter through a classical linear free energy relationship: $-\Delta G \propto \log \boldsymbol{k} \propto$ Mayr E when $s_E$ is 1. In early work, Mayr and Houk showed that calculated methyl anion affinity (AM1 $H_f$, gas phase) gives good linear correlation with the Mayr electrophilicity (Mayr E) for various cations: carbenium, iminium, and oxonium ions (Figure 5-2B).[257,258] It is promising that these diverse cationic electrophiles fall on the same line. Subsequent work focused on individual functional groups but no attempt was made to correlate MAA with Mayr E for both neutral and cationic electrophiles. At higher levels of theory (MP2 and B3LYP), calculated methyl anion affinities also correlate linearly with Mayr electrophilicity for other classes of electrophiles: diarylallyl,[259,260] benzhydryl cations,[260] and azacarbenium ions.[261] Mayr and coworkers have also shown that neutral electrophiles such as ketones,[262] Michael acceptors.[263] and nitroarenes[264] give good linear correlation between calculated MAAs and Mayr E. In theory, the common slope of these lines should correlate with $1/s_N$ for a methyl anion.

**Figure 5-2**: Previous correlations of MAA with Mayr E. (**A**) MAA is defined as the negative of the free energy change for reaction of $H_3C^-$ with electrophiles so that higher affinity correlates intuitively with higher energy, and higher kinetic electrophilicity. (**B**) Calculated MAA vs Mayr E generated lines that were dramatically different for neutral and cationic electrophiles. At higher levels of theory, different functional groups give different linear correlations.

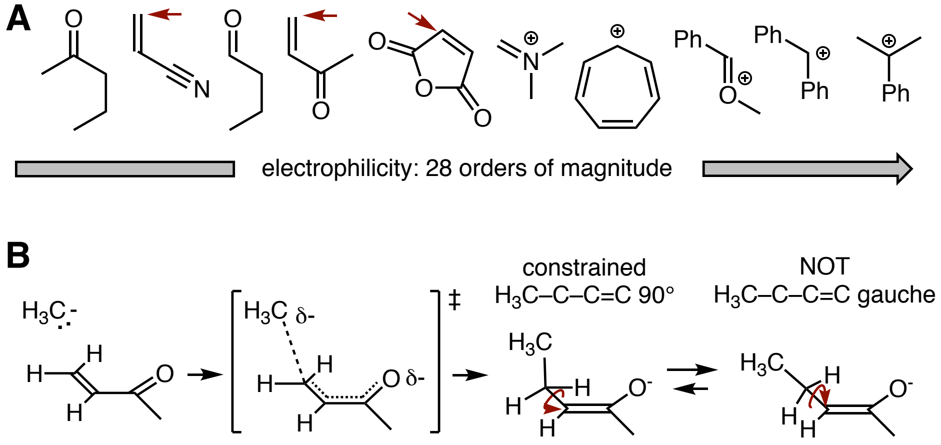


At all levels of theory, the correlation between MAA and Mayr E are linear with similar slopes but it is sobering to see that, even at high levels of theory, different classes of functional groups such as ketones, Michael acceptors, nitroarenes, benzhydryl cations, allyl cations, and azacarbenium ions, fall on *different* lines, suggesting that it may be impossible to broadly correlate MAA with Mayr E across all of the canonical functional groups in organic chemistry. The SMD solvation model (DMSO) improves the linear correlation but did not lead to convergence of the lines for ketones and enones (Figure 5-2B). It is unclear if any theoretical treatment can be used to correlate the calculated methyl anion affinity with the solution phase electrophilicity of canonical organic functional groups.

### Electrophilicity Results and Discussion

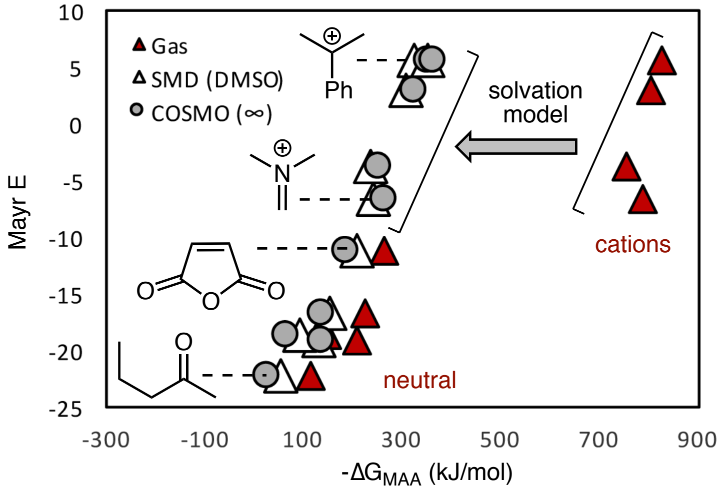
**Solvation Improves Correlation of MAA* with Electrophilicity.** We set out to compare the COSMO(∞) solvation model with SMD(DMSO) for calculation of MAAs that would correlate with electrophilicity. For this study, we chose a functionally diverse test set of electrophilic species that span almost the entire range of experimentally determined Mayr E parameters (Figure 5-3A): cumyl cation,[265] benzhydryl cation,[266] methoxyphenylmethylium cation,[267] tropylium ion,267 dimethylmethyleneammonium cation,267 maleic anhydride,[268] methyl vinyl ketone,263 butanal,[269] acrylonitrile,263 and pentan-2-one.262 We restricted the product geometries to idealized transition state-like conformations. For example, methyl vinyl ketone was constrained to the *S*-cis conformation and newly formed $H_3C$—C bond in the product was constrained to be 90° to the original enone pi system, instead of the lower energy gauche conformation that minimizes $A_{1,3}$ strain (Figure 5-3B). For most electrophiles, the minimized product geometries tend to be geometrically and energetically similar to the transition state geometries.

**Figure 5-3**: The test set. (**A**) Test set of electrophiles for which Mayr has reported experimental E parameters. Arrows show sites of attack. (**B**) MAAs were calculated by restricting products to transition state-like geometries.



The correlation between MAA and Mayr E is particularly poor when both neutral and cationic electrophiles are compared (Figure 5-4). When COSMO(∞) was used in the calculation of methyl anion affinity, the MAA gave surprisingly good linear correlation with Mayr E across both cationic and neutral electrophiles. Unexpectedly, on the full scale of measured Mayr E parameters, the SMD(DMSO) solvation was about as good as COSMO(∞) ($R^2$ 0.95 vs 0.96, respectively) for calculation of MAAs that correlate with experimental electrophilicity although the correlation was not quite as good for aldehydes and ketones. **Going forward, we define MAA* as a methyl anion affinity calculated with a solvation model** to distinguish it from the traditional notion of a gas phase methyl anion affinity (MAA). MAA*s calculated with PBE0(disp)/def2-TZVP[270] gave about the same or better ($R^2$ 0.97 vs. 0.96) linear correlation with Mayr electrophilicity compared to B3LYP/6-311++G(3df,2pd) but was significantly faster and was used for all subsequent calculations of MAA*s.

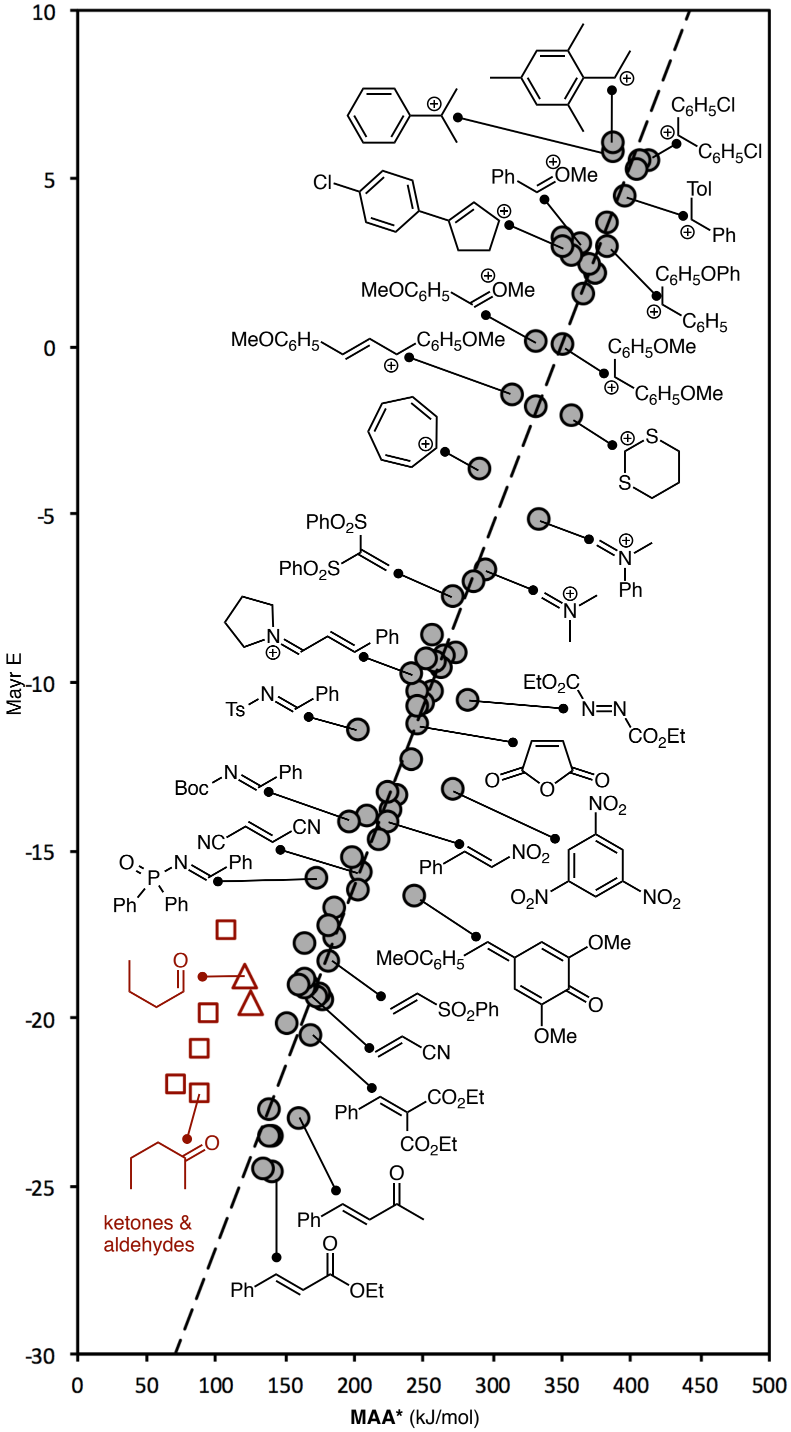
**Figure 5-4**: Solvation models lead to correlation of MAA with Mayr E. Inclusion of a solvation model like SMD or COSMO leads to good linear correlation between calculated MAA and Mayr E for both cationic and neutral functional groups.



**MAA* Correlates with Mayr E Across A Broad Range of Electrophiles**. Having shown that MAA*s correlate well with the Mayr E parameter for the test set of ten electrophiles, we set out to extend that analysis to a much fuller set of structurally diverse electrophiles. To date, Mayr and Ofial, have reported Mayr E parameters for over 319 electrophiles.[271] These include molecules from over 30 different classes of functional groups: i) empty p orbitals with p conjugation: benzylic carbenium ions,[265-267,272-277] allyl cations,[259,267] and the tropylium ion[267] ii) empty p* orbitals: ketones,[262] aldehydes,[267,269] iminium ions,[267,278] oxacarbenium ions,[267] sulfacarbenium ions,[267] acyl imines,[269] tosyl imines,[269] phosphoryl imines,[269] quinone methides,[279,280] indolylmethylium ions,[281,282] alpha,beta-unsaturated ketones,[263,269,283-285] acrylates,[263] acrylamides,[263] cinnamates,[263] acrylonitriles,[263] alkylidenemalonates and related compounds,[286-288] maleates and related compounds,[268] alkylidene malonitriles,[268] nitrostyrenes,[289] cinnamyliminium ion derivatives,[290-294] benzylidene malonitriles,[295] quinones,[296,297] sulfone acceptors,[263,298,299] electrophilic arenes,[300-303] azocarboxylates[304,305] iii) empty s* orbitals: chlorinating agents

($s_{C\text{-}Cl}$*),[306] electrophilic fluorinating agents ($s_{N\text{-}F}$*),[307] and electrophilic trifluoromethylsulfenylating agents ($s_{X\text{-}S}$*)[308] Cationic pi-metal complexes[267,272,309,310] can be represented as empty p orbitals or empty σ*. We selected 75 of the 319 molecules (28 out of 32 functional groups) in the Mayr-Ofial database in an attempt to capture as many of the common canonical functional groups in organic chemistry as possible, excluding cationic pi-metal complexes, chlorinating, fluorinating, and sulfenylating reagents that react through $S_N2$-like processes as discussed below. MAA* was found to correlate linearly with the Mayr E parameters for nearly all of the functional groups, including the most reactive electrophiles (e.g., 1-(mesityl)ethenium ion, E = 6.04 ) and the least reactive electrophiles (e.g., cinnamonitrile, E = -24.60) (Figure 5-5). As discussed below, aldehydes and ketones are a notable exception to this linear correlation and were not used in the linear regression ($R^2$ 0.97); the mean absolute error for Mayr E was ±1.2. Inclusion of an additional term for $(E_{HOMO}\text{-}E_{LUMO})^{-1}$ did not change $R^2$.

**Figure 5-5**: Correlation between experimental parameters and theory. There is good correlation between calculated MAA* (PBE0/def2-TZVP COSMO(∞)) and Mayr E parameter across a broad range of organic electrophiles.



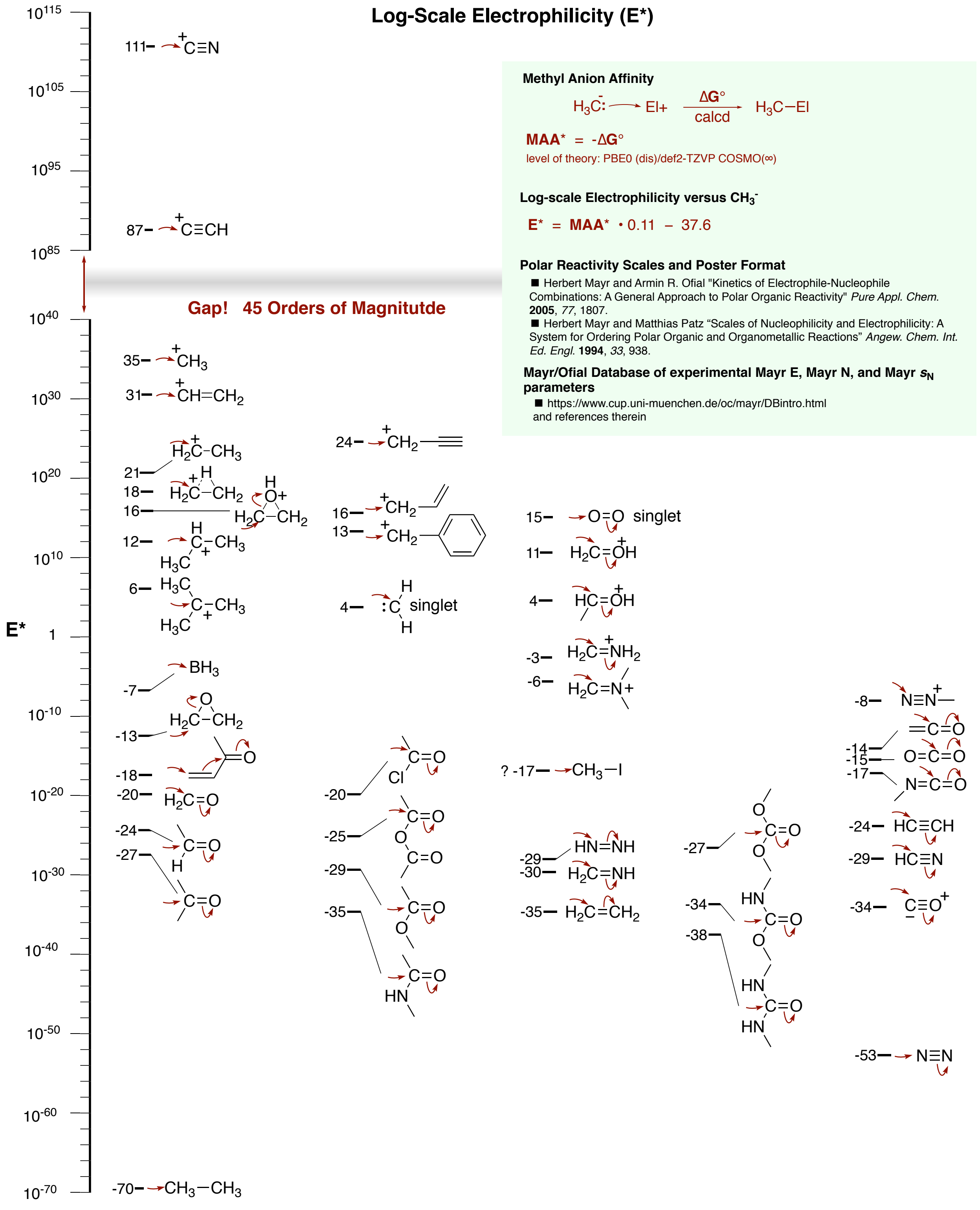
No Mayr E parameter has ever been reported for an $S_N2$ displacement reaction at carbon although Mayr has reported E parameters for electrophiles in three other types of displacement reactions: chlorination by attack on Cl-C bonds, fluorination by attack on F-N bonds, and (trifluoromethyl)sulfenylation. Mayr has noted that "deviations are expected for $S_N2$ type reactions, where making one s-bond is coupled with breaking another s-bond."267 E and $s_E$ parameters can be estimated based on published kinetic data for $S_N2$ attack on $CH_3S^+R_2$ (E = -10),[311] $CH_3I$ (E = -23)[311] and $CH_3Br$ (E = -22)[312] in protic solvents and for $CH_3I$ (E = -17),[313] in DMSO but the resulting E and $s_E$ values are less reliable for calculation of rates than for other types of electrophiles.[313] Thus, it is not surprising that a plot of MAA* versus these renegade E parameters does not fall on the same line as the other types of electrophiles for which E values have been vetted, even after correction for translational entropy differences[314] and distortion energies.[315] It is ironic that the relative reactivity of $S_N2$ substrates, long studied with linear free energy relationships,[312] remains among the most pressing issues of our time in the field of physical organic chemistry.

**Deviations from the MAA*-Mayr E Line Suggest a Deviation from Typical Depictions**. The utility of quantifying electrophilicity using MAA* is that the simplistic definition of methyl anion affinity matches the over-simplified representations used throughout the field of organic chemistry. When the common arrow-pushing depiction for addition to an electrophile matches the solution-phase mechanism, the point for that electrophile should lie on the line for MAA* v Mayr E; but any solution effects – such as hydrogen-bonding, metal coordination, or aggregation – that accelerate reactions will lead to points above the line. Likewise, any solution effects that retard reactions will lead to points below the line. Even when MAA* is calculated with a solvent model, carbonyls are above the line by five to six log units. Attempts to model addition of the simplest of nucleophiles such as $H_2O$[316] or $NH_3$[317] to the simplest carbonyl, formaldehyde, are not consistent with a bimolecular addition to form a simple unstable zwitterionic tetrahedral intermediate.[318] As with addition of organometallic reagents,[319,320] realistic models of carbonyl addition require Brønsted or Lewis acid interactions with the carbonyl oxygen. The Mayr E parameters for aldehydes and ketones were determined in the presence of $K^+$ and *t*-BuOH. Which value best reveals the "electrophilicity" of a carbonyl group: the MAA*, which matches the common arrow-pushing depiction or a Mayr E parameter determined in the presence of species that are not depicted? After philosophical reflection one should answer: both. That is the only way to evaluate the difference between what we draw and what is going on in solution. We use the abbreviation E* for log-scale electrophilicity parameters derived from MAA* in order to distinguish it from the Mayr E parameters established in solution phase experiments.

**Quantifying the Reactivity of the Canonical Electrophiles on the Mayr Scale.** With good confidence in the linear correlation between MAA* (PBE0/def2-TZVP COSMO(∞)) and our quantitative notion of functional group electrophilicity, we were then motivated to calculate MAA*s for unsubstituted canonical electrophiles (Figure 5-6). To the extent that methyl anion affinity, calculated with solvation, correlates with solution phase reactivity we begin to glimpse the breathtaking range of electrophilicity for canonical organic functional groups, as commonly depicted with arrow-pushing representations, on the scale of the Mayr E parameter. The diverse electrophiles on the E* scale are valuable because they allow us to make non-obvious predictions about electrophilicity. For example, electrophilicity is easy to rank when lower π* LUMO and higher polarity go hand in hand as in the case of C=O versus C=C, but what about the electrophilicity of C=O versus N=N? The

E* values suggest that electrophilicity will follow the trend: C=O (-20) > N=N(-29.1) ~ C=N (-29.5) > C=C (-35).

**Figure 5-6**: Log scale E* for the Canonical Electrophiles in Organic Chemistry. Prediction of log scale electrophilicity E* for the full range of canonical electrophiles based on MAA*.



**Methyl Anion Affinity**

$$H_3\overset{-}{C}: \longrightarrow El+ \xrightarrow[\text{calcd}]{\Delta G^\circ} H_3C-El$$

**MAA*** = -**ΔG**°

level of theory: PBE0 (dis)/def2-TZVP COSMO(∞)

**Log-scale Electrophilicity versus $CH_3^-$**

**E*** = **MAA*** • 0.11 − 37.6

**Polar Reactivity Scales and Poster Format**

- Herbert Mayr and Armin R. Ofial "Kinetics of Electrophile-Nucleophile Combinations: A General Approach to Polar Organic Reactivity" *Pure Appl. Chem.* **2005**, *77*, 1807.
- Herbert Mayr and Matthias Patz "Scales of Nucleophilicity and Electrophilicity: A System for Ordering Polar Organic and Organometallic Reactions" *Angew. Chem. Int. Ed. Engl.* **1994**, *33*, 938.

**Mayr/Ofial Database of experimental Mayr E, Mayr N, and Mayr $s_N$ parameters**

- https://www.cup.uni-muenchen.de/oc/mayr/DBintro.html and references therein

Armed with quantititive estimates of electrophilicity, we are forced to confront the fact that E* for triple bonds follows the opposite trend of double bonds.[321] Everyone knows that nitrogen exhibits low electrophilicity; the surprise is that C≡C triple bonds seem to be more electrophilic than a C≡N triple bond in the order N≡N (E*=-53) < HC≡N (E*=-29) < HC≡CH (E*=-24) and MeC≡N (E*=-34) < MeC≡CH (E*=-26). These series are more consistent with the costs of bond enthalpy than an enhancement related to bond polarity. The addition of metal alkoxides and related nucleophiles to HC≡CH at high temperature is well known[322,323] but it will never be easy to quantify the rate of unassisted addition to RC≡CH or RCN in solution due to the tendency toward deprotonation, hydrogen bonding, and oligomerization.[324,325] Further experimental studies may help to shed light on the surprisingly high E* values for alkynes relative to nitriles.

**Accuracy and Relevance of Electrophilicity Quantified by E*.** Mayr E parameters can be used to predict solution phase rate constants for combinations of electrophiles and nucleophiles within two orders of magnitude; no such utility is yet claimed for E* parameters estimated from MAA* – that merits further study – but the linear relationship between MAA* and Mayr E seems compelling. If the linearity holds and the distribution is normal, then the furthest reaches of predicted electrophilicity, from $H_3C—CH_3$ to $^+C≡N$ range from E* of -70 (±3) to +111(±5) at a 95% confidence level. The structure of the Mayr equation, $\log \boldsymbol{k}_{20^\circ} = s_N\ s_E\ (E + N)$ suggests that a truly independent scale of nucleophilicity and electrophilicity may be out of reach for some classes of polar reactions, such as $S_N2$. Approaches involving deep learning could allow us to make predictions based on complex non-linear structure-reactivity relationships.[326-328]

What is the significance of electrophiles that cannot be studied in solution? Reactions of the canonical methyl cation,[329] $H_3C^+$ and even the supremely reactive cyanide cation ($^+C{\equiv}N$)[330] have been studied in gas phase experiments. Singlet methylidene,[331] and vinyl, ethyl and propargyl cations have been identified in atmospheres within our solar system and in interstellar environments.[332] Allyl cation and less reactive carbenium ions have been studied in solution on our own planet under superacid conditions.[333] Understanding the kinetic electrophilicity of these species on a common scale inspires us to think about their potential reactivity on Earth and beyond.

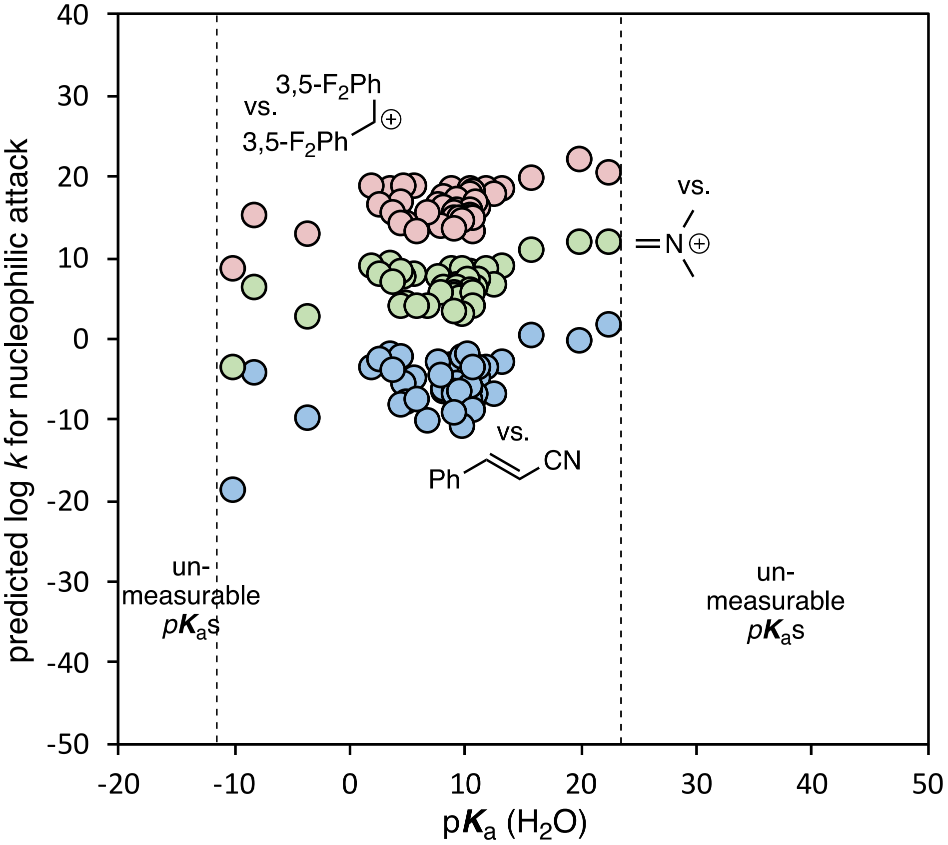
## Electrophilicity Conclusion

The linear correlation of MAA* with experimental Mayr E allows one to contrast the simple arrow-pushing mechanisms depicted in textbooks with the true mechanisms in solution. Using MAA* we are able to estimate the log scale electrophilicity (E*) of the canonical organic funcitonal groups, covering a staggering range of 180 orders of magnitude. More such experimental determinations of Mayr E parameters are needed to better appreciate the differences between depiction and reality.

## Nucleophilicity and Methyl Cation Affinity

An abundance of readily available titration data leads most organic chemists to estimate nucleophilicity using p$\boldsymbol{K}_a$s (a Brønsted relationship), because the expediency of a one-parameter nucleophilicity correlation often outweighs the accuracy afforded by additional parameters such as those in the four-parameter Edwards equation that are not readily available.[334,335] A major limitation of a one-parameter Brønsted relationship is that experimental p$\boldsymbol{K}_a$s can not be directly measured for functional groups far less acidic than the solvent or far more acidic than the conjugate acid of the solvent.[336,337,338] Moreover, even when p$\boldsymbol{K}_a$s can be accurately calculated, the correlation with nucleophilicity is poor (Figure 5-7), as shown in a plot of p$\boldsymbol{K}_a$ ($H_2O$) versus log *k* for nucleophilic addition;[339,340] the correlation is comparable poor using p$\boldsymbol{K}_a$s measured in DMSO.

**Figure 5-7:** Equilibrium p$K_a$s correlate poorly ($R^2 = 0.33$) with nucleophilicity, estimated from the Mayr equation, regardless of electrophile.



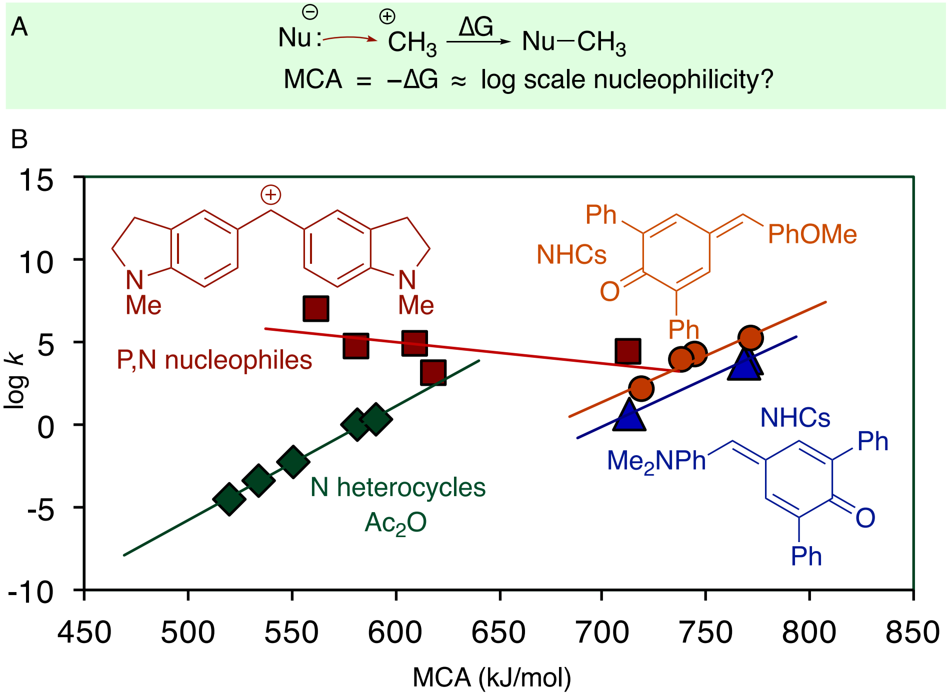
Mayr and coworkers developed independent scales of nucleophilicity and electrophilicity for a wide range of polar compounds and a powerful equation for prediction of reaction rate constants: log $\boldsymbol{k}_{20^\circ} = s_N\, s_E\, (E + N)$, where E and N are log-scale electrophilicity and log-scale nucleophilicity parameters, respectively, which can be plotted on a useful scale of reactivity order.[341,342] Mayr and his team determined Mayr *E* parameters for over 300 electrophiles and within that range $s_E$ is sufficiently close to unity that it could be neglected. Mayr *N* parameters and nucleophile-specific parameters $s_N$ have been reported for over 1100 nucleophile/solvent combinations, with far more diversity than the electrophilic functional groups. These parameters are readily available,[343] yet for chemists looking for the nucleophilicity of a free alkyl anion, an amide oxygen, or a carbon-carbon bond, the necessary Mayr $N$ and $s_N$ parameters seem far out of reach.

The first part of this chapter described the use of methyl anion affinity (MAA*), calculated with a continuum solvation model, to predict log scale electrophilicity (E*) consistent with the Mayr scale. Based on the readily calculated MAA* values, we were able to estimate a range of electrophilicities for functional groups ranging from a C-C bond to a CN cation, spanning 180 orders of magnitude. The success of this correlation invites a similar exploration of the relationship between methyl cation affinities and nucleophilicity.

**Does Methyl Cation Affinity Correlate with Nucleophilic Addition Rates?** Methyl cation affinities (MCAs) are related to methyl transfer affinities introduced by Hine and Weimar in 1965.[344] MCAs have been shown to give good correlation with nucleophilicity. In 1983, Pellerite and Brauman correlated the methyl cation affinities of eight anionic nucleophiles ($Br^-$, $Cl^-$, $AcO^-$, $CD_3S^-$, $t$-$BuO^-$, $MeO^-$, $HCC^-$) with the intrinsic barriers for $S_N2$ displacement of methyl halides in the gas phase.[345] Calculated MCAs[346,347] have been tabulated for organocatalysts within narrow ranges of nucleophilic functional groups: substituted phosphines[348], amines and 4-aminopyridines,[349] and sterically hindered pyridines.[350]

When MCA is defined as the negative of the free energy change for reaction of $H_3C^+$ with nucleophiles, higher affinity correlates intuitively with higher energy and higher kinetic nucleophilicity (Figure 5-8A). Attempts have been made to correlate calculated MCAs for nucleophilic organocatalysis with rate constants (Figure 5-8B). In 2008, Zipse and coworkers showed that calculated methyl cation affinities of pyridine derivatives correlate with the log *k* for Steglich acylations, where addition of the amine to the carbonyl is rate-determining.[351] They also showed that calculated MCAs of pyridines, tertiary amines, amidines, and phosphine organocatalysts correlate well with log $k_{obs}$ in Baylis-Hillman reactions. However, it is worth noting that in the Baylis-Hillman reaction, the reversible[352] nucleophilic addition of the amine catalyst to the enone is a thermodynamic phenomenon, like MCA, and not a kinetic effect like a rate-determining irreversible addition of an amine to an electrophile.[353]

**Figure 5-8**: Broad Correlation of MCA with log-Scale Nucleophilicity Never Seemed Promising.

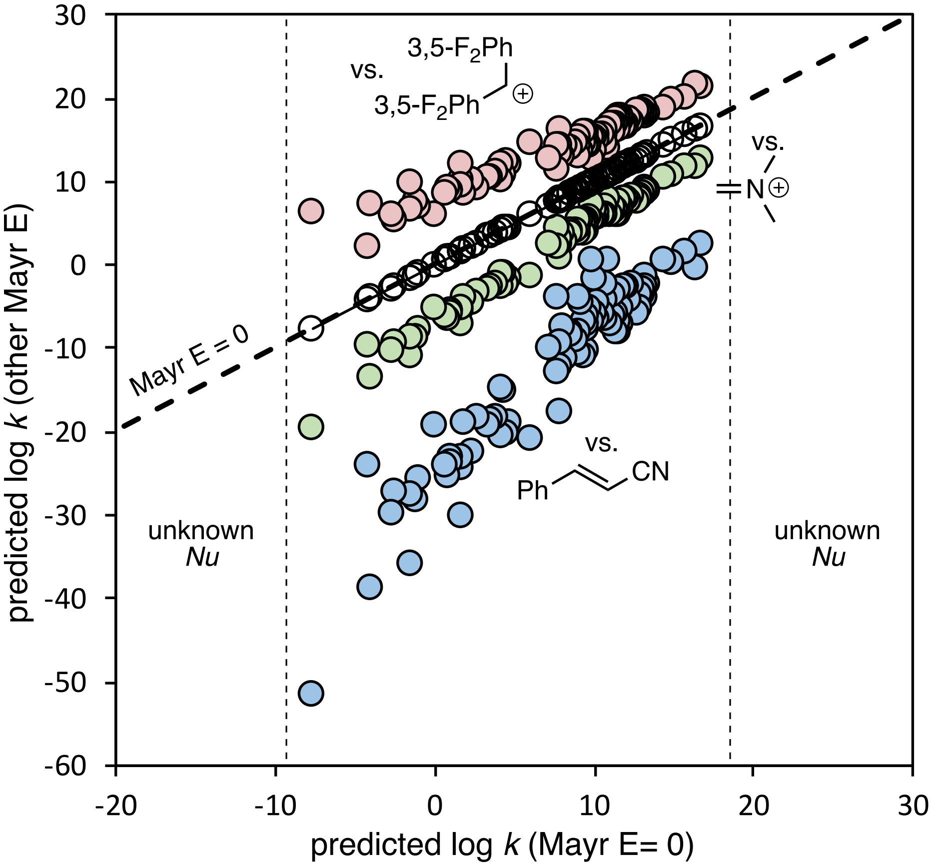


For p-quinone methide electrophiles it was shown that MCAs seem to correlate with the log $k_{rel}$ for reactions catalyzed by N-heterocyclic carbenes[354,355] but not with the log $k_{rel}$ of the sterically diverse nucleophiles DBU, DABCO, 4-DMAP and triphenylphosphine.[356,357] Taken together, there seems to be good correlation between MCAs and log *k* for each class of nucleophiles as long as the electrophile is similar, but there is poor correlation across different classes of nucleophiles (Figure 5-8B).

**How Does One Choose a Reference Scale for Nucleophilicity?** There is no such thing as a nucleophilicity scale because relative and absolute nucleophilicities are dependent on the electrophile (Figure 5-9). Mayr has previously noted the existence of a nucleophilicity scale versus an electrophile with $E$ = 0 (for the bis-4-methoxyphenylmethl cation) where the Mayr equation simplifies to log $k_{20}$ = $N \bullet s_N$ = $Nu$[358] Mayr notes the superiority of a floating scale that varies with each electrophile for accurate calculation of log $k$. Strict adherence to experimental $N$, $s_N$, and $E$ parameters imposes limitations on the range of measurable nucleophilicities. It is challenging to determine nucleophilicity parameters for nucleophiles less reactive than solvent; ironically, it is also challenging to determine nucleophilicity parameters for highly reactive nucleophiles, which must be paired with electrophiles that tend to be less reactive than solvent. These challenges have been well met by Mayr and his dedicated team, yet we still seem far from knowing the nucleophilicity of highly reactive methyl anions or highly unreactive nucleophiles such as nitrogen gas.

If nucleophilicity were *independent* of electrophile then a plot of log $k$ against one electrophile versus log $k$ against another nucleophile would be linear. That's not the case for log $k$ values predicted from the Mayr equation which deviate from linearity (Figure 5-9). However, the correlation is sufficiently linear that, if one quantified nucleophilicity ($Nu$) versus the Mayr cation, it could provide insight into the relative nucleophilicity versus other electrophiles – a strategy employed with p$\boldsymbol{K}_a$s (Figure 5-7). We set out to estimate the nucleophilicities of the canonical organic nucleophiles (*Nu*) on the Mayr scale versus E=0 using methyl cation affinity.

**Figure 5-9**: Nucleophilicity against the Mayr cation $(4\text{-MeOPh})_2CH+$ correlates loosely with the nucleophilicity against other electrophiles, ranging from the most reactive electrophile characterized (3,3',5,5'-tetrafluoro-benzhydryl cation, Mayr *E* = +8), to a rather average electrophile (*N*,*N*-dimethyliminium, Mayr E = -7) to the least reactive electrophile characterized (*E*-cinnamonitrile, Mayr *E* = -25)

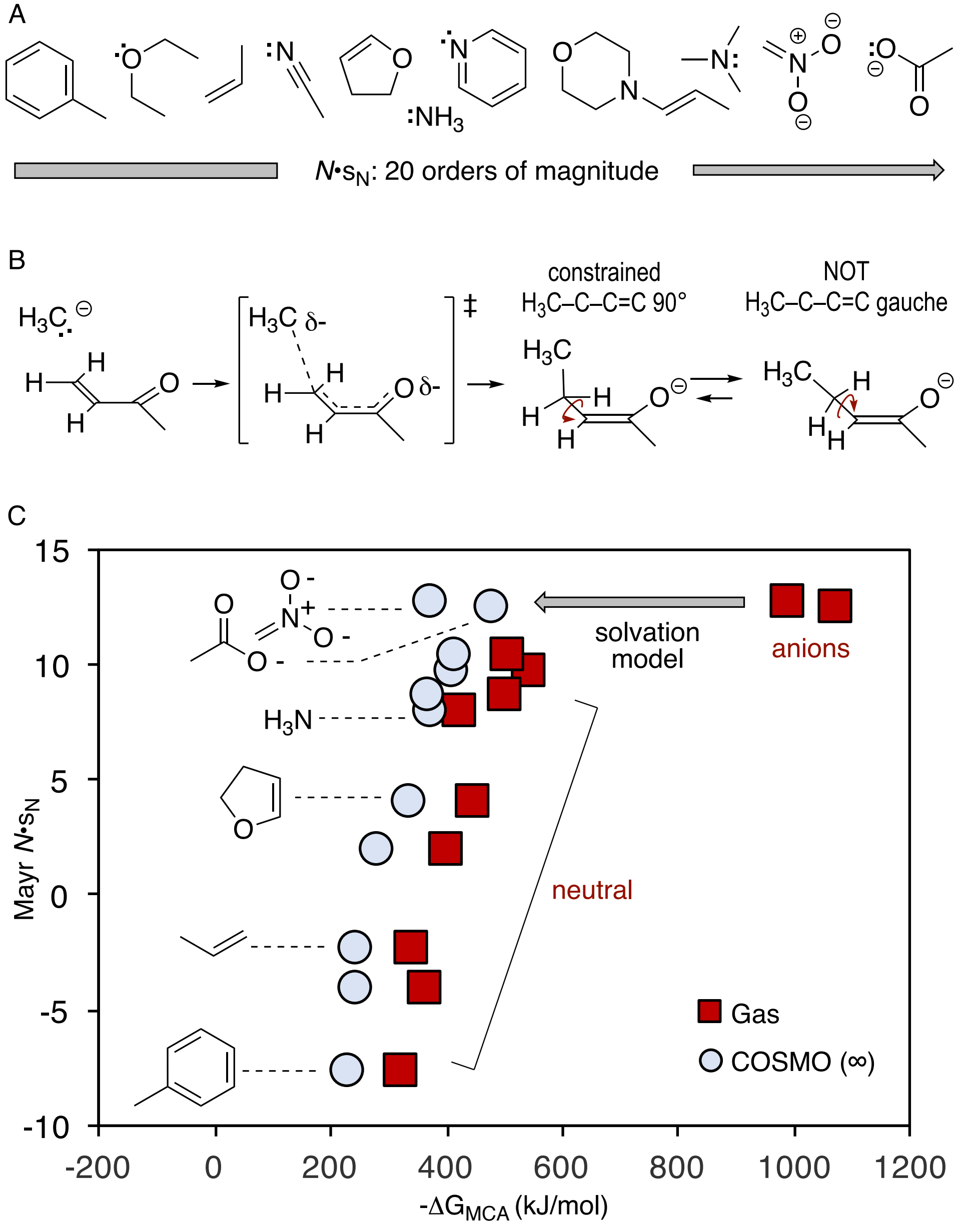


**Why Choose Methyl Cation Affinity to Estimate Nucleophilicity toward a Benzhydryl Cation (E=0)?** Methyl cation affinity has four advantages over benzhydryl cation affinity: i) computational economy, ii) minimization of entropic effects, iii) minimization of steric effects, iv) high reactivity. Firstly, in addition to the obvious computational economy resulting from smaller species, a methyl group has three fewer degrees of freedom than a benzhydryl group, faciliting the calculation of entropies. Thirdly methyl cation is small and steric effects can easily dominate over the inherent nucleophilicity of a functional group.[359] Finally, for a highly reactive electrophile like the methyl cation, the enthalpic barriers are negligible for nucleophilic addition. In this work we show that methyl cation affinity is a predictor of nucleophilicity, minimizing steric effects, on the Mayr scale for which Mayr E is 0.

### Nucleophilicity Results and Discussion

**Solvation Models are Essential for Correlation of MCA with Mayr N•$s_N$.** In our previous work we showed that PBE0(disp)/def2-TZVP COSMO(∞) gave the same or slightly better correlation between calculated methyl anion affinity (MAA) and Mayr E compared to B3LYP/6-311++G(3df,2pd) SMD(DMSO). Similarly, in this work, we chose a test set of eleven different nucleophiles spanning 20 orders of magnitude in nucleophilicity in $N$•$s_N$. MCAs calculated with the PBE0 and B3LYP methods gave equally strong correlations with the experimental nucleophilicities (SMD $R^2 = 0.875$, COSMO $R^2 = 0.873$), so all further work was carried out with the faster PBE0 method (Figure 5-10). We define MCA* as a methyl anion affinity ($-\Delta G_{MCA}$) calculated with a solvation model in order to distinguish it from the traditional notion of a gas phase methyl cation affinity (MCA).

**Figure 5-10**: The Test Set. (A) Test set of electrophiles for which Mayr has reported experimental E parameters. Arrows show sites of attack. (B) MCAs were calculated by restricting products to transition state-like geometries. (C) A solvation models leads to correlation of MCA with Mayr *N*•$s_N$.

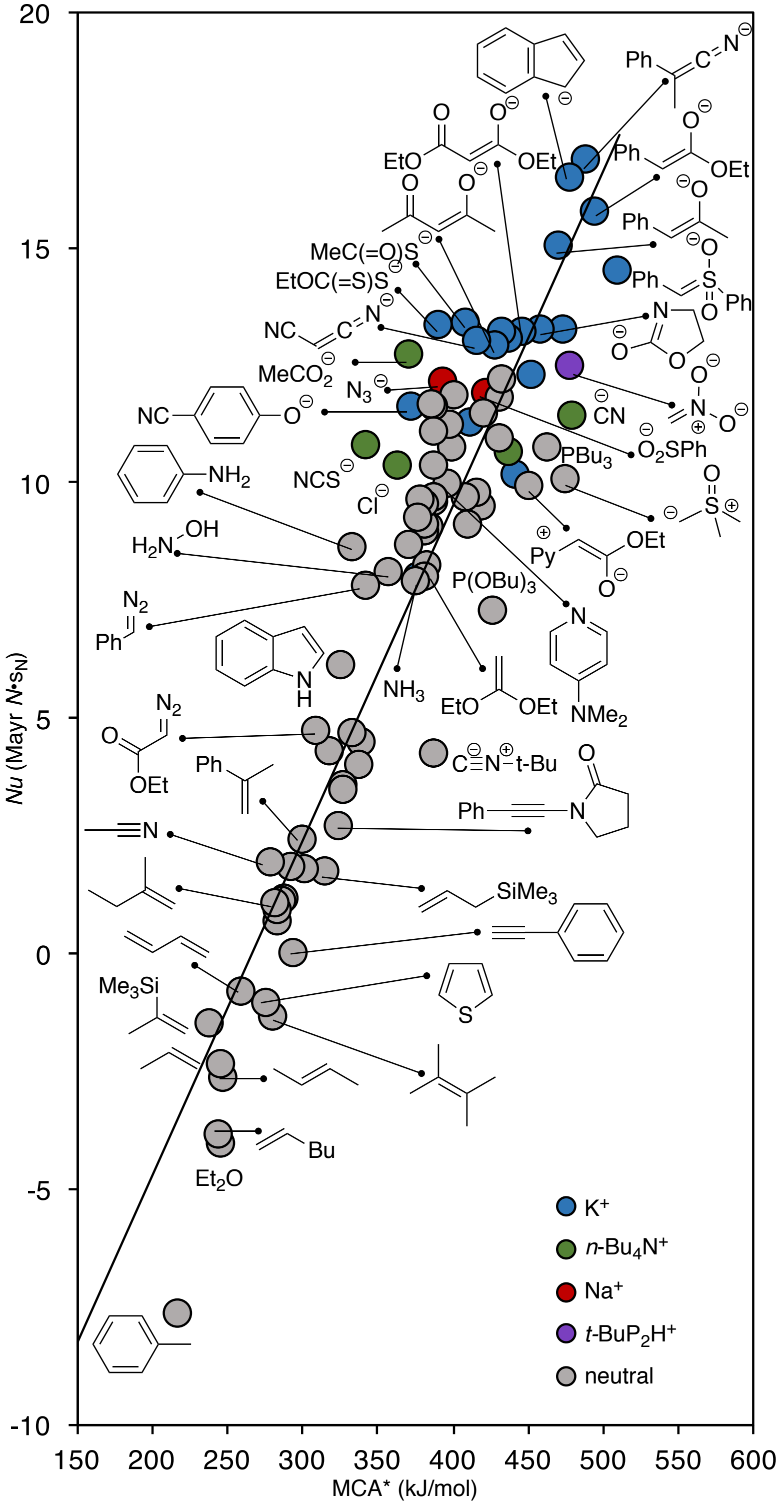


**The Correlations Between MCA* and Nucleophilicity (Mayr *N*•$s_N$).** Having shown that MCA*s correlate well with the *N*•$s_N$ term in the Mayr equation for the test set of eleven nucleophiles, we set out to extend that analysis to a much fuller set of structurally diverse nucleophiles. To date, Mayr and Ofial, have reported Mayr N and $s_N$ parameters for over

1100 different nucleophile/solvent combinations – a much broader range of functional groups than the corresponding electrophiles. There is substantial redundancy in the set of measured nucleophiles (e.g., 73 aliphatic amines); they include molecules from over 60 general classes of functional groups.[360] These functional groups include: i) non-bonding lone pairs: alkoxides, alcohols, ethers, carboxylates, peroxy anions, oxyhalites, amines, anilines, imines, azoles, hydrazines, hydroxylamines, pyridines, azide, nitrile, amidines and isothioureas, guanidines, cyanate anion, nitrite anion, sulfonyl carbanions, sulfonium ylides, sulfoxonium ylides, phosphorous ylides, N-heterocyclic carbenes, cyanide anion, isonitriles, thiolates, thiocyanate, sulfinate, thioacetate, xanthate, sulfite anion, phosphines, phosphites, halide anions; ii) π orbitals: alkenes, dienes, styrene, allylsilanes and related allylmetal species, vinylsilanes, arylboronates, benzenes, aromatic heterocycles, subsituted enolates, stabilized enolates, enamines, enol ethers, *benzylic anions*, acetonitrile anion, organometallic complexes, nitronate anions, diazoalkanes, amide anions, carbamate anions, imide anions, alkynes, ynamides; and iii) σ orbitals: hydridoborates, hydridosilanes and related compounds, diazaphospholenium hydrides, alkylboronates, C-H bonds (in allylic, benzylic, alkoxyalkyl, beta-metallo compounds), and transition metal hydrides.

We selected 93 molecules from the Mayr-Ofial database encompassing the entire range of nucleophilicities, from the least reactive nucleophile toluene ($N \bullet s_N$ = -7.7) to the most reactive nucleophile Ph(NC)MeCK ($N \bullet s_N$ = 16.8). An attempt was made to capture as many of the common functional groups as possible but we excluded most of the inorganic anions, phosphonium ylides, and organometallic complexes. Where possible, we avoided parameters determined in protic solvents in order to minimize the effects of solvent re-organization that would require the inclusion of explicit solvent molecules in the MCA calculations. Where possible, we also tried to avoid parameters associated with sterically demanding nucleophiles. The MCA calculations were meant to quantify the typical depictions of nucleophiles without explicit solvent interactions and without the effects of sterics. For this work, we avoided sigma donors in order to avoid issues of translational entropy arising from transformations that generate two products instead of one. MCA*s calculated for these nucleophiles were found to **correlate linearly with the Mayr nucleophilicity term $N \bullet s_N$** with a looser fit for the more reactive anionic nucleophiles (Figure 5-11).

**Figure 5-11**: The line. There is good correlation between calculated MCA* (PBE0/def2-TZVP COSMO(∞)) and Mayr N•$s_N$ parameter across a broad range of organic nucleophiles.



**Some Deviations from the MCA*-N•$s_N$ Line Suggest a Deviation from Typical Depictions.** The most dramatic outliers, between three and six orders of magnitude off the line, include: inorganic anions, $N^+$–$C^-$ ylides, select enolate anions, phenolate, anilines, and third-row nucleophiles.

Parameters for the many of the anionic nucleophiles were determined in the presence of $K^+$ (blue), sometimes in the presence of 18-crown-6, *n*-$Bu_4N^+$ (green) or $Na^+$ (red) salts. In contrast, calculations were performed on structures without counter ions, as is commonly depicted. Arnett and coworkers established that stabilized enolates in DMSO react 26,000 times more slowly when paired with $Na^+$, 600 times more slowly when paired with $K^+$ and 1,100 times more slowly when paired with the non-coordinating counterion *n*-$Bu_4N^+$.[361] These types of counterion effects are expected to lead to lower $N$•$s_N$ than expected from MCA* for the naked anions.

In many cases, highly nucleophilic anions were generated with *t*-BuOK in situ. If the *t*-BuOH by-product hydrogen bonds to the nucleophile, then the measured $N$•$s_N$ could be lower than expected from MCA* if explicit interactions with solvent are not accounted for by the solvation model.

Intrinsic barriers take into account a number of kinetic phenomena including counterion effects, solvent reorganization and geometric deformation. MCA* is intended to quantify the inherent nucleophilicity of canonical functional groups based on typical depictions without solvent molecules and without stabilizing counterions. MCA* captures the deformation that occurs in the nucleophilic addition to an $sp^2$ center to form an $sp^3$ center; but the deformation that occurs at the point of attack in an $S_N2$ process, from $sp^3$ in the reactant to $sp^2$ in the transition state and back to $sp^3$ in the product, will not be captured by ground state concepts such as methyl cation affinity nor methyl anion affinity.

The measured nucleophilicity ($N$•$s_N$) of one of the three alpha-pyridinium enolates (Py+CH=C(O-)OEt) was significantly lower than expected based on MCA*. As alluded to by Mayr and coworkers, it is possible that this ylide undergoes [3+2] cycloaddition through a concerted rather stepwise mechanism.[362]

Aniline and p-cyanophenolate anion were 3.7 and 3.5 orders of magnitude more nucleophilic than expected from the MCA*. It is tempting to speculate that the higher than expected solution phase nucleophilicity of these aromatic nucleophiles toward benzhydryl cations and related electrophiles[363,364] might be attributable to pi interactions.[365] Methyl cation affinity is not expected to recapitulate effects of this type.

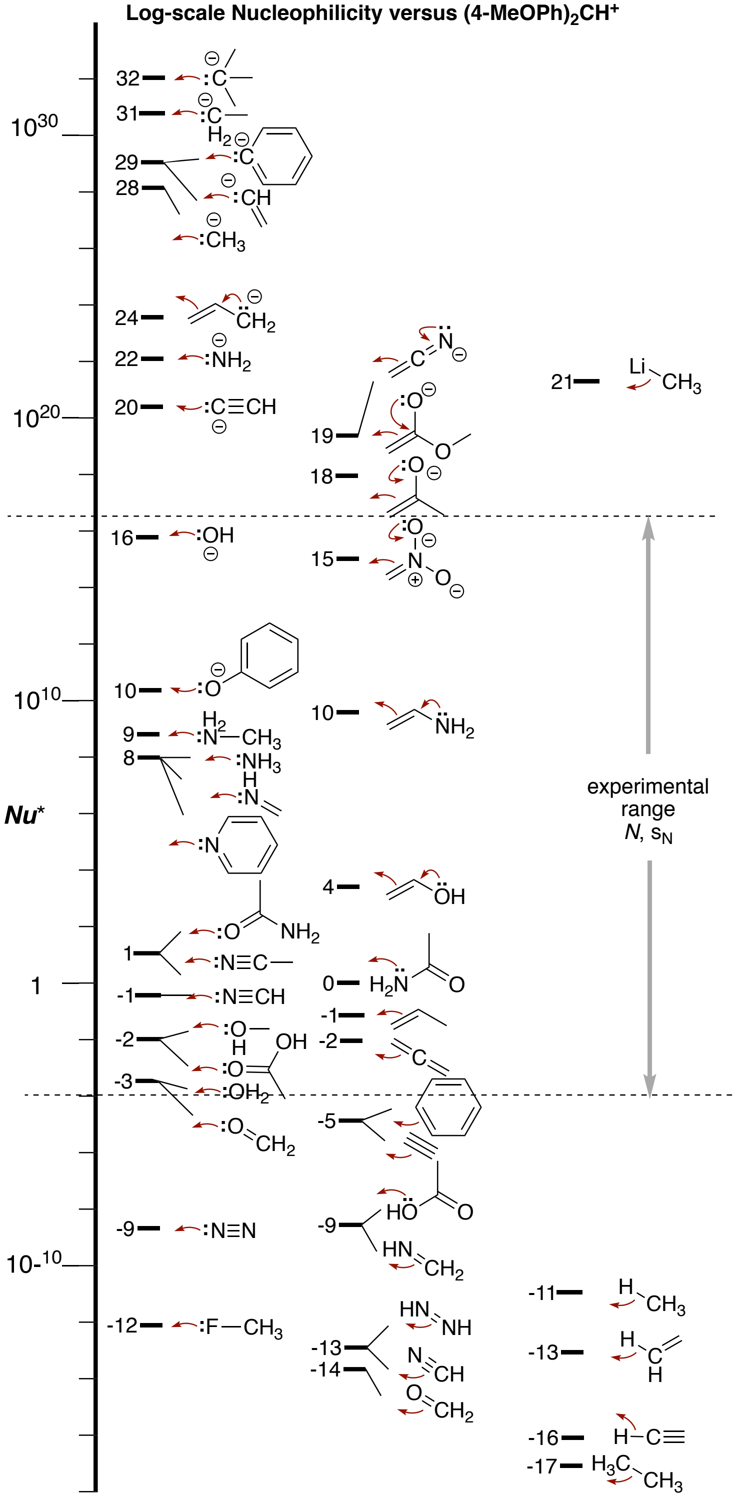
**Some Deviations from the MCA*-*N*•*s*$_N$ Line May Result from a Weakness with Chosen Level of Theory**. The inclusion of dispersion correction greatly improves the correlation between MCA* and $N$•$s_N$ for nucleophiles with third-row atoms. However, MCA* for tri-*n*-butylphosphine and tri-*n*-butylphosphite were about 60 kJ/mol higher than expected based on $N$•$s_N$. Conversely, the MCA*s for anionic sulfur nucleophiles (thioacetate, ethyl xanthate, isothiocyanate) were 29 to 64 kJ/mol higher than expected from the measured nucleophilicities.

Phosphine nucleophiles, but not phosphonium products, were well represented in the SMD training and the calculated MCA* values turned out to be *higher* than expected. Thiother products but not thiolate nucleophiles were represented in the SMD training set and the calculated MCA* values turned out to be *lower* than expected.

It is notable that the MCA* for the *sp*-hybridized carbon nucleophiles cyanide and *t*-butyl isonitrile are both about 60 kJ/mol higher than expected from the measure $N \bullet s_N$. However, the values for acetonitrile were in good agreement. It isn't clear if deviations associated with third-row or sp-hybridized nucleophiles are associated with dispersion effects, gaps in the proprietary COSMO training set or some other aspect of the calculations.[366] Undoubtedly, electronic structure calculations and solvation models will continue to evolve in speed and accuracy.

**Quantifying the Reactivity of the Canonical Nucleophiles on the Mayr Scale**. Since MCA* (PBE0/def2-TZVP COSMO(∞)) correlates linearly *Nu**, we set out to use that correlation to estimate the full range of log-scale nucleophilicities of the canonical functional groups in organic chemistry. To the extent that methyl cation affinity, calculated with solvation, correlates linearly with solution phase reactivity we begin to see the range of nucleophilicity of the canonical organic functional groups referenced to the Mayr cation, a range covering 49 orders of magnitude – more than twice the log-scale range of $N \bullet s_N$ determined experimentally (Figure 5-12).

**Figure 5-12**: Log-scale nucleophilicities versus the Mayr cation calculated assuming a linear correlation between *Nu** and MCA*



***Nu** = MCA* · 0.0705 – 18.617**

MCA* calculated at PBE0 (dis)/def2-TZVP COSMO(∞)

**Accuracy and Relevance of Nucleophilicity Quantified by Nu***. Mayr *E*, *N* and $s_N$ parameters can be used to predict solution phase rate constants for any combinations of electrophiles and nucleophiles within ±2 orders of magnitude. The nucleophilicity *Nu** corresponds to the log scale nucleophilicity against just one electrophile, the Mayr cation. As shown in Figure 5-9, the relative nucleophilicity is expected to change from one electrophile to another, but the rank order of nucleophilicity is expected to be relatively constant. If the linearity holds and the distribution is normal, then the scale of nucleophilicity versus the Mayr cation, from $H_3C—CH_3$ to t-Bu$^-$ would range from *Nu** of -17 (±3) to +32 (±3) at a 95% confidence level.

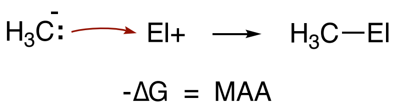
## Nucelophilicity Conclusion

The linear correlation of MCA* with experimental *Nu* allows one to contrast the simple arrow-pushing mechanisms depicted in textbooks with the true mechanisms in solution. Using MCA* we are able to estimate the log scale nucleophilicitiy (Nu*) of the canonical organic funcitonal groups, covering 49 orders of magnitude. More such experimental determinations of Mayr *N* and $s_N$ parameters are needed to better appreciate the differences between depiction and reality.

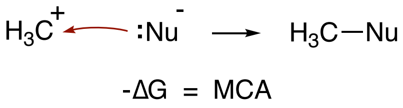
## Computational Details and Methods

### General Methods

Methyl anion affinities were calculated as the difference in negative free energy between products and reactants. In this chapter, MAA is used for methyl anion affinities in the gas phase and MAA* is used for methyl anion affinities with a solvation model.



Methyl Cation affinities were calculated as the difference in negative free energy between products and reactants. In this chapter, MCA is used for methyl cation affinities in the gas phase and MCA* is used for methyl cation affinities with a solvation model.



Unless otherwise stated, reactants and products were calculated in the most stable ground state conformations. Some products were restricted to reactant-like conformations using torsional constraints as described for each entry. For unstable adducts of acetic anhydride and acetyl chloride, the bond between the attacked carbon atom and the leaving group was constrained to a covalent distance as described for each entry.

Calculations of all molecules in the gas phase or with the COSMO Solvation model[367,368] were run using either Turbomole V7.2 or Turbomole V7.3[369] using Tmolex as the graphical user interface. Unless otherwise stated COSMO solvation was implemented using the default parameters with e = Infinity. Calculations with the Free energies of molecules run in Turbomole were determined by using the equation G = H - TS at 298.15 K. Entropy was determined from frequency calculations as were enthalpy corrections to total energies. SCF and geometry optimization energy criteria were set at either $10^{-6}$ or $10^{-7}$ hartree.

Calculations with the SMD[370] solvation model were run using the Aug 18, 2016 version of GAMESS using the default PCM parameters for SMD with SOLVNT=DMSO.[371,372] Free energies of molecules run in GAMESS were determined by adding free energy corrections determined from frequency calculations to the total energies. Four different levels of theory were used in this work: B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p), B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p), B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p), and PBE0(disp)/def2-TZVP COSMO (∞).[373]

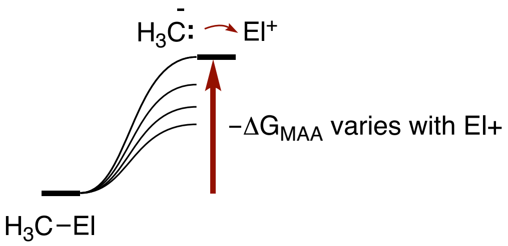
## Comparison of Computational Time for Different Levels of Theory

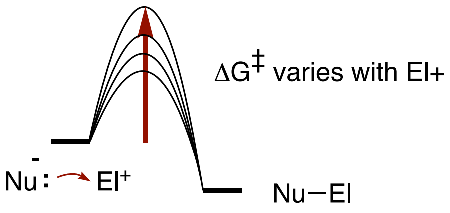
Computation times were compared for PBE0 (disp)/def2-TZVP COSMO(∞) and B3LYP/6-311++G(3df,2dp) COSMO(∞). For, $CH_3^-$, $Me_2N{=}CH_2^+$, 2-pentanone, cumyl$^+$, *t*-butylbenzene, $Ph_2CH^+$, $Ph_2CHCH_3$: PBE0 (disp)/def2-TZVP COSMO(∞) was about 4 times faster than B3LYP/6-311++G(3df,2dp) COSMO(∞) using Turbomol on a 2013 Macbook Pro.

## Derivation of $s_n$ for Methyl Anion

The slope of MAA* vs. Mayr E may be Inversely related to $s_N$ for a Methyl Anion

If $-\Delta G_{MAA}$ and $-\Delta G^\ddagger$ exhibit a similar variation with respect to electrophiles "El+":





From transition state theory,

$$k = \frac{k_B T}{h} e^{\frac{-\Delta G^\ddagger}{RT}}$$

$$\log k = \frac{1}{2.303} \ln \frac{k_B T}{h} - \frac{\Delta G^\ddagger}{2.303\ RT}$$

From the Mayr equation,

E = electrophilicity parameter
N = nucleophilicity parameter for $CH_3^-$
$s_N$ = nucleophile-specific parameter for $CH_3^-$

$$\log k \;=\; (E + N)\, s_N$$

$$E \;=\; \frac{1}{s_N} \log k \;-\; N$$

Substituting log *k* from transition state theory and rearranging yields the anticipated linear relationship:

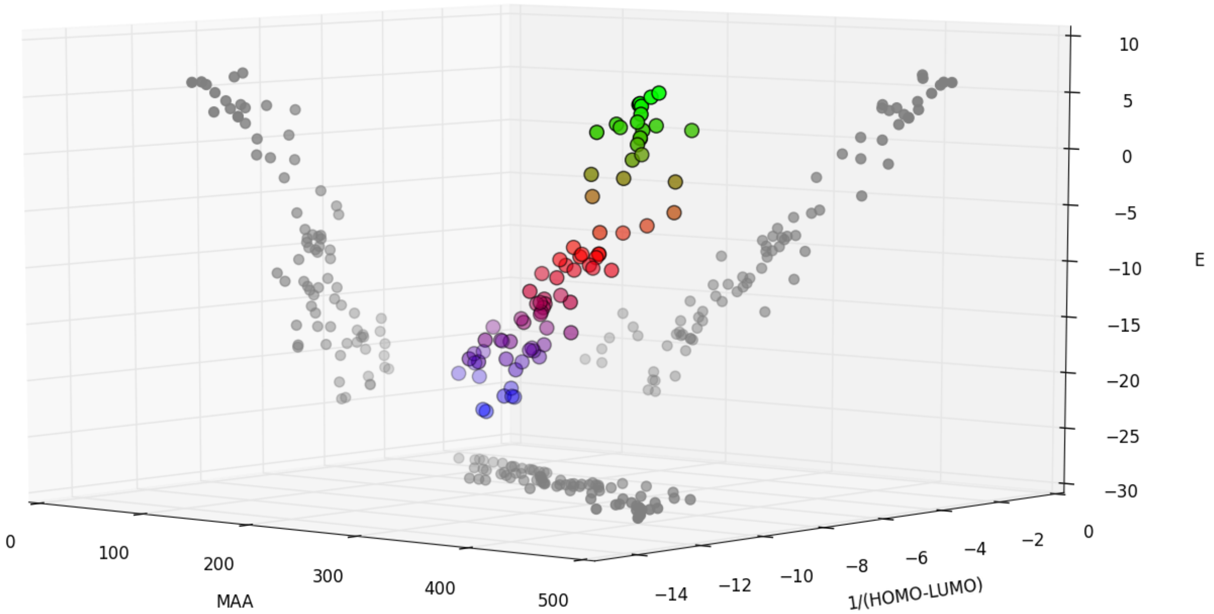
$$E \;=\; \frac{1}{s_N}\left[\frac{1}{2.303} \ln \frac{k_B T}{h} - \frac{\Delta G^{\ddagger}}{2.303\ RT}\right] - N$$

$$E \;=\; \underbrace{\frac{-1}{2.303\ RT \cdot s_N}}_{\text{slope}}\ \underbrace{\Delta G^{\ddagger}}_{\text{-MAA*}} \quad + \quad \underbrace{\left[\frac{1}{s_N} \ln \frac{k_B T}{h} - N\right]}_{\text{intercept}}$$

To the extent that Methyl Anion Affinity correlates linearly with Mayr E, a plot of Mayr E vs. MAA* ($-\Delta G_{MAA}$) should generate a line with a slope $(2.303RT \bullet s_N)^{-1}$ where $s_N$ is the nucleophile-specific parameter for $CH_3^-$. Note that the Mayr equation is parameterized for $k_{20°C}$ whereas the calculate MAA*s in this manuscript are $\Delta G_{298}$.

## Mayr E. vs. MAA vs. 1/(HOMO-LUMO) 3D Graph

**Figure 5-13**: Mayr E. vs. MAA vs. 1/(HOMO-LUMO) 3D Graph. The HOMO-LUMO interaction offers some predictive power for electrophilicity but the correlation with Mayr E is not as tight and the plot is curved for highly reactive electrophiles. A multiple linear regression analysis including a term for $1/(E_{HOMO}-E_{LUMO})$ did not lead to a better correlation using the HOMO energy for a typical nucleophile, methylamine -6.8 eV.



## Tables of MAA, MAA*, Experimental E, and E* and MCA, MCA*, Experimental *Nu*, and *Nu**.

**Table 5-1**: MAA and E Values Calculated at the B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) Level of Theory

| Compound | SMILES | MAA (kJ/mol) | Mayr E |
|---|---|---|---|
| 2-Phenylpropan-2-ylium | C[C+](C)C1=CC=CC=C1 | 825.9 | 5.74 |
| Diphenylmethylium | C1([CH+]C2=CC=CC=C2)=CC=CC=C1 | 824.4 | 5.47 |
| (E)-Benzylidene(methyl)oxonium | C/[O+]=C/C1=CC=CC=C1 | 802.3 | 2.97 |
| Cyclohepta-2,4,6-trien-1-ylium | C1=C[CH+]C=CC=C1 | 753.3 | -3.72 |
| N-Methyl-N-methylenemethanaminium | C=[N+](C)C | 786.2 | -6.69 |
| Furan-2,5-dione | O=C(O1)C=CC1=O | 262.3 | -11.31 |
| But-3-en-2-one | C=CC(C)=O | 224.5 | -16.76 |
| Acrylonitrile | C=CC#N | 206.1 | -19.05 |
| Butyraldehyde | O=CCCC | 146.2 | -18.7 |
| Pentan-2-one | O=C(C)CCC | 116.1 | -22.3 |

### **Table 5-2**: MAA* and E Values Calculated at the B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) Level of Theory

| Compound | SMILES | MAA* (kJ/mol) | Mayr E |
|---|---|---|---|
| 2-Phenylpropan-2-ylium | C[C+](C)C1=CC=CC=C1 | 325.4 | 5.74 |
| Diphenylmethylium | C1([CH+]C2=CC=CC=C2)=CC=CC=C1 | 352.0 | 5.47 |
| (E)-Benzylidene(methyl)oxonium | C/[O+]=C/C1=CC=CC=C1 | 309.1 | 2.97 |
| Cyclohepta-2,4,6-trien-1-ylium | C1=C[CH+]C=CC=C1 | 236.0 | -3.72 |
| N-Methyl-N-methylenemethanaminium | C=[N+](C)C | 240.7 | -6.69 |
| Furan-2,5-dione | O=C(O1)C=CC1=O | 206.9 | -11.31 |
| But-3-en-2-one | C=CC(C)=O | 151.3 | -16.76 |
| Acrylonitrile | C=CC#N | 128.8 | -19.05 |
| Butyraldehyde | O=CCCC | 88.9 | -18.7 |
| Pentan-2-one | O=C(C)CCC | 51.9 | -22.3 |

### **Table 5-3:** MAA* and E Values Calculated at the B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) Level of Theory

| Compound | SMILES | MAA* (kJ/mol) | Mayr E |
|---|---|---|---|
| 2-Phenylpropan-2-ylium | C[C+](C)C1=CC=CC=C1 | 351.6 | 5.74 |
| Diphenylmethylium | C1([CH+]C2=CC=CC=C2)=CC=CC=C1 | 363.4 | 5.47 |
| (E)-Benzylidene(methyl)oxonium | C/[O+]=C/C1=CC=CC=C1 | 323.3 | 2.97 |
| Cyclohepta-2,4,6-trien-1-ylium | C1=C[CH+]C=CC=C1 | 253.1 | -3.72 |
| N-Methyl-N-methylenemethanaminium | C=[N+](C)C | 263.1 | -6.69 |
| Furan-2,5-dione | O=C(O1)C=CC1=O | 188.0 | -11.31 |
| But-3-en-2-one | C=CC(C)=O | 137.1 | -16.76 |
| Acrylonitrile | C=CC#N | 136.9 | -19.05 |
| Butyraldehyde | O=CCCC | 62.2 | -18.7 |
| Pentan-2-one | O=C(C)CCC | 24.9 | -22.3 |

### **Table 5-4:** MAA* and E Values Calculated at the PBE0(disp)/def2-TZVP COSMO (∞) Level of Theory

| Compound | SMILES | MAA (kJ/mol) | Mayr E |
|---|---|---|---|
| Bis(4-chlorophenyl)methylium | ClC1=CC=C([CH+]C2=CC=C(Cl)C=C2)C=C1 | 414.1 | 5.48 |
| Diphenylmethylium | C1([CH+]C2=CC=CC=C2)=CC=CC=C1 | 406.7 | 5.47 |
| (4-Fluorophenyl)(phenyl)methylium | FC1=CC=C([CH+]C2=CC=CC=C2)C=C1 | 403.8 | 5.20 |
| Phenyl(p-tolyl)methylium | CC1=CC=C([CH+]C2=CC=CC=C2)C=C1 | 396.0 | 4.43 |
| 2-Phenylpropan-2-ylium | C[C+](C)C1=CC=CC=C1 | 388.0 | 5.74 |
| 1-Mesitylethan-1-ylium | CC1=C([CH+]C)C(C)=CC(C)=C1 | 387.6 | 6.04 |
| (4-Phenoxyphenyl)(phenyl)methylium | C1(OC2=CC=CC=C2)=CC=C([CH+]C3=CC=CC=C3)C=C1 | 384.4 | 2.90 |
| Di-p-tolylmethylium | CC1=CC=C([CH+]C2=CC=C(C)C=C2)C=C1 | 383.5 | 3.63 |
| (4-Methoxyphenyl)(phenyl)methylium | COC1=CC=C([CH+]C2=CC=CC=C2)C=C1 | 375.6 | 2.11 |
| (4-Phenoxyphenyl)(p-tolyl)methylium | CC1=CC=C([CH+]C2=CC=C(OC3=CC=CC=C3)C=C2)C=C1 | 375.5 | 2.16 |
| 9-Ethylidene-9H-carbazol-9-ium | C/C=[N+]1C2=C(C=CC=C2)C3=C\1C=C | 371.3 | 2.41 |

|  |  |  |  |
|---|---|---|---|
|  | C=C3 |  |  |
| (4-Methoxyphenyl)(p-tolyl)methylium | COC1=CC=C([CH+]C2=CC=C(C)C=C2)C=C1 | 366.7 | 1.48 |
| (E)-Benzylidene(methyl)oxonium | C/[O+]=C/C1=CC=CC=C1 | 364.7 | 2.97 |
| (E)-1,3-Diphenylallylium | C1(/C=C/[CH+]C2=CC=CC=C2)=CC=CC=C1 | 357.9 | 2.70 |
| 1,3-Dithian-2-ylium | [CH+]1SCCCS1 | 357.6 | -2.14 |
| Bis(4-methoxyphenyl)methylium | COC1=CC=C([CH+]C2=CC=C(OC)C=C2)C=C1 | 351.9 | 0.00 |
| 1-(4-Chlorophenyl)cyclopent-2-en-1-ylium | ClC(C=C1)=CC=C1[C+]2CCC=C2 | 351.8 | 3.20 |
| 1-Phenylcyclopent-2-en-1-ylium | C1([C+]2C=CCC2)=CC=CC=C1 | 351.3 | 2.89 |
| N-Methyl-N-methylenebenzenaminium | C=[N+](C)C1=CC=CC=C1 | 333.6 | -5.17 |
| (Z)-3-Benzylidene-1-methyl-3H-indol-1-ium | C[N+]1=C/C(C2=C1C=CC=C2)=C\C3=CC=CC=C3 | 332.5 | -1.80 |
| (E)-(4-Methoxybenzylidene)(methyl)oxonium | C/[O+]=C/C1=CC=C(OC)C=C1 | 332.2 | 0.14 |
| (E)-1,3-Bis(4-methoxyphenyl)allylium | COC1=CC=C(/C=C/[CH+]C2=CC=C(OC)C=C2)C=C1 | 315.5 | -1.45 |
| N-Methyl-N-methylenemethanaminium | C=[N+](C)C | 295.0 | -6.69 |
| Cyclohepta-2,4,6-trien-1-ylium | C1=CC=C[CH+]C=C1 | 291.9 | -3.72 |
| Bis(4-(dimethylamino)phenyl)methylium | CN(C)C1=CC=C([CH+]C2=CC=C(N(C)C)C=C2)C=C1 | 287.6 | -7.02 |
| Diethyl (E)-diazene-1,2-dicarboxylate | O=C(OCC)/N=N/C(OCC)=O | 281.9 | -10.55 |
| 5-Benzylidene-2,2-dimethyl-1,3-dioxane-4,6-dione | O=C(OC(C)(C)O1)/C(C1=O)=C\C2=CC=CC=C2 | 273.0 | -9.15 |
| 1,3,5-Trinitrobenzene | O=[N+](C1=CC([N+]([O-])=O)=CC([N+]([O-])=O)=C1)[O-] | 271.8 | -13.19 |
| (Ethene-1,1-diyldisulfonyl)dibenzene | C=C(S(=O)(C1=CC=CC=C1)=O)S(=O)(C2=CC=CC=C2)=O | 271.0 | -7.50 |
| N-Benzylidene-N-methylmethanaminium | C/[N+](C)=C/C1=CC=CC=C1 | 265.1 | -9.27 |
| 1-Benzylidenepiperidin-1-ium | [N+]1(/CCCCC1)=C\C2=CC=CC=C2 | 262.5 | -9.60 |
| 2-(4-Methylbenzylidene)malononitrile | N#C/C(C#N)=C/C1=CC=CC=C1 | 260.1 | -9.42 |
| 5-(4-Methoxybenzylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione | O=C(OC(C)(C)O1)/C(C1=O)=C\C2=CC=C(OC)C=C2 | 257.9 | -10.28 |
| (E)-4-(3-Phenylallylidene)morpholin-4-ium | [N+]1(/CCOCC1)=C\C=C\C2=CC=CC=C2 | 256.1 | -8.60 |
| 1-Benzylidenepyrrolidin-1-ium | [N+]1(/CCCC1)=C\C2=CC=CC=C2 | 251.8 | -9.35 |
| N-(4-Methoxybenzylidene)-N-methylmethanaminium | C/[N+](C)=C/C1=CC=C(OC)C=C1 | 251.3 | -10.69 |
| Furan-2,5-dione | O=C(C=C1)OC1=O | 246.6 | -11.31 |
| (E)-1-(3-Phenylallylidene)piperidin-1-ium | [N+]1(/CCCCC1)=C\C=C\C2=CC=CC=C2 | 245.7 | -10.30 |
| 2-(4-Methoxybenzylidene)malononitrile | COC1=CC=C(/C=C(C#N)/C#N)C=C1 | 245.4 | -10.80 |
| 2,6-Dimethoxy-4-(4-methoxybenzylidene)cyclohexa-2,5-dien-1-one | O=C(C(OC)=C/1)C(OC)=CC1=C\C2=CC=C(OC)C=C2 | 244.8 | -16.38 |
| (E)-1-(3-Phenylallylidene)pyrrolidin-1-ium | [N+]1(/CCCC1)=C\C=C\C2=CC=CC=C2 | 242.1 | -9.80 |
| (E)-1-Nitro-4-(2-nitrovinyl)benzene | O=[N+](/C=C/C1=CC=C([N+]([O-])=O)C=C1)[O-] | 241.5 | -12.37 |
| (E)-1-Bromo-4-(2-nitrovinyl)benzene | BrC1=CC=C(/C=C/[N+]([O-])=O)C=C1 | 230.4 | -13.37 |
| (E)-(2-Nitrovinyl)benzene | O=[N+](/C=C/C1=CC=CC=C1)[O-] | 227.7 | -13.85 |
| (E)-1-Methyl-4-(2-nitrovinyl)benzene | CC1=CC=C(/C=C/[N+]([O-])=O)C=C1 | 224.1 | -14.23 |

| | | | |
|---|---|---|---|
| 2-(4-(Dimethylamino)benzylidene)malononitrile | CN(C)C1=CC=C(/C=C(C#N)/C#N)C=C1 | 223.7 | -13.30 |
| (E)-1-Methoxy-4-(2-nitrovinyl)benzene | COC1=CC=C(/C=C/[N+]([O-])=O)C=C1 | 218.5 | -14.70 |
| 1-Methyl-1H-pyrrole-2,5-dione | O=C(N1C)C=CC1=O | 210.0 | -14.07 |
| Fumaronitrile | N#C/C=C/C#N | 204.4 | -15.71 |
| (E)-N-Benzylidene-4-methylbenzenesulfonamide | CC1=CC=C(S(/N=C/C2=CC=CC=C2)(=O)=O)C=C1 | 203.5 | -11.50 |
| Benzoquinone | O=C(C=C1)C=CC1=O | 203.2 | -16.19 |
| 1-Phenylprop-2-en-1-one | C=CC(C1=CC=CC=C1)=O | 198.4 | -15.25 |
| tert-Butyl (E)-benzylidenecarbamate | O=C(OC(C)(C)C)/N=C/C1=CC=CC=C1 | 195.9 | -14.22 |
| But-3-en-2-one | C=CC(C)=O | 186.0 | -16.76 |
| (E)-4-(3-Oxo-3-phenylprop-1-en-1-yl)benzonitrile | O=C(C1=CC=CC=C1)/C=C/C2=CC=C(C#N)C=C2 | 185.9 | -17.64 |
| (E)-3-(4-Nitrophenyl)-1-phenylprop-2-en-1-one | O=C(C1=CC=CC=C1)/C=C/C2=CC=C([N+]([O-])=O)C=C2 | 182.2 | -17.33 |
| (Vinylsulfonyl)benzene | C=CS(=O)(C1=CC=CC=C1)=O | 180.8 | -18.36 |
| Diethyl maleate | O=C(/C=C\C(OCC)=O)OCC | 176.6 | -19.49 |
| (E)-4-(4-Nitrophenyl)but-3-en-2-one | CC(/C=C/C1=CC=C([N+]([O-])=O)C=C1)=O | 174.7 | -19.36 |
| (E)-Chalcone | O=C(C1=CC=CC=C1)/C=C/C2=CC=CC=C2 | 174.3 | -19.39 |
| (E)-N-Benzylidene-P,P-diphenylphosphinic amide | O=P(/N=C/C1=CC=CC=C1)(C2=CC=CC=C2)C3=CC=CC=C3 | 174.0 | -15.89 |
| Diethyl 2-benzylidenemalonate | O=C(/C(C(OCC)=O)=C\C1=CC=CC=C1)OCC | 169.9 | -20.55 |
| Acrylonitrile | C=CC#N | 167.2 | -19.05 |
| (E)-4-Methyl-1-(4-nitrophenyl)pent-1-en-3-one | O=C(C(C)C)/C=C/C1=CC=C([N+]([O-])=O)C=C1 | 165.6 | -19.17 |
| Diethyl fumarate | O=C(/C=C/C(OCC)=O)OCC | 165.0 | -17.79 |
| Methyl acrylate | C=CC(OC)=O | 163.9 | -18.84 |
| Ethyl acrylate | C=CC(OCC)=O | 161.0 | -19.07 |
| (E)-4-Phenylbut-3-en-2-one | CC(/C=C/C1=CC=CC=C1)=O | 160.0 | -23.01 |
| tert-Butyl acrylate | C=CC(OC(C)(C)C)=O | 152.2 | -20.22 |
| Cinnamonitrile | N#C/C=C/C1=CC=CC=C1 | 140.9 | -24.60 |
| Ethyl (E)-but-2-enoate | O=C(OCC)/C=C/C | 140.6 | -23.59 |
| Ethyl 3-methylbut-2-enoate | C=C(C)C(OCC)=O | 139.2 | -22.77 |
| N,N-Dimethylacrylamide | C=CC(N(C)C)=O | 138.3 | -23.54 |
| Ethyl cinnamate | O=C(OCC)/C=C/C1=CC=CC=C1 | 134.0 | -24.52 |
| Benzaldehyde | O=CC1=CC=CC=C1 | 123.9 | -19.5 |
| Butyraldehyde | CCCC=O | 119.3 | -18.7 |
| Cyclobutanone | O=C1CCC1 | 109.3 | -17.5 |
| Cyclohexanone | O=C1CCCCC1 | 96.3 | -19.9 |
| Pentan-2-one | CC(CCC)=O | 89.0 | -22.3 |
| Cyclopentanone | O=C1CCCC1 | 88.9 | -21.0 |
| Cycloheptanone | O=C1CCCCCC1 | 72.6 | -22.1 |

**Table 5-5:** MAA* and E* Values Calculated at the PBE0(disp)/def2-TZVP COSMO (∞) Level of Theory

| Compound | SMILES | MAA* (kJ/mol) | E* |
|---|---|---|---|
| Ammoniaylidynemethylium | N#[C+] | 1372.9 | 110.7 |

| | | | |
|---|---|---|---|
| Ethylium | C#[C+] | 1157.3 | 87.4 |
| Methylium | [CH3+] | 670.1 | 34.8 |
| Vinyl cation | C=[CH+] | 631.4 | 30.6 |
| Prop-2-yn-1-ylium | C#C[CH2+] | 568.0 | 23.7 |
| Ethyl cation | C[CH2+] | 539.1 | 20.6 |
| Ethyl cation (bridged) | C1C[H+]1 | 518.4 | 18.4 |
| Protonated oxirane | [OH+]1CC1 | 497.7 | 16.1 |
| Allylium | C=C[CH2+] | 492.7 | 15.6 |
| Oxygen (singlet) | O=O | 489.0 | 15.2 |
| Phenylmethylium | [CH2+]C1=CC=CC=C1 | 470.4 | 13.2 |
| Propan-2-ylium | C[CH+]C | 458.4 | 11.9 |
| Methyleneoxonium | [OH+]=C | 446.9 | 10.7 |
| 2-Methylpropan-2-ylium | C[C+](C)C | 404.4 | 6.1 |
| Protonated acetaldehyde | CC=[OH+] | 386.1 | 4.1 |
| Carbene | [CH2] | 382.6 | 3.7 |
| Methaniminium | C=[NH2+] | 323.3 | -2.7 |
| N-Methyl-N-methylenemethanaminium | C=[N+](C)C | 295.1 | -5.7 |
| Borane | [H]B([H])[H] | 285.5 | -6.8 |
| Methanediazonium | N#[N+]C | 273.0 | -8.1 |
| Oxirane | O1CC1 | 232.2 | -12.5 |
| Ethenone | C=C=O | 217.2 | -14.1 |
| Carbon dioxide | O=C=O | 208.8 | -15.1 |
| Isocyanatomethane | CN=C=O | 189.3 | -17.2 |
| But-3-en-2-one | C=CC(C)=O | 186.0 | -17.5 |
| Acetyl chloride | CC(Cl)=O | 164.0 | -19.9 |
| Formaldehyde | O=C | 161.0 | -20.2 |
| Ethyne | C#C | 126.7 | -23.9 |
| Acetic anhydride | CC(OC(C)=O)=O | 124.2 | -24.2 |
| Acetaldehyde | CC=O | 123.0 | -24.3 |
| Propyne | C#CC | 105.6 | -26.2 |
| Dimethyl carbonate | O=C(OC)OC | 94.2 | -27.4 |
| Propan-2-one | O=C(C)C | 93.1 | -27.5 |
| Hydrogen cyanide | N#C | 81.5 | -28.8 |
| Diazene | [H]/N=N\[H] | 78.7 | -29.1 |
| Methyl acetate | CC(OC)=O | 78.4 | -29.1 |
| Methanimine | C=N | 74.6 | -29.5 |
| Methyl methylcarbamate | O=C(OC)NC | 37.8 | -33.5 |
| Acetonitrile | N#CC | 37.2 | -33.6 |
| Carbon monoxide | [C-]#[O+] | 32.8 | -34.1 |
| N-Methylacetamide | O=C(C)NC | 28.5 | -34.5 |
| Ethene | C=C | 28.3 | -34.5 |
| 1,3-Dimethylurea | O=C(NC)NC | -0.3 | -37.6 |
| Dinitrogen | N#N | -140.1 | -52.7 |
| Ethane | CC | -296.5 | -69.6 |

**Table 5-6**: MCA* and *Nu* Values Calculated at the B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) Level of Theory

| Compound | SMILES | MCA* (kJ/mol) | Mayr *Nu* |
|---|---|---:|---:|
| Nitromethane Anion | [CH2-][N+]([O-])=O | 467.3 | 12.4 |
| Acetate | O=C(C)[O-] | 374.8 | 12.7 |
| (E)-1-(N-morpholino)propene | CC=CN1CCOCC1 | 366.7 | 9.6 |
| Trimethylamine | CN(C)C | 343.1 | 10.4 |
| Ammonia | N | 330.2 | 7.9 |
| Pyridine | C1=CC=CC=N1 | 328.0 | 8.6 |
| Dihydrofuran | C1=COCC1 | 295.3 | 3.9 |
| Acetonitrile | CC#N | 242.7 | 1.9 |
| Propene | C=CC | 211.0 | -2.4 |
| Diethyl ether | CCOCC | 199.7 | -4.1 |
| Toluene | CC1=CC=CC=C1 | 193.2 | -7.7 |

**Table 5-7:** MCA and *Nu* Values Calculated at the PBE0(disp)/def2-TZVP Level of Theory

| Compound | SMILES | MCA (kJ/mol) | Mayr *Nu* |
|---|---|---:|---:|
| Nitromethane Anion | [CH2-][N+]([O-])=O | 1075.3 | 12.4 |
| Acetate | O=C(C)[O-] | 989.5 | 12.7 |
| (E)-1-(N-morpholino)propene | CC=CN1CCOCC1 | 546.0 | 9.6 |
| Trimethylamine | CN(C)C | 508.8 | 10.4 |
| Ammonia | N | 426.8 | 7.9 |
| Pyridine | C1=CC=CC=N1 | 504.2 | 8.6 |
| Dihydrofuran | C1=COCC1 | 449.8 | 3.9 |
| Acetonitrile | CC#N | 401.2 | 1.9 |
| Propene | C=CC | 341.8 | -2.4 |
| Diethyl ether | CCOCC | 364.0 | -4.1 |
| Toluene | CC1=CC=CC=C1 | 324.7 | -7.7 |

**Table 5-8:** MCA* and *Nu* Values Calculated at the PBE0(disp)/def2-TZVP COSMO (∞) Level of Theory

| Compound | SMILES | MCA* (kJ/mol) | Mayr *Nu* |
|---|---|---:|---:|
| $PhSO_2CHPh$ carbanion | O=S([CH-]C1=CC=CC=C1)(C2=CC=CC=C2)=O | 510 | 14.4 |
| 2-$PhCH(-)CO_2Et$ | O=C(OCC)[CH-]C1=CC=CC=C1 | 496 | 15.7 |
| Ph(Me)C=C=N- | CC(C1=CC=CC=C1)=C=[N-] | 490 | 16.8 |
| NC- | N#[C-] | 480 | 11.4 |
| Indenyl anion | C1(C=CC=C2)=C2C=C[CH-]1 | 479 | 16.4 |

| | | | |
|---|---|---|---|
| Nitromethane Anion | C=[N+]([O-])[O-] | 479 | 12.4 |
| Dimethyl sulfoxonium methylide | O=[S+](C)([CH2-])C | 476 | 10.0 |
| Alpha sulfinyl enolate | CS([CH-]C(OCC)=O)=O | 475 | 13.2 |
| Me(-O)C=CHPh | [O-]/C(C)=C/C1=CC=CC=C1 | 472 | 15.0 |
| Bu$_3$P | CCCCP(CCCC)CCCC | 464 | 10.7 |
| 1,3-Oxazolidin-2-one anion | O=C1[N-]CCO1 | 459 | 13.2 |
| Phospinate carbanion | O=P([CH-]C#N)(OCC)OCC | 454 | 12.3 |
| Py+HC=C(O-)OEt | O=C(OCC)[CH-][N+]1=CC=CC=C1 | 452 | 9.9 |
| Diethyl malonate anion | O=C(OCC)/C=C(OCC)\[O-] | 447 | 13.1 |
| CF$_3$CONH- | O=C(C(F)(F)F)[NH-] | 443 | 10.1 |
| Succinimide anion | O=C1[N-]C(CC1)=O | 438 | 10.6 |
| Ethyl acetylacetate anion | CC([CH-]C(OCC)=O)=O | 438 | 13.0 |
| Ethyl cyanoacetate anion | O=C(OCC)[CH-]C#N | 434 | 13.1 |
| Py+HC=C(O-)Me | CC([CH-][N+]1=CC=CC=C1)=O | 434 | 12.1 |
| DBN | N1(CCC2)C2=NCCC1 | 432 | 11.8 |
| Py+HC=C=N- | N#C[CH-][N+]1=CC=CC=C1 | 432 | 10.9 |
| Acetylacetone anion | CC([CH-]C(C)=O)=O | 429 | 12.9 |
| (BuO)$_3$P | CCCCOP(OCCCC)OCCCC | 427 | 7.3 |
| Phenylsulfinate anion | [O-]S(C1=CC=CC=C1)=O | 423 | 11.9 |
| TBO | N12CCNC1=NCC2 | 422 | 11.4 |
| (N-morpholino)cyclohexene | C1(N2CCOCC2)CCCC=C1 | 420 | 9.5 |
| Malononitrile anion | N#C[CH-]C#N | 417 | 13.0 |
| Cyanomethyl sulfonium ylide | CS(C)=CC#N | 417 | 9.7 |
| Diacetimide anion | CC([N-]C(C)=O)=O | 413 | 11.2 |
| Cyclic imine | N1=CCCCC1 | 411 | 9.1 |
| Thioacetate anion | O=C(C)[S-] | 410 | 13.4 |
| Morpholino enamine | C/C=C(N1CCOCC1)\C | 410 | 9.6 |
| Piperidine | C1NCCCC1 | 402 | 11.8 |
| N-methyl-pyrrolidine | CN1CCCC1 | 401 | 10.7 |
| Pyrrolidine | N1CCCC1 | 399 | 11.2 |
| DMAP | CN(C)C1=CC=NC=C1 | 397 | 9.9 |
| Azide anion | [N-]=[N+]=[N-] | 394 | 12.1 |
| Xanthate anion | [S-]C(OCC)=S | 391 | 13.3 |
| Propylamine | NCCC | 389 | 9.5 |
| Butylamine | NCCCC | 389 | 9.6 |
| Methylamine | NC | 389 | 10.3 |
| *tert*-BuNC | [C-]#[N+]C(C)(C)C | 388 | 4.2 |
| Morpholine | C1NCCOC1 | 388 | 11.6 |
| Diethylamine | CCNCC | 388 | 11.0 |
| Isopropylamine | NC(C)C | 388 | 9.6 |
| Dipropylamine | CCCNCCC | 387 | 11.6 |

| | | | |
|---|---|---|---|
| Triethylamine | CCN(CC)CC | 385 | 9.0 |
| Diazomethane | C=[N+]=[N-] | 384 | 8.2 |
| Diethoxyethene | C=C(OCC)OCC | 382 | 7.9 |
| *tert*-Butylamine | NC(C)(C)C | 382 | 8.9 |
| Imidazole | C1=CNC=N1 | 382 | 9.1 |
| Allylamine | NCC=C | 382 | 9.5 |
| Benzylamine | NCC1=CC=CC=C1 | 379 | 9.6 |
| Hydrazine | NN | 378 | 9.2 |
| 4MeFuranBF$_3$- | CC1=CC=C(O1)[B-](F)(F)F | 377 | 8.0 |
| Ammonia | N | 376 | 7.9 |
| Cyanophenolate anion | [O-]C1=CC=C(C#N)C=C1 | 374 | 11.6 |
| Acetate | CC([O-])=O | 372 | 12.7 |
| Acetate | C1=NC=CC=C1 | 372 | 8.6 |
| Chloride | [Cl-] | 364 | 10.3 |
| Hydroxylamine | NO | 358 | 8.1 |
| NCS- | [S-]C#N | 343 | 10.8 |
| Phenyldiazomethane | [N-]=[N+]=CC1=CC=CC=C1 | 343 | 7.8 |
| N-acetyl enamine | CC(NC1=CCCCC1)=O | 341 | 4.5 |
| Dihydrofuran | C1=CCCO1 | 339 | 3.9 |
| Anline | NC1=CC=CC=C1 | 335 | 8.6 |
| Pyrrole | C1=CNC=C1 | 334 | 4.6 |
| Ethyl vinyl ether | C=COCC | 329 | 3.5 |
| Butyl vinyl ether | C=COCCCC | 328 | 3.4 |
| Indole | C1(C=CC=C2)=C2C=CN1 | 327 | 6.0 |
| Ynamide | O=C1N(C#CC2=CC=CC=C2)CCC1 | 326 | 2.7 |
| Isobutylenyl-ethylether | C/C(C)=C/OCC | 320 | 4.2 |
| AllylSiMe$_3$ | C=CC[Si](C)(C)C | 316 | 1.7 |
| Ethyl diazoacetate | O=C(OCC)C=[N+]=[N-] | 311 | 4.7 |
| Furan | C1=COC=C1 | 302 | 1.7 |
| Alphamethylstyrene | C=C(C)C1=CC=CC=C1 | 301 | 2.4 |
| Phenylacetylene | C#CC1=CC=CC=C1 | 295 | 0.0 |
| Methylvinylbenzene | C=CC1=CC=C(C)C=C1 | 293 | 1.8 |
| Isobutylene | C=C(C)C | 289 | 1.1 |
| Isoprene | C=C(C)C=C | 287 | 1.1 |
| Dimethylbutene | C=C(C)C(C)C | 285 | 0.7 |
| 2Methylpentene | C=C(C)CCC | 285 | 0.9 |
| Methylbutene | C=C(C)CC | 283 | 1.0 |
| Tetramethylethylene | C/C(C)=C(C)/C | 281 | -1.4 |
| Acetonitrile | N#CC | 280 | 1.9 |
| Thiophene | C1=CSC=C1 | 277 | -1.1 |
| Butadiene | C=CC=C | 260 | -0.9 |

| | | | |
|---|---|---|---|
| But2ene | C/C=C/C | 249 | -2.7 |
| Diethyl ether | CCOCC | 247 | -4.1 |
| Propene | C=CC | 247 | -2.4 |
| Hexene | C=CCCCC | 245 | -3.9 |
| IsopropenylSiMe$_3$ | C=C(C)[Si](C)(C)C | 240 | -1.5 |
| Toluene | CC1=CC=CC=C1 | 219 | -7.7 |

**Table 5-9:** MCA* and *Nu** Values Calculated at the PBE0(disp)/def2-TZVP COSMO (∞) Level of Theory

| Compound | SMILES | MCA* (kJ/mol) | Nu* |
|---|---|---|---|
| 2-Methylpropan-2-ide | C[C-](C)C | 718.3 | 32.0 |
| Ethanide | [CH2-]C | 701.2 | 30.8 |
| Benzen-1-ide | C1=CC=CC=[C-]1 | 672.5 | 28.8 |
| Ethenide | [CH-]=C | 668.6 | 28.5 |
| Methanide | [CH3-] | 665.5 | 28.3 |
| Prop-2-en-1-ide | C=C[CH2-] | 599.7 | 23.7 |
| Amide Anion | [NH2-] | 577.1 | 22.1 |
| Methyl lithium | [Li]C | 567.7 | 21.4 |
| Ethynide | C#[C-] | 552.5 | 20.3 |
| Vinylideneamide | C=C=[N-] | 540.5 | 19.5 |
| 1-Methoxyethen-1-olate | [O-]C(OC)=C | 539.3 | 19.4 |
| Prop-1-en-2-olate | [O-]C(C)=C | 518.7 | 18.0 |
| Hydroxide | [OH-] | 487.9 | 15.8 |
| Nitromethanide | [CH2-][N+]([O-])=O | 478.5 | 15.1 |
| Phenoxide | [O-]C1=CC=CC=C1 | 408.8 | 10.2 |
| Ethenamine | C=CN | 400.2 | 9.6 |
| Methanamine | NC | 389.2 | 8.8 |
| Ammonia | N | 375.6 | 7.9 |
| Methanimine | N=C | 374.4 | 7.8 |
| Pyridine | C1=CC=CC=N1 | 371.6 | 7.6 |
| Ethanol | C=CO | 313.5 | 3.5 |
| Acetamide (O attack) | O=C(C)N | 281.4 | 1.2 |
| Acetonitrile | N#CC | 280.2 | 1.1 |
| Acetamide (N attack) | O=C(C)N | 265.9 | 0.1 |
| Hydrogen Cyanide | N#C | 256.5 | -0.5 |
| Prop-1-ene | C=CC | 246.6 | -1.2 |
| Methoxymethane | COC | 235.1 | -2.0 |
| Methanol | OC | 234.8 | -2.1 |

| | | | |
|---|---|---|---|
| Propa-1,2-diene | C=C=C | 234.2 | -2.1 |
| Acetic acid (O attack) | O=C(C)O | 231.6 | -2.3 |
| Water | O | 221.4 | -3.0 |
| Formaldehyde | O=C | 216.4 | -3.4 |
| Benzene | C1=CC=CC=C1 | 199.2 | -4.6 |
| Ethyne | C#C | 196.3 | -4.8 |
| Acetic acid (OH attack) | O=C(C)O | 148.9 | -8.1 |
| Methanimine (pi) | N=C | 144.2 | -8.5 |
| Nitrogen Gas | N#N | 141.5 | -8.6 |
| Methane (C-H) | C | 109.9 | -10.9 |
| Fluoromethane | CF | 92.5 | -12.1 |
| Ethene (C-H) | C=C | 78.2 | -13.1 |
| Hydrogen Cyanide (pi) | N#C | 74.5 | -13.4 |
| Diazene (pi) | N=N | 74.1 | -13.4 |
| Formaldehyde (pi) | O=C | 68.7 | -13.8 |
| Ethyne (C-H) | C#C | 38.6 | -15.9 |
| Ethane (C-C sigma) | CC | 20.1 | -17.2 |

**Table 5-10**: Accessible p$K_a$ Values of Mayr Nucleophiles

| Compound | SMILES | Mayr *Nu* | pK$_a$ H$_2$O | pK$_a$ DMSO |
|---|---|---|---|---|
| Ph(Me)C=C=N- | CC(C1=CC=CC=C1)=C=[N-] | 16.8 | | 23.00 |
| Indenyl anion | C1(C=CC=C2)=C2C=C[CH-]1 | 16.4 | 20.00 | 20.10 |
| 2-PhCH(-)CO2Et | O=C(OCC)[CH-]C1=CC=CC=C1 | 15.7 | 22.70 | 18.00 |
| Me(-O)C=CHPh | [O-]/C(C)=C/C1=CC=CC=C1 | 15.0 | 15.90 | 14.20 |
| PhSO2CHPh carbanion | O=S([CH-]C1=CC=CC=C1)(C2=CC=CC=C2)=O | 14.4 | | 23.40 |
| Thioacetate anion | O=C(C)[S-] | 13.4 | 3.62 | |
| Xanthate anion | [S-]C(OCC)=S | 13.3 | 2.20 | |
| 1,3-Oxazolidin-2-one anion | O=C1[N-]CCO1 | 13.2 | | 20.80 |
| Alpha sulfinyl enolate | CS([CH-]C(OCC)=O)=O | 13.2 | | 23.40 |
| Ethyl cyanoacetate anion | O=C(OCC)[CH-]C#N | 13.1 | 9.00 | 13.10 |
| Diethyl malonate anion | O=C(OCC)/C=C(OCC)\[O-] | 13.1 | 13.30 | 16.40 |
| Ethyl acetylacetate anion | CC([CH-]C(OCC)=O)=O | 13.0 | 10.68 | 14.20 |
| Malononitrile anion | N#C[CH-]C#N | 13.0 | 12.00 | 11.10 |
| Acetylacetone anion | CC([CH-]C(C)=O)=O | 12.9 | 5.85 | 13.30 |
| Acetate | CC([O-])=O | 12.7 | 4.76 | 12.30 |
| Nitromethane Anion | C=[N+]([O-])[O-] | 12.4 | 10.00 | 17.20 |
| Phospinate carbanion | O=P([CH-]C#N)(OCC)OCC | 12.3 | | 6.40 |

|  |  |  |  |  |
|---|---|---|---|---|
| Py+HC=C(O-)Me | CC([CH-][N+]1=CC=CC=C1)=O | 12.1 |  | 11.77 |
| Azide anion | [N-]=[N+]=[N-] | 12.1 | 4.72 | 7.90 |
| Phenylsulfinate anion | [O-]S(C1=CC=CC=C1)=O | 11.9 | 2.76 | 7.10 |
| Piperidine | C1NCCCC1 | 11.8 | 11.22 | 10.90 |
| DBN | N1(CCC2)C2=NCCC1 | 11.8 | 12.70 |  |
| Dipropylamine | CCCNCCC | 11.6 | 10.91 |  |
| Morpholine | C1NCCOC1 | 11.6 | 8.36 | 9.20 |
| Cyanophenolate anion | [O-]C1=CC=C(C#N)C=C1 | 11.6 | 7.95 |  |
| TBO | N12CCNC1=NCC2 | 11.4 | 10.60 |  |
| NC- | N#[C-] | 11.4 | 9.40 | 12.90 |
| Diacetimide anion | CC([N-]C(C)=O)=O | 11.2 |  | 17.90 |
| Pyrrolidine | N1CCCC1 | 11.2 | 11.31 | 11.10 |
| Diethylamine | CCNCC | 11.0 | 11.00 |  |
| Py+HC=C=N- | N#C[CH-][N+]1=CC=CC=C1 | 10.9 |  | 16.50 |
| NCS- | [S-]C#N | 10.8 | 4.00 |  |
| N-methyl-pyrrolidine | CN1CCCC1 | 10.7 | 10.46 |  |
| Bu$_3$P | CCCCP(CCCC)CCCC | 10.7 | 8.43 |  |
| Succinimide anion | O=C1[N-]C(CC1)=O | 10.6 | 9.50 | 14.70 |
| Methylamine | NC | 10.3 | 10.62 |  |
| Chloride | [Cl-] | 10.3 | -8.00 | -2.00 |
| CF$_3$CONH- | O=C(C(F)(F)F)[NH-] | 10.1 |  | 17.20 |
| Dimethyl sulfoxonium methylide | O=[S+](C)([CH2-])C | 10.0 |  | 18.20 |
| DMAP | CN(C)C1=CC=NC=C1 | 9.9 | 9.20 |  |
| Py+HC=C(O-)OEt | O=C(OCC)[CH-][N+]1=CC=CC=C1 | 9.9 |  | 14.10 |
| Isopropylamine | NC(C)C | 9.6 | 10.64 |  |
| Butylamine | NCCCC | 9.6 | 10.64 | 11.10 |
| Benzylamine | NCC1=CC=CC=C1 | 9.6 | 9.35 | 10.20 |
| Propylamine | NCCC | 9.5 | 10.57 |  |
| Allylamine | NCC=C | 9.5 | 9.69 |  |
| Hydrazine | NN | 9.2 | 8.12 |  |
| Imidazole | C1=CNC=N1 | 9.1 | 6.95 |  |
| Triethylamine | CCN(CC)CC | 9.0 | 10.75 | 9.00 |
| tert-Butylamine | NC(C)(C)C | 8.9 | 10.87 |  |
| Acetate | C1=NC=CC=C1 | 8.6 | 5.21 | 3.40 |
| Anline | NC1=CC=CC=C1 | 8.6 | 4.60 | 3.60 |
| Diazomethane | C=[N+]=[N-] | 8.2 | 10.00 |  |
| Hydroxylamine | NO | 8.1 | 5.96 |  |
| Ammonia | N | 7.9 | 9.20 | 10.50 |
| (BuO)$_3$P | CCCCOP(OCCCC)OCCCC | 7.3 | -3.46 |  |
| Acetonitrile | N#CC | 1.9 | -10.00 |  |

## References:

[1] Fungal Infections, https://www.thelancet.com/series/fungal-infections (accessed April 23, 2019).

[2] Xiang, M.; Liu, J.; Ni, P.; Wang, S.; Shi, C.; Wei, B.; Ni, Y.; Ge, H. *FEMS Yeast Res.* **2013**, *13*, 386–393.

[3] Fungal Diseases, https://www.cdc.gov/fungal/infections/index.html (accessed April 23, 2019).

[4] Candidiasis (Invasive) (Eds.: Revankar, S. G.; Sobel, J. D.), Merck Manual, 2014; www.merckmanuals.com/professional/infectious-diseases/fungi/candidiasis-invasive.

[5] Ahmadi, A.; Ardehali, S. H.; Beigohammadi, M. T.; Hajiadolbaghi, M.; Hashemian, S. M. R.; Kouchek, M.; Majidpour, A.; Mokhtari, M.; Moghaddam, O. M.; Najafi, A.; Negat, R.; Niakin, M.; Lotfi, A. H.; Amirsavadkouhi, A.; Shirazian, F.; Tabarsi, P.; Taher, M. T.; Torabi-Nami, M. JRSM Open 2014, 5, 2042533313517689, doi: 10.1177/2042533313517689.

[6] Colombo, A. L.; de Almeida, J. N. Jr.; Slavin, M. A.; Chen, S. C. A.; Sorrel, T. C. *Lancet Infect. Dis.* **2017**, *17*, e344–356.

[7] Scorzoni L, de Paula e Silva, A. C. A.; Marcos, C. M.; Assato, P. A.; de Melo, W. C. M. A.; de Oliveira, H. C.; Costa-Orlandi, C. B.; Mendes-Giannini, M. J. S.; Fusco-Almeida, A. M. *Front. Microbiol.* **2017**, *8*, 36.

[8] Leber, R.; Fuchsbichler, S.; Klobucníková, V.; Schweighofer, N.; Pitters, E.; Wohlfarter, K.; Lederer, M.; Landi, K.; Ruckenstuhl, C.; Hapala, I.; Turnowsky, F. *Antimicrob. Agents Chemother.* **2003**, *47*, 3890–3900.

[9] Tatsumi, Y.; Nagashima, M.; Shibanushi, T.; Iwata, A.; Kangawa, Y.; Inui, F.; Siu, W. J.; Pillai, R.; Nishiyama, Y. *Antimicrob. Agents Chemother.* **2013**, *57*, 2405–2409.

[10] Song, J.; Zhai, P.; Zhang, Y.; Zhang, C.; Sang, H.; Han, G.; Keller, N. P.; Lu, L. *MBio* **2016**, *7*, e01919.

[11] Bhattacharya, S.; Esquivel, B. D.; White, T. C. *mBio* **2018**, *9*, e01291-18.

[12] Bloch, K. E. *Crit. Rev. Biochem. Mol. Biol*. **1983**, *14,* 47–92*.*

[13] Cholesterol Biosynthesis Disorders, http://faculty.washington.edu/libinxu/cholesterol-biosynthesis-disorders/ (accessed April 23, 2019).

[14] Veen, M.; Lang, C. *Biochem. Soc. Trans.* **2005**, *33*, 1178–1181.

[15] Cerqueira, N. M. F. S. A.; Oliveira, E. F.; Gesto, D. S.; Santos-Martins, D.; Moreira, C.; Moorthy, H. N.; Ramos, M. J.; Fernandes, P. A. *Biochemistry* **2016**, *55*, 5483–5506.

[16] Lepesheva, G. I.; Waterman, M. R. *Biochimica et Biophysica Acta* **2011**, *1814*, 88–93.

[17] Antifungal Drugs Market Size, Share & Trends Analysis Report By Drug Class (Azoles, Echinocandins, Polyenes, Allyamines), By Indication (Dermatophytosis, Aspergillosis, Candidiasis), and Segment Forecasts, 2018–2025, https://www.grandviewresearch.com/industry-analysis/antifungal-drugs-market (accessed April 26, 2019).

[18] Whaley, S. G.; Berkow, E. L.; Rybak, J. H.; Nishimoto, A. T.; Barker, K. S.; Rogers, P. D. *Front Microbiol.* **2016**, *7*, 2173.

[19] Antifungal Drugs Market Size, Share & Trends Analysis Report By Drug Class (Azoles, Echinocandins, Polyenes, Allyamines), By Indication (Dermatophytosis, Aspergillosis, Candidiasis), and Segment Forecasts, 2018 – 2025,

https://www.grandviewresearch.com/industry-analysis/antifungal-drugs-market (accessed April 26, 2019).
[20] Sheehan, D. J.; Hitchcock, C. A.; Sibley, C. M. *Clin. Microbiol. Rev.* **1999**, *12*, 40–79.
[21] Kluwer, W. UpToDate. Management of candidemia and invasive candidiasis in adults, https://www.uptodate.com/contents/management-of-candidemia-and-invasive-candidiasis-in-adults, (accessed July 26, 2019).
[22] Kathiravan, M. K.; Salake, A. B.; Chothe, A. S.; Dudhe, P. B.; Watode, R. P.; Mukta, M. S.; Gadhwe, S. *Bioorg. Med. Chem.* **2012**, *20*, 5678–5698.
[23] Tatsumi, Y.; Nagashima, M.; Shibanushi, T.; Iwata, A.; Kangawa, Y.; Inui, F.; Siu, W. J.; Pillai, R.; Nishiyama, Y. *Antimicrob. Agents Chemother.* **2013**, *57*, 2405–2409.
[24] Strushkevich, N.; Usanov, S. A.; Park H. W. *J. Mol. Biol.* **2010**, *397*, 1067-1078.
[25] Perfect, J. R. *Nat. Rev. Drug Discov.* **2017**, *16*, 603–616.
[26] Odds, F. C.; Brown, A. J.; Gow, N. A. *Trends Microbiol.* **2003**, *11*, 272–279.
[27] Walsh, T. J.; Anaissie, E. J.; Denning, D. W.; Herbrecht, R.; Kontoyiannis, D. P.; Marr, K. A.; Morrison, V. A.; Segal, B. H.; Steinbach, W. J.; Stevens, D. A.; van Burik, J. A.; Wingard, J. R.; Patterson, T. F. *Clin. Infect. Dis.* **2008**, *46*, 327–360.
[28] Baginski, M.; Czub, J. *Curr. Drug Metab.* **2009**, *10*, 459–469.
[29] Sangalli-Leite, F.; Scorzoni, L.; Cecilia Mesa-Arango, A.; Casas, C.; Herrero, E.; Mendes Gianinni, M. J. S.; Rodríguez-Tudela, J. L.; Cuenca-Estrella, M.; Zaragoza, O. *Microbes Infect.* **2011**, *13*, 457–467.
[30] Mesa-Arango, A. C.; Scorzoni, L.; Zaragoza, O. *Front. Microbiol.* **2012**, *3*, 286.
[31] Kathiravan, M. K.; Salake, A. B.; Chothe, A. S.; Dudhe, P. B.; Watode, R. P.; Mukta, M. S.; Gadhwe, S. *Bioorg. Med. Chem.* **2012**, *20*, 5678–5698.
[32] Bhattacharya, S.; Esquivel, B. D.; White, T. C. *mBio* **2018**, *9*, e01291-18.
[33] Ngo, H. X.; Garneau-Tsodikova, S.; Green, K. D. *MedChemComm 2016*, **7**, 1285–1306.
[34] Perfect, J. R. *Nat. Rev. Drug Discov.* **2017**, *16*, 603–616.
[35] Odds, F. C.; Brown, A. J.; Gow, N. A. *Trends Microbiol.* **2003**, *11*, 272–279.
[36] Kathiravan, M. K.; Salake, A. B.; Chothe, A. S.; Dudhe, P. B.; Watode, R. P.; Mukta, M. S.; Gadhwe, S. *Bioorg. Med. Chem.* **2012**, *20*, 5678–5698.
[37] Vermes, A.; Guchelaar, H.-J.; Dankert, J. *J. Antimicrob. Chemother.* **2000**, *46*, 171–179.
[38] Perfect, J. R. *Nat. Rev. Drug Discov.* **2017**, *16*, 603–616.
[39] Pappas P. G.; Kauffman, C. A.; Andes, D. R.; Clancy, C. J.; Marr, K. A.; Ostrosky-Zeichner, L.; Reboli, A. C.; Schuster, M. G.; Vazquez, J. A.; Walsh, T. J.; Zaoutis, T. E.; Sobel, J. D. *Clin. Infect. Dis.* **2016**, *62*, e1–e50.
[40] Song, J. C.; Stevens, D. A. *Crit. Rev. Microbiol.* **2016**, *42*, 813–846.
[41] Perlin, D. S. *Clin. Infect. Dis*. **2015**, *61*, Suppl 6: S612–7.
[42] Scorzoni L, de Paula e Silva, A. C. A.; Marcos, C. M.; Assato, P. A.; de Melo, W. C. M. A.; de Oliveira, H. C.; Costa-Orlandi, C. B.; Mendes-Giannini, M. J. S.; Fusco-Almeida, A. M. *Front. Microbiol.* **2017**, *8*, 36.
[43] Flowers, S.; Barker, K.; Berkow, E.; Toner, G.; Chadwick, S.; Gygax, S.; Morschhauser, J.; Rogers, D. *Eukaryotic Cell* **2012**, *11*, 1289–1299.
[44] Prasad, R.; Rawal, M. K. *Front. Pharmacol.* **2014**, *5*, 202.
[45] Sanglard, D.; Ischer, F.; Monod, M.; Bille, J. *Microbiology* **1997**, *143*, 405–416.
[46] Sanglard, D.; Coste, A.; Ferrari, S. *FEMS Yeast Res.* **2009**, *9*, 1029–1050.

[47] Prasad, R.; Goffeau, A. *Annu. Rev. Microbiol.* **2012**, *66*, 39–63.
[48] Gaur, M.; Puri, N.; Manoharlal, R.; Rai, V.; Mukhopadhayay, G.; Choudhury, D.; Prasad, R. *BMC Genomics* **2008**, *9*, 579.
[49] Chen, S. H.; Sheng, C. Q.; Xu, X. H.; Jiang, Y. Y.; Zhang, W. N.; He, C. *Biol. Pharm. Bull.* **2007**, *30*, 1246–1253.
[50] Sanglard, D.; Ischer, F.; Koymans, L.; Bille, J. *Antimicrob. Agents Chemother.* **1998**, *42*, 241–253.
[51] Lamb, D. C.; Kelly, D. E.; White, T. C.; Kelly, S. L. *Antimicrob. Agents Chemother.* **2000**, *44*, 63–67.
[52] Morio, F.; Loge, C.; Besse, B.; Hennequin, C.; Le Pape, P. *Diagn. Microbiol. Infect. Dis.* **2010**, *66*, 373–384.
[53] Gonçalves, S. S.; Souza, A. C.; Chowdhary, A.; Meis, J. F.; Colombo, A. L. *Mycoses* **2016**, *59*, 198–219.
[54] Albertson, G. D.; Niimi, M.; Cannon, R. D.; Jenkinson, H. F. *Antimicrob. Agents Chemother.* **1996**, *40*, 2835–2841.
[55] Franz, R.; Kelly, S. L.; Lamb, D. C.; Kelly, D. E.; Ruhnke, M.; Morschhäuser, J. *Antimicrob. Agents Chemother*. **1998**, *42*, 3065–3072.
[56] Selmecki, A.; Forche, A.; Berman, J. *Science* **2006**, *313*, 367–370.
[57] Dunkel, N.; Liu, T. T.; Barker, K. S.; Homayouni, R.; Morschhäuser, J.; Rogers, P. D. *Eukaryot. Cell* **2008**, *7*, 1180–1190.
[58] Kanafani, Z. A.; Perfect, J. R. *Clin. Infect. Dis.* **2008**, *46*, 120–128.
[59] Sanglard, D.; Odds, F. C. *Lancet. Infect. Dis.* **2002**, *2*, 73–85.
[60] Mast, N.; Zheng, W.; Stout, C. D.; Pikuleva, I. A. *Mol. Pharmacol.* **2013**, *84*, 86–94.
[61] Panackal, A.; Gribskov, J.; Staab, J.; Kirby, A.; Rinaldi, M.; Marr, K. *J. Clin. Microbiol*. **2006**, *44*, 1740–1743.
[62] LaFleur, M.; Lucumi, E.; Napper, A.; Diamond, S.; Lewis, K. *J. Antimicrob. Chemother.* **2011**, *66*, 820–826.
[63] Spitzer, M.; Griffiths, E.; Blakely, K.; Wildenhain, J.; Ejim, L.; Rossi, L.; De Pascale, G.; Curak, J.; Brown, E.; Tyers, M.; Wright, G. D. *Mol. Syst. Biol.* **2011**, *21*, 1–14.
[64] Robbins, N.; Spitzer, M.; Yu, T.; Cerone, R.; Averette, A.; Bahn, Y.; Heitman, J.; Sheppard, D.; Tyers, M.; Wright, G. *Cell Reports* **2015**, *13*, 1481–1492.
[65] Liu, H.; Wang, L.; Li, Y.; Liu, J.; An, M.; Zhu, S.; Cao, Y.; Jiang, Z.; Zhao, M.; Cai, Z.; Dai, L.; Ni, T.; Liu, W.; Chen, S.; Wei, C.; Zang, C.; Tian, S.; Yang, J.; Wu, C.; Zhang, D.; Liu, H.; Jiang, Y. *ChemMedChem* **2014**, *9*, 207-216.
[66] Youngsaye, W.; Hartland, C.; Morgan, B.; Ting, A.; Nag, P.; Vincent, B.; Mosher, C.; Bittker, J.; Dandapani, S.; Palmer, M.; Whitesell, L.; Lindquist, S.; Schreiber, S.; Munoz, B. *Beilstein J. Org. Chem.* **2013**, *9*, 1501–1507.
[67] Chaturvedi, V.; Ramani, R.; Andes, D.; Diekema, D.; Pfaller, M.; Ghannoum, M.; Knapp, C.; Lockhart, S.; Ostrosky-Zeichner, L.; Walsh, T.; Marchillo, K.; Messer, S.; Welshenbaugh, A.; Bastulli, C.; Iqbal, N.; Paetznick, V.; Rodriguez, J.; Sein T. *Antimicrob. Agents Chemother*. **2011**, *55*, 1543–1548.
[68] Mukherjee, P.; Sheehan, D.; Hitchcock, C. *Clin. Microbiol. Rev.* **2005**, *18*, 163–194.
[69] Cui, J.; Ren, B.; Tong, Y.; Dai, H.; Zhang, L. *Virulence* **2015**, *6*, 362–71.
[70] Girmenia, C.; Venditti, M.; Martino, P. *Diagn. Microbiol. Infect. Dis*. **2003**, *46*, 227–31.

[71] Onyewu, C.; Blankenship, J.; Del Poeta, M.; Heitman, J. *Antimicrob. Agents Chemother.* **2003**, *47*, 956–964.

[72] Sun, S.; Li, Y.; Guo, Q.; Shi, C.; Yu, J.; Ma, L. *Antimicrob. Agents Chemother.* **2008**, *52*, 409–417.

[73] Uppuluri, P.; Nett, J.; Heitman, J.; Andes, D. *Antimicrob. Agents Chemother*. **2008**, *52*, 1127–1132.

[74] Denardi, L.; Mario, D.; Loreto, É.; Santurio, J.; Alves, S. *Braz. J. Microbiol.* **2015**, *46*, 125–129.

[75] Steinbach, W.; Schell, W.; Blankenship, J.; Onyewu, C.; Heitman, J.; Perfect, J. *Antimicrob. Agents Chemother*. **2004**, *48*, 1664–1669.

[76] Te Dorsthorst, D.; Verweij, P.; Meletiadis, J.; Bergervoet, M.; Punt, N; Meis, J.; Mouton, J. *Antimicrob. Agents Chemother*. **2002**, *46*, 2982–2989.

[77] Johnson, M.; MacDougall, C.; Ostrosky-Zeichner, L.; Perfect, J.; Rex, J. *Antimicrob. Agents Chemother*. **2004**, *48*, 693–715.

[78] Kuypers, D.; Claes, K.; Evenepoel, P.; Vanrenterghem, Y. *Transplantation*. **2006**, *81*, 1750–1752.

[79] Imbert, S.; Bresler, P.; Boissonnas, A.; Gauthier, L.; Souchet, L.; Uzunov, M.; Leblond, V.; Mazier, D.; Nguyen, S.; Fekkar, A. *J. Allergy Clin. Immunol.* **2016**, *138*, 860-868.

[80] Dodds-Ashley, E. *Pharmacotherapy* **2010**, *30*, 842–854.

[81] LaFleur, M.; Lucumi, E.; Napper, A.; Diamond, S.; Lewis, K. *J. Antimicrob. Chemother.* **2011**, *66*, 820–826.

[82] Spitzer, M.; Griffiths, E.; Blakely, K.; Wildenhain, J.; Ejim, L.; Rossi, L.; De Pascale, G.; Curak, J.; Brown, E.; Tyers, M.; Wright, G. D. *Mol. Syst. Biol.* **2011**, *21*, 1–14.

[83] National Center for Biotechnology Information. PubChem BioAssay Database; AID=2007, Source=Broad Institute. https://pubchem.ncbi.nlm.nih.gov/assay/assay.cgi?aid=2007 (accessed Mar. 11, 2015).

[84] Youngsaye, W.; Hartland, C.; Morgan, B.; Ting, A.; Nag, P.; Vincent, B.; Mosher, C.; Bittker, J.; Dandapani, S.; Palmer, M.; Whitesell, L.; Lindquist, S.; Schreiber, S.; Munoz, B. *Beilstein J. Org. Chem.* **2013**, *9*, 1501–1507.

[85] National Center for Biotechnology Information. PubChem BioAssay Database; AID=2007, Source=Broad Institute. https://pubchem.ncbi.nlm.nih.gov/assay/assay.cgi?aid=2007 (accessed Mar. 11, 2015).

[86] Youngsaye, W.; Hartland, C.; Morgan, B.; Ting, A.; Nag, P.; Vincent, B.; Mosher, C.; Bittker, J.; Dandapani, S.; Palmer, M.; Whitesell, L.; Lindquist, S.; Schreiber, S.; Munoz, B. *Beilstein J. Org. Chem.* **2013**, *9*, 1501–1507.

[87] Youngsaye, W.; Hartland, C.; Morgan, B.; Ting, A.; Nag, P.; Vincent, B.; Mosher, C.; Bittker, J.; Dandapani, S.; Palmer, M.; Whitesell, L.; Lindquist, S.; Schreiber, S.; Munoz, B. *Beilstein J. Org. Chem.* **2013**, *9*, 1501–1507.

[88] Youngsaye, W.; Vincent, B.; Hartland, C.; Morgan, B.; Buhrlage, S.; Johnston, S.; Bittker, J.; MacPherson, L.; Dandapani, S.; Palmer, M.; Whitesell, L.; Lindquist, S.; Schreiber, S.; Munoz, B. *Bioorg. Med. Chem. Lett.* **2011**, *21*, 5502–5505.

[89] Youngsaye, W.; Dockendorff, C.; Vincent, B.; Hartland, C.; Bittker, J.; Dandapani, S.; Palmer, M.; Whitesell, L.; Lindquist, S.; Schreiber, S. L.; Munoz, B. *Bioorg. Med. Chem. Lett.* **2012**, *22*, 3362–3365.

[90] Premachandra, I. D. U. A. PhD. Dissertation, UCI, 2016.

[91] Premachandra, I. D. U. A.; Scott, K. A.; Shen, C.; Wang, F.; Lane, S.; Liu, H.; Van Vranken, D. L. *ChemMedChem*. **2015**, *10*, 1672–1686.

[92] Premachandra, I. D. U. A.; Scott, K. A.; Shen, C.; Wang, F.; Lane, S.; Liu, H.; Van Vranken, D. L. *ChemMedChem*. **2015**, *10*, 1672–1686.

[93] Colombo, A. L.; de Almeida, J. N. Jr.; Slavin, M. A.; Chen, S. C. A.; Sorrel, T. C. *Lancet Infect. Dis.* **2017**, *17*, e344–356.

[94] National Center for Biotechnology Information. PubChem BioAssay Database; AID=2007, Source=Broad Institute. https://pubchem.ncbi.nlm.nih.gov/assay/assay.cgi?aid=2007 (accessed Mar. 11, 2015).

[95] Youngsaye, W.; Hartland, C.; Morgan, B.; Ting, A.; Nag, P.; Vincent, B.; Mosher, C.; Bittker, J.; Dandapani, S.; Palmer, M.; Whitesell, L.; Lindquist, S.; Schreiber, S.; Munoz, B. *Beilstein J. Org. Chem.* **2013**, *9*, 1501–1507.

[96] Youngsaye, W.; Vincent, B.; Hartland, C.; Morgan, B.; Buhrlage, S.; Johnston, S.; Bittker, J.; MacPherson, L.; Dandapani, S.; Palmer, M.; Whitesell, L.; Lindquist, S.; Schreiber, S.; Munoz, B. *Bioorg. Med. Chem. Lett.* **2011**, *21*, 5502–5505.

[97] Youngsaye, W.; Dockendorff, C.; Vincent, B.; Hartland, C.; Bittker, J.; Dandapani, S.; Palmer, M.; Whitesell, L.; Lindquist, S.; Schreiber, S. L.; Munoz, B. *Bioorg. Med. Chem. Lett.* **2012**, *22*, 3362–3365.

[98] Premachandra, I. D. U. A.; Scott, K. A.; Shen, C.; Wang, F.; Lane, S.; Liu, H.; Van Vranken, D. L. *ChemMedChem*. **2015**, *10*, 1672–1686.

[99] Wolfbeis, O. *Liebigs Ann. Chem.* **1981**, *5*, 819–827.

[100] Patil, C. D.; Sadana, A.; Deodhar, S. *J. Indian Chem. Soc.* **1990**, *67*, 654–656.

[101] Dieckmann, W.; Meiser, W. *Ber. Dtsch. Chem. Ges.* **1908**, *41*, 3253–3269.

[102] Liu, Z., et al. *Bioorg. Med. Chem.* **2014**, *22*, 3642 – 3653.

[103] Reddy, T.; Reddy, G.; Reddy, L.; Jammula, S.; Lingappa, Y.; Kapavarapu, R.; Meda, C.; Parsa, K.; Pal, M. *Eur. J. Med. Chem.* **2012**, *48*, 265–274.

[104] Chen, Y.; Onaran, M.; Doss, C.; Seto, C. *Bioorg. Med. Chem. Lett.* **2001**, *11*, 1935–1938.

[105] Geneste, H.; Ochse, M.; Drescher, K.; Dinges, J.; Jakob, C. “Heterocyclic Carboxamides Useful As Inhibitors of Phosphodiesterase Type 10A.” U.S. Patent 2 013 116 229, 2013.

[106] Brittain, D.; Wood, R. “Phthalazin-4-ylacetic acid derivatives.” U.S. Patent 4 251 528, 1981.

[107] Su, W.; Dai, G.; Xiao, K.; Jia, H.; Venable, J.; Bembenek, S. “Novel Heteroaryl and Heterocycle Compounds, Compositions, and Methods.” WO Patent 201 415 675, 2014.

[108] Liu, B.; Yi, W.; Zhang, J.; Liu, Q.; Liu, Y.; Fan, S.; Yu, X. *Org. Biomol. Chem.* **2014**, *12*, 3484–3492.

[109] Zinelaabidine, C.; Souad, O.; Zoubir, J,; Malika, B.; Nour-Eddine, A. *Int. J. Chem.* **2012**, *4*, 73–79.

[110] Martin, L.; Coello, M.; Reyes, B.; Rodriguez, V.; Garranzo, G.; Murcia, P.; Francesch, S.; Sanchez, S.; Fernandez, R. Antitumoral dihydropyran-2-one compounds. WO Patent 2007 144 423, 2007.

[111] Liu, Z., Wang, R.; Guo, R.; Hu, J.; Li, R.; Zhao, Y.; Gong, P. *Bioorg. Med. Chem.* **2014**, *22*, 3642–3653.

[112] Flowers, S.; Barker, K.; Berkow, E.; Toner, G.; Chadwick, S.; Gygax, S.; Morschhauser, J.; Rogers, D. *Eukaryotic Cell* **2012**, *11*, 1289–1299.

[113] Warrilow A. G.; Martel, C. M.; Parker, J. E.; Melo, N.; Lamb, D. C.; Nes, W. D.; Kelly, D. E.; Kelly, S. L. *Antimicrob. Agents Chemotherm*. **2010**, *54*, 4235-4245.

[114] Cormack, B. P.; Falkow, S. *Genetics*. **1999**, *151,* 979–87.

[115] Fidel, P. L.; Cutright, J. L.; Tait, L.; Sobel, J. D. **1996**, *173*, 425–431.

[116] Janbon, G. et. al. *PLoS Genet*. **2014**, *10*, 1-26.

[117] Pangborn, A. B.; Giardello, M. A.; Grubbs, R. H.; Rosen, R. K.; Timmers, F. J. *Organometallics.* **1996**, *15*, 1518–1520.

[118] Selwood, D. "Benzamide derivatives useful in the treatment of muscular disorders and pain and for controlling spasticity and tremors*."* WO Patent 201 582 938, 2015.

[119] Ozer, M. S.; Koza, G.; Sahin, E.; Balci, M. *Tetrahedron Lett.* **2013**, *54*, 6553–6556.

[120] Koza, G.; Balci. M. *Tetrahedron* **2011,** *67*, 8679–8685.

[121] Wolfbeis, O. *Liebigs Ann. Chem.* **1981**, *5*, 819–827.

[122] Wolfbeis, O. *Liebigs Ann. Chem.* **1981**, *5*, 819–827.

[123] Patil, C. D.; Sadana, A.; Deodhar, S. *J. Indian Chem. Soc.* **1990**, *67*, 654–656.

[124] Brittain, D.; Wood, R. Phthalazin-4-ylacetic acid derivatives. U.S. Patent 4 251 528, 1981.

[125] Su, W.; Dai, G.; Xiao, K.; Jia, H.; Venable, J.; Bembenek, S. Novel Heteroaryl and Heterocycle Compounds, Compositions, and Methods. WO Patent 201 415 675, 2014.

[126] Selwood, D. "Benzamide derivatives useful in the treatment of muscular disorders and pain and for controlling spasticity and tremors*."* WO Patent 201 582 938, 2015.

[127] Awuah, E.; Ma, E.; Hoegl, A.; Vong, K.; Habib, E.; Auclair, K. *Bioorg. Med. Chem.* **2014**, *22*, 3083–3090.

[128] Zinelaabidine, C.; Souad, O.; Zoubir, J.; Malika, B.; Nour-Eddine, A. *Int. J. Chem.* **2012**, *4*, 73–79.

[129] Berghausen, J.; Buschmann, N.; Furet, P.; Gessier, F.; Hergovich Lisztwan, J.; Holzer, P.; Jacoby, E.; Kallen, J.; Masuya, K.; Pissot Soldermann, C.; Ren, H.; Stutz, S. Isoquinolinone and quinazolinone derivatives as MDM2 and MDM4 inhibitors and their preparation and use for the treatment of diseases. PCT Int. Appl. 2 011 076 786, 2011.

[130] Liu, Z.; Wang, R.; Guo, R.; Hu, J.; Li, R.; Zhao, Y.; Gong, P. *Bioorg. Med. Chem.* **2014**, *22*, 3642–3653.

[131] Reddy, T.; Reddy, G.; Reddy, L.; Jammula, S.; Lingappa, Y.; Kapavarapu, R.; Meda, C.; Parsa, K.; Pal, M. *Eur. J. Med. Chem.* **2012**, *48*, 265–274.

[132] Ochoa-Puentes, C.; Bauer, S.; Kuhnle, M.; Bernhardt, G.; Buschauer, A.; Konig. B. *ACS Med. Chem. Lett.* **2013**, *4,* 393–396.

[133] Reddy, T.; Reddy, G.; Reddy, L.; Jammula, S.; Lingappa, Y.; Kapavarapu, R.; Meda, C.; Parsa, K.; Pal, M. *Eur. J. Med. Chem.* **2012**, *48*, 265–274.

[134] Liu, B.; Yi, W.; Zhang, J.; Liu, Q.; Liu, Y.; Fan, S.; Yu, X. *Org. Biomol. Chem.* **2014**, *12*, 3484–3492.

[135] Zinelaabidine, C.; Souad, O.; Zoubir, J.; Malika, B.; Nour-Eddine, A. *Int. J. Chem.* **2012**, *4*, 73–79.

[136] Liu, B.; Yi, W.; Zhang, J.; Liu, Q.; Liu, Y.; Fan, S.; Yu, X. *Org. Biomol. Chem.* **2014**, *12*, 3484–3492.

[137] Martin, L.; Coello, M.; Reyes, B.; Rodriguez, V.; Garranzo, G.; Murcia, P.; Francesch, S.; Sanchez, S.; Fernandez, R. Antitumoral dihydropyran-2-one compounds. WO Patent 2 007 144 423, 2007.

[138] Geneste, H.; Ochse, M.; Drescher, K.; Dinges, J.; Jakob, C. Heterocyclic Carboxamides Useful As Inhibitors of Phosphodiesterase Type 10A. U.S. Patent 2 013 116 229, 2013.

[139] Flowers, S.; Barker, K.; Berkow, E.; Toner, G.; Chadwick, S.; Gygax, S.; Morschhauser, J.; Rogers, D. *Eukaryotic Cell* **2012**, *11*, 1289–1299.

[140] Basso, L.; Gast, C.; Bruzual, I.; Wong, B. *J. Antimicrob Chemother* **2015**, 70, 1396–407.

[141] Cormack, B. P.; Falkow, S. *Genetics*. **1999**, *151,* 979–987.

[142] Premachandra, I. D. U. A.; Scott, K. A.; Shen, C.; Wang, F.; Lane, S.; Liu, H.; Van Vranken, D. L. *ChemMedChem*. **2015**, *10*, 1672–1686.

[143] Premachandra, I. D. U. A.; Scott, K. A.; Shen, C.; Wang, F.; Lane, S.; Liu, H.; Van Vranken, D. L. *ChemMedChem*. **2015**, *10*, 1672–1686.

[144] Cormack, B. P.; Falkow, S. *Genetics*. **1999**, *151,* 979–87.

[145] Fidel, P. L.; Cutright, J. L.; Tait, L.; Sobel, J. D. **1996**, *173*, 425–431.

[146] Janbon, G. et. al. *PLoS Genet*. **2014**, *10*, 1-26.

[147] Nascimento-Jfflnior, N. M.; Mendes, T. C. F.; Leal, D. M.; Correa, C. M. N.; Sudo, R. T.; Zapata-Sudo, G; Barreiro, E. J.; Fraga, C. A. *Bioorg. Med. Chem. Lett.* **2010**, *20*, 74–77.

[148] Sandmeyer, T. *Helvetica Chim. Acta* **1919**, *2*, 234–242.

[149] Marvel, C. S.; Hiers, G. S. *Org. Synth.* **1925**, *5*, 71.

[150] Phippen, C.; McErlean, C. *Tetrahedron Letters*, **2011**, *52*, 1490–1492.

[151] Curran, D. P.; Geib, S.; DeMello, N. Tetrahedron **1999**, *55*, 5681–5704.

[152] Zhao, C.; Parrish, R. M.; Smith, M. D.; Pellechia, P. J.; Sherrill, C. D.; Shimizu, K. D. *J. Am. Chem. Soc.* **2012**, *134*, 14306–14309.

[153] Raimondi, L.; Benaglia, M.; Cozzi, F. *Eur. J. Org. Chem.* **2014**, 4993–4998.

[154] Kishikawa, K.; Yoshizaki, K.; Kohmoto, S.; Yamamoto, M.; Yamaguchi, K.; Yamada, K. *J. Chem. Soc. Perkin Trans. 1* **1997**, 1233–1239.

[155] Zhao, C.; Li, P.; Smith, M. D.; Pellechia, P. J.; Shimizu, K. D. *Org. Lett.* **2014**, *16*, 3520–3523.

[156] Pangborn, A. B.; Giardello, M. A.; Grubbs, R. H.; Rosen, R. K.; Timmers, F. J. *Organometallics.* **1996**, *15*, 1518–1520.

[157] Kalia, D.; Pawar, S. P.; Thopate, J. S. *Angew. Chem. Int. Ed.* **2017**, 56, 1885–1889.

[158] Salewska, N.; Boros-Majewska, J.; Lcka, I.; Chylinska, K.; Sabisz, M.; Milewski, S.; Milewska, M. J. *J. Enzyme Inhib. Med. Chem.* **2012**, *27*, 117–124.

[159] Barrales-Rienda, J. M.; Gonzalez Ramos, J.; Sanchez Chavez, M. *J. Fluor. Chem.* **1977**, 9, 293–308.

[160] Abu Bakr, S. M.; Abd El-Karim, S. S.; Said, M. M.; Youns, M. M. *Res. Chem. Intermediat.* **2016**, *42*, 1387–1399.

[161] Hagiwara, K.; Iwatsu, M.; Urabe, D.; Inoue, M. *Heterocycles* **2015**, *90*, 659–672.

[162] Nascimento-Junior, N. M.; Mendes, T. C. F.; Leal, D. M.; Correa, C. M. N.; Sudo, R. T.; Zapata-Sudo, G.; Barreiro, E. J.; Fraga, C. A. M. *Bioorg. Med. Chem. Lett.* **2010**, *20*, 74–77.

[163] Matuszak, N.; Muccioli, G. G.; Labar, G.; Lambert, D. M. *J. Med. Chem.* **2009**, *52*, 7410–7420.

[164] Garad, D. N.; Tanpure, S. D.; Mhaske, S. B. *Beilstein J. Org. Chem.* **2015**, *11*, 1008–1016.

[165] Oikawa, M.; Sasaki, S.; Sakai, M.; Ishikawa, Y.; Sakai, R. *Eur. J. Org. Chem.* **2012**, *29*, 5789–5802.

[166] Matuszak, N.; Muccioli, G. G.; Labar, G.; Lambert, D. M. *J. Med. Chem.* **2009**, *52*, 7410–7420.

[167] Matuszak, N.; Muccioli, G. G.; Labar, G.; Lambert, D. M. *J. Med. Chem.* **2009**, *52*, 7410–7420.

[168] Blessy, M.; Patel, R. D.; Prajapati, P. N.; Agrawal, Y. K. *J. Pharm. Sci.* **2014**, *4*, 159–165.

[169] "ICH Harmonised Tripartite Guideline - Impurities in New Drug Products Q3B(R2), Current Step 4 version" International Conference on Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use, June 2, 2006. https://www.ich.org/fileadmin/Public_Web_Site/ICH_Products/Guidelines/Quality/Q3B_R2/Step4/Q3B_R2__Guideline.pdf

[170] "Guidance for Industry ANDAs: Impurities in Drug Products" U.S. Department of Health and Human Services, Food and Drug Administration Center for Drug Evaluation and Research (CDER), November 2010. https://www.fda.gov/media/71351/download

[171] Szymkuć, S.; Gajewska, E. P.; Klucznik, T.; Molga, K.; Dittwald, P.; Startek, M.; Bajczyk, M.; Grzybowski, B. A. *Angew. Chem. Int. Ed.* **2016**, *55*, 5904–5937.

[172] Liao, R.-Z.; Thiel, W. *J. Chem. Theory Comput.* **2012**, *8*, 3793–3803.

[173] Polyak, I.; Reetz, M. T.; Thiel, W. *J. Am. Chem. Soc.* **2012**, *134*, 2732–2741.

[174] Abad, E.; Zenn, R. K.; Kästner, J. *J. Phys. Chem. B* **2013**, *117*, 14238–14246.

[175] Andrejićand, M.; Mata, R. A. *J. Chem. Theory Comput.* **2014**, *10*, 5397–5404.

[176] Shoji, M.; Isobe, H.; Yamaguchi, K. *Chem. Phys. Lett.* **2015**, *636*, 172–179.

[177] Jenkin, M. E.; Saunders, S. M.; Pilling, M. J. Atmos. Environ. 1997, 31, 81–104.

[178] Saunders, S. M.; Jenkin, M. E.; Derwent, R. G.; Pilling, M. J. *Atmos. Chem. Phys.* **2003**, *3*, 161–180.

[179] Jenkin, M. E.; Saunders, S. M.; Wagner, V.; Pilling, M. J. *Atmos. Chem. Phys.* **2003**, *3*, 181–193.

[180] Jenkin, M. E.; Wyche, K. P.; Evans, C. J.; Carr, T.; Monks, P. S.; Alfarra, M. R.; Barley, M. H.; McFiggans, G. B.; Young, J. C.; Rickard, A. R. *Atmos. Chem. Phys.* **2012**, *12*, 5275–5308.

[181] Jenkin, M. E.; Young, J. C.; Rickard, A. R. *Atmos. Chem. Phys.* **2015**, *15*, 11433–11459.

[182] Jorgensen, W. L.; Laird, E. R.; Gushurst, A. J.; Fleischer, J. M.; Gothe, S. A.; Helson, H. E.; Paderes, G. D.; Sinclair, S. *Pure Appl. Chem.* **1990**, *62*, 1921–1932.

[183] William L. Jorgensen Research Group, http://zarbi.chem.yale.edu/ (accessed July 26, 2019).

[184] Gasteiger, J.; Hutchings, M. G.; Christoph, B.; Gann, L.; Hiller, C.; Loew, P.; Marsili, M.; Saller, H.; Yuki, K. *Topics. Curr. Chem.* **1987**, *137*, 19–73.

[185] Sello, G. *J. Chem. Inf. Model.* **1992**, *32*, 713–717.

[186] Satoh, H.; Funatsu, K. *J. Chem. Inf. Model.* **1995**, *35*, 34–44.

[187] Socorro, I. M.; Taylor, K.; Goodman, J. M. *Org. Lett*. **2005**, *7*, 3541–3544.

[188] Testa, B.; Balmat, A.-L.; Long, A.; Judson, P. *Chem. Biodiversity* **2005**, *2*, 872–855.

[189] Pole, D. L.; Ando, H. Y.; Murphy, S. T. *Mol. Pharmaceutics* **2007**, *4*, 539–549.

[190] Zeneth, https://www.lhasalimited.org/products/zeneth.htm (accessed July 26, 2019).

[191] Kleinman, M. H.; Baertschi, S. W.; Alsante, K. M.; Reid, D. L.; Mowery, M. D.; Shimanovich, R.; Foti, C.; Smith, W. K.; Reynolds, D. W.; Nefliu, M.; Ott, M. A. *Mol. Pharmaceutics* **2014**, *11*, 4179–4188.

[192] Lederberg, J.; Sutherland, G. L.; Buchanan, B. G.; Feigenbaum, E. A.; Robertson, A. V.; Duffield, A. M; Djerassi, C. *J. Am. Chem. Soc.* **1969**, *91*, 2973–2977.

[193] Duffield, A. M.; Robertson, A. V.; Djerassi, C.; Buchanan, B. G.; Sutherland, G. L.; Feigenbaum, E. A.; Lederberg, J. *J. Am. Chem. Soc.* **1969**, *91*, 2977–2981.

[194] Lindsay, R. K.; Buchanan, B. G.; Feigenbaum, E. A.; Lederberg. J. *Applications of Artificial Intelligence for Organic Chemistry: The DENDRAL Project*; McGraw-Hill Book Company: New York, 1980.

[195] Gelernter, H.; Rose, J. R.; Chen, C. *J. Chem. Inf. Model.* **1990**, *30*, 492–504.

[196] Feng, F.; Lai, L.; Pei, J. *Front. Chem.* **2018**, *6*, 199.

[197] Carrera, G. V.; Gupta, S.; Aires-de-Sousa, J. *J. Comput. Aided Mol. Des.* **2009**, *23*, 419–429.

[198] Wei, J. N.; Duvenaud, D.; Aspuru-Guzik, A. *ACS Cent. Sci.* **2016**, *2*, 725–732.

[199] Segler, M. H. S.; Waller, M. P. *Chem. Eur. J.* **2017**, *23*, 5966 –5971.

[200] Segler, M. H. S.; Preuss, M.; Waller, M. P. *Nature* **2018**, 555, 604–619.

[201] Bradshaw, J.; Kusner, M. J.; Paige, B.; Segler, M. H. S.; Hernández-Lobato, J. M. ICLR, 2019, abs/1805.10970.

[202] Coley, C. W.; Barzilay, R.; Jaakkola, T. S.; Green, W. H.; Jensen, K. F. *ACS Cent. Sci.* **2017**, *3*, 434–443.

[203] Coley, C. W.; Jin, W.; Rogers, L.; Jamison, T, F.; Jaakkol, T. S.; Green, W. H.; Barzilay, R.; Jensen, K. F. *Chem. Sci.* **2019**, *10*, 370–377.

[204] Shi, Z.; Fan, J.; Kronenthal, D. R.; Mudryk. B. M. *Org. Process Res. Dev.* **2018**, *22*, 1534–1540.

[205] Kayala, M. A.; Azencott, C.-A.; Chen, J. H.; Baldi, P. *J. Chem. Inf. Model.* 2011, *51*, 2209–2222.

[206] Kayala, M. A.; Baldi, P. *J. Chem. Inf. Model.* **2012**, *52*, 2526–2540.

[207] Hochreiter, S.; Schmidhuber, J. *Neural Comput.* **1997**, *9*, 1735–1780.

[208] Graves, A.; Schmidhuber, J. *Neural Netw.* **2005**, *18*, 602–610.

[209] James, C.; Weininger, D.; Delany, J. *Daylight theory manual daylight version 4.82*, Daylight Chemical Information Systems, 2003.

[210] OEChem, version 1.7.4, OpenEye Scientific Software, Inc., Santa Fe, NM, USA, 2012, www.eyesopen.com.

[211] Chen, J. H.; Baldi, P. *J. Chem. Inf. Model.* 2009, *49*, 2034–2043.

[212] Holman, R. W. *J. Chem. Educ.* **2003**, *80*, 1259.

[213] Libby, R. D. *J. Chem. Educ.* **2001**, *78*, 314.

[214] Kurti, L.; Czakó, B. *Strategic Applications of Named Reactions in Organic Synthesis*; Elsevier: Boston, 2005.

[215] Tu, Y. Q.; Yang, L. M.; Chen, Y. Z. *Chem. Lett.* **1998**, *27*, 285–286.

[216] Mulzer, J.; Pointner, A.; Chucholowski, A.; Bruntrup, G. *J. Chem. Soc., Chem. Commun.* **1979**, 52–54.

[217] Baumann, K. L.; Butler, D. E.; Deering, C. F.; Mennen, K. E.; Millar, A.; Nanninga, T. N.; Palmer, C. W.; Roth, B. D. *Tetrahedron Lett.* **1992**, *33*, 2283–2284.

[218] Hinton, G. E.; Srivastava, N.; Krizhevsky, A.; Sutskever I.; Salakhutdinov, R. CoRR, 2012, abs/1207.0580.

[219] Baldi, P.; Sadowski, P. *Artificial Intelligence* **2014**, *210*, 78–122.

[220] Glorot X.; Bengio, Y. Proceedings of the Thirteenth International Conference on Artificial Intelligence and Statistics, Chia Laguna Resort, Sardinia, Italy, 2010, pp. 249–256.

[221] Kingma, D. P.; Ba, J. CoRR, 2014, abs/1412.6980.

[222] Baldi, P.; Chauvin, Y. *Neural Comput.* **1993**, *5*, 402–418.

[223] Bromley, J.; Guyon, I.; LeCun, Y.; Säckinger, E.; Shah, R. Proceedings of the 6th International Conference on Neural Information Processing Systems, San Francisco, CA, USA, 1993, pp. 737–744.

[224] Swamidass, S. J.; Chen, J.; Bruand, J.; Phung, P.; Ralaivolaand, L.; Baldi, P. *Bioinformatics*, **2005**, *21*, i359–i368.

[225] Kraskov, A.; Stögbauer, H.; Grassberger, P*. Phys. Rev. E: Stat., Nonlinear, Soft Matter Phys.* **2004**, *69*, 066138.

[226] Pedregosa, F.; Varoquaux, G.; Gramfort, A.; Michel, V.; Thirion, B.; Grisel, O.; Blondel, M.; Prettenhofer, P.; Weiss, R.; Dubourg, V.; Vanderplas, J.; Passos, A.; Cournapeau, D.; Brucher, M.; Perrot, M.; Duchesnay, E. *J. Mach. Learn. Res.* **2011**, *12*, 2825–2830.

[227] Paquette, L. A.; Yang, J.; Long, Y. O. J. Am. Chem. Soc. **2002**, *124*, 6542–6543.

[228] Chung, J. Y.; Ho, G.-J.; Chartrain, M.; Roberge, C.; Zhao, D.; Leazer, J.; Farr, R.; Robbins, M.; Emerson, K.; Mathre, D. J; McNamara, J. M. Hughes, D. L.; Grabowski, E. J.; Reider, P. J. *Tetrahedron Lett.* **1999**, *40*, 6739–6743.

[229] Kopecky, D. J.; Rychnovsky, S. D. *J. Am. Chem. Soc.* **2001**, *123*, 8420–8421.

[230] Tanino, K.; Onuki, K.; Asano, K.; Miyashita, M.; Nakamura, T.; Takahashi Y.; Kuwajima, I. *J. Am. Chem. Soc.* **2003**, *125*, 1498–1500.

[231] Gomtsyan, A.; Schmidt, R. G.; Bayburt, E. K.; Gfesser, G. A.; Voight, E. A.; Daanen, J. F.; Schmidt, D. L.; Cowart, M. D.; Liu, H.; Altenbach, R. J.; Kort, M. E.; Clapham, B.; Cox, P. B.; Shrestha, A.; Henry, R.; Whittern, D. N.; Reilly, R. M.; Puttfarcken, P. S.; Brederson, J.-D.; Song, P; Li, B; Huang, S. M.; McDonald, H. A.; Neelands, T. R.; McGaraughty, S. P; Gauvin, D. M.; Joshi, S. K.; Banfor, P. N.; Segreti, J. A.; Shebley, M.; Faltynek, C. R.; Dart M. J; Kym, P. R. *J. Med. Chem.* **2016**, *59*, 4926–4947.

[232] Huang, H.-S.; Chiu, H.-F.; Lee, A.-L.; Guo, C.-L.; Yuan, C.-L. *Bioorg. Med. Chem.* **2004**, *12*, 6163–6170.

[233] Cai, F.; Pu, X.; Qi, X.; Lynch, V.; Radha A.; Ready, J. M. *J. Am. Chem. Soc.* **2011**, *133*, 18066–18069.

[234] Baldwin, J. E. *J. Chem. Soc., Chem. Commun*. **1976**, 734–736.

[235] Arredondo, V.; Hiew, S. C.; Gutman, E. S.; Premachandra, I. D. U. A.; Van Vranken, D. L. *Angew. Chem. Int. Ed.* **2017**, *56*, 4156–4159.

[236] Ewan, H. S.; Iyer, K.; Hyun, S.-H.; Wleklinski, M.; Cooks, R. G.; Thompson, D. H. *Org. Process Res. Dev.* **2017**, *21*, 1566–1570.

[237] Wleklinski, M.; Falcone, C. E.; Loren, B. P.; Jaman, Z.; Iyer, K.; Ewan, H. S.; Hyun, S.-H. Thompson, D. H.; Cooks, R. G. *Eur. J. Org. Chem.* **2016**, 5480–5484.

[238] Saxena, D.; Damale, S.; Joshi, A.; Datar, A. *Int. J. LifeSc. Bt & Pharm. Res.* **2014**, *3*, *196–207*.

[239] Tiwari, R.; Shah, N.; Bhalani, V.; Mahajan, A. *Journal of Pharmaceutical Analysis* **2015**, 5, 33–42.

[240] Stoiljković, Z.; Jadranin, M.; Đurić, S.; Petrović, S.; Ivić Avramov, M.; Mijin, D. *Chem. Ind. Chem. Eng. Q.* **2014**, *20*, 295–304.
[241] Davi, A.; Rao, Y.; Satish, M.; Jyothi, G.; Rao, K.; Omdutt, T. *Magn. Reson. Chem.* **2007**, *45*, 688–691.
[242] Zaazaa, H.; Abbas, S.; Essam H.; El-Bardicy, M. *Journal of Chromatographic Science* **2013**, *51*, 533–543.
[243] Rapolu, R.; Raju, C.; Srinivas, K.; Awasthi, A.; Navalgund, K.; Surendranath, V. *Journal of Pharmaceutical and Biomedical Analysis* **2014**, 99, 59–66.
[244] Baldi, P. *Data Min. Knowl. Discov. 2017*, 1–13.
[245] LeCun, Y.; Bengio, Y. Convolutional Networks for Images, Seech, and Time Series. In *The handbook of brain theory and neural networks*; Arbib, M. A. Ed.; MIT Press, Cambridge, MA, USA, 1998; pp. 255–258.
[246] Harris, J. M. Nucleophilicity. In *Advances in Chemistry Series*; McManus, S. P., Ed.; American Chemical Society: Washington D. C., 1987.
[247] Mayr, H.; Patz, M. *Angew. Chem. Int. Ed. Engl.* **1994**, *33*, 938–957.
[248] Swain, C. G.; Scott, C. B. *J. Am. Chem. Soc.* **1953**, *75*, 141–147.
[249] Edwards, J. O. *J. Am. Chem. Soc.* **1954**, *76*, 1540-1547.
[250] Edwards, J. O. *J. Am. Chem. Soc.* **1956**, *78*, 1819–1820.
[251] A. J. Parker. *Chem. Rev.* **1969**, *69*, 1–32.
[252] Ritchie, C. D. *Acc. Chem. Res.* **1972**, *5*, 348–354.
[253] Ritchie. C. D. *Can. J. Chem.* **1986**, *64*, 2239–2250.
[254] Phan, T. B.; Breugst, M.; Mayr, H. *Angew. Chem. Int. Ed.* **2006**, *45*, 3869–3874.
[255] Mayr, H.; Ofial, A. R. *J. Phys. Org. Chem.* **2008**, *21*, 584–595.
[256] Ofial, A. R. Mayr's Database of Reactivity Parameters. https://www.cup.lmu.de/oc/mayr/reaktionsdatenbank2/ (accessed April 8, 2019).
[257] Mayr, H.; Patz, M.; Gotta, M. F.; Ofial, A. R. *Pure & Appl. Chem.* **1998**, *70*, 1993–2000.
[258] Schindele, C.; Houk, K. N.; Mayr, H. *J. Am. Chem. Soc.* **2002**, *124*, 11208–11214.
[259] Troshin, K.; Schindele, C.; Mayr, H. *J. Org. Chem.* **2011**, *76*, 9391–9408.
[260] Troshin, K.; Mayr, H. *J. Org. Chem.* **2013**, *78*, 2649–2660.
[261] Böttger, G. M.; Fröhlich, R.; Würthwein, E.-U. *Eur. J. Org. Chem.* **2000**, 1589–1593.
[262] Li, Z.; Jangra, H.; Chen, Q.; Mayer, P.; Ofial, A. R.; Zipse, H.; Mayr, H. *J. Am. Chem. Soc.* **2018**, *140*, 5500–5515.
[263] Allgäuer, D. S.; Jangra, H.; Asahara, H.; Li, A.; Chen, Q.; Zipse, H.; Ofial, A. R.; Mayr, H. *J. Am. Chem. Soc.* **2017**, *139*, 13318–13329.
[264] Seeliger, F.; Blazej, S.; Bernhardt, S.; Makosza, M.; Mayr, H. *Chem. Eur. J.* **2008**, *14*, 6108–6118.
[265] Ammer, J.; Mayr, H. *Macromolecules* **2010**, 43, 1719–1723.
[266] Ammer, J.; Nolte, C.; Mayr, H. *J. Am. Chem. Soc.* **2012**, *134*, 13902–13911.
[267] Mayr, H.; Kempf, B.; Ofial, A. R. *Acc. Chem. Res*. **2003**, *36*, 66–77.
[268] Allgäuer, D. S.; Mayr, H. *Eur. J. Org. Chem.* **2014**, 2956–2963.
[269] Appel, R.; Mayr, H. *J. Am. Chem. Soc.* **2011**, *133*, 8240–8251.
[270] Grimme, S.; Ehrlich, S.; Goerigk, L. *J. Comput. Chem.* **2011**, *32*, 1456–1465.
[271] Ofial, A. R. Mayr's Database of Reactivity Parameters. https://www.cup.lmu.de/oc/mayr/reaktionsdatenbank2/ (accessed April 8, 2019)

[272] Mayr, H.; Bug, T.; Gotta, M. F.; Hering, N.; Irrgang, B.; Janker, B.; Kempf, B.; Loos, R.; Ofial, A. R.; Remennikov, G.; Schimmel, H. *J. Am. Chem. Soc.* **2001**, *123*, 9500–9512.

[273] Mayr, H.; Ofial, A. R.; Schimmel, H. *Macromolecules* **2005**, *38*, 33–40.

[274] Minegishi, S.; Mayr, H. *J. Am. Chem. Soc.* **2003**, *125*, 286–295.

[275] Horn, M.; Mayr, H. *Eur. J. Org. Chem.* **2011**, 6470–6475.

[276] Henninger, J.; Mayr, H.; Patz, M.; Stanescu, M. D. *Liebigs Ann.* **1995**, 2005–2009.

[277] Follet, E.; Mayer, P.; Berionni, G. *Chem. Eur. J.* **2017**, *23*, 623–630.

[278] Appel, R.; Chelli, S.; Tokuyasu, T.; Troshin, K.; Mayr, H. *J. Am. Chem. Soc.* **2013**, *135*, 6579–6587.

[279] Richter, D.; Hampel, N.; Singer, T.; Ofial, A. R.; Mayr, H. *Eur. J. Org. Chem.* **2009**, 3203–3211.

[280] Lucius, R.; Loos, R.; Mayr, H. *Angew. Chem. Int. Ed.* **2002**, *41*, 91–95.

[281] Follet, E.; Berionni, G.; Mayer, P.; Mayr, H. *J. Org. Chem.* **2015**, *80*, 8643–8656.

[282] Follet, E.; Mayer, P.; Mayr, H. *Eur. J. Org. Chem.* **2016**, 4050–4058.

[283] Samanta, R. C.; Maji, B.; De Sarkar, S.; Bergander, K.; Fröhlich, R.; Mück-Lichtenfeld, C.; Mayr, H.; Studer, A. *Angew. Chem. Int. Ed.* **2012**, *51*, 5234–5238.

[284] Baidya, M.; Remennikov, G. Y.; Mayer, P.; Mayr, H. *Chem. Eur. J.* **2010**, *16*, 1365–1371.

[285] Levens, A.; An, F.; Fernando, J. E. M.; Ofial, A. R.; Lupton, D. W.; Mayr, H. *Top. Catal.* **2018**, *61*, 585–590.

[286] Kaumanns, O.; Lucius, R.; Mayr, H. *Chem. Eur. J.* **2008**, *14*, 9675–9682.

[287] Kaumanns, O.; Mayr, H. *J. Org. Chem.* **2008**, *73*, 2738–2745.

[288] Berger, S. T. A.; Seeliger, F. H.; Hofbauer, F.; Mayr, H. *Org. Biomol. Chem.* **2007**, *5*, 3020–3026.

[289] Zenz, I.; Mayr, H. *J. Org. Chem.* **2011**, *76*, 9370–9378.

[290] Lakhdar, S.; Tokuyasu, T.; Mayr, H. *Angew. Chem. Int. Ed.* **2008**, *47*, 8723–8726.

[291] Lakhdar, S.; Ammer, J.; Mayr, H. *Angew. Chem. Int. Ed.* **2011**, *50*, 9953–9956.

[292] Lakhdar, S.; Appel, R.; Mayr, H. *Angew. Chem. Int. Ed.* **2009**, *48*, 5034–5037.

[293] Holland, M. C.; Paul, S.; Schweizer, W. B.; Bergander, K.; Mück-Lichtenfeld, C.; Lakhdar, S.; Mayr, H.; Gilmour, R. *Angew. Chem. Int. Ed.* **2013**, *52*, 7967–7971.

[294] An, F.; Paul, S.; Ammer, J.; Ofial, A. R.; Mayer, P.; Lakhdar, S.; Mayr, H. *Asian J. Org. Chem.* **2014**, *3*, 550–555.

[295] Lemek, T.; Mayr, H. *J. Org. Chem.* **2003**, *68*, 6880–6886.

[296] Guo, X.; Mayr, H. *J. Am. Chem. Soc.* **2014**, *136*, 11499–11512.

[297] Guo, X.; Mayr, H. *J. Am. Chem. Soc.* **2013**, *135*, 12377–12387.

[298] Asahara, H.; Mayr, H. *Chem. Asian J.* **2012**, *7*, 1401–1407.

[299] Chen, Q.; Mayer, P.; Mayr, H. *Angew. Chem. Int. Ed.* **2016**, *55*, 12664–12667.

[300] Remennikov, G. Y.; Kempf, B.; Ofial, A. R.; Polborn, K.; Mayr, H. *J. Phys. Org. Chem.* **2003**, *16*, 431–437.

[301] Lakhdar, S.; Westermaier, M.; Terrier, F.; Goumont, R.; Boubaker, T.; Ofial, A. R.; Mayr, H. *J. Org. Chem*. **2006**, *71*, 9088–9095.

[302] Terrier, F.; Lakhdar, S.; Boubaker, T.; Goumont, R. *J. Org. Chem.* **2005**, *70*, 6242–6253.

[303] Lakhdar, S.; Goumont, R.; Berionni, G.; Boubaker, T.; Kurbatov, S.; Terrier, F. *Chem. Eur. J.* **2007**, *13*, 8317–8324.

[304] Kanzian, T.; Mayr, H. *Chem. Eur. J.* **2010**, *16*, 11670–11677.

[305] Kanzian, T.; Nicolini, S.; De Crescentini, L.; Attanasi, O. A.; Ofial, A. R.; Mayr, H. *Chem. Eur. J.* **2010**, *16*, 12008–12016.

[306] Duan, X.-H.; Mayr, H. *Org. Lett.* **2010**, *12*, 2238–2241.

[307] Timofeeva, D. S.; Ofial, A. R.; Mayr, H. *J. Am. Chem. Soc.* **2018**, *140*, 11474–11486.

[308] Zhang, J.; Yang, J.-D.; Zheng, H.; Xue, X.-S.; Mayr, H.; Cheng, J.-P. *Angew. Chem. Int. Ed.* **2018**, *57*, 12690–12695.

[309] Dulich, F.; Muller, K.-H.; Ofial, A. R.; Mayr, H. *Helv. Chim. Acta* **2005**, *88*, 1754–1768.

[310] Troshin, K.; Mayer, P.; Mayr, H. *Organometallics* **2012**, *31*, 2416–2424.

[311] Phan, T. B.; Breugst, M.; Mayr, H. *Angew. Chem. Int. Ed.* **2006**, *45*, 3869–3874.

[312] Swain, C. G.; Scott, C. B. *J. Am. Chem. Soc.* **1953**, *75*, 141–147.

[313] Antipova, A. PhD. Dissertation, Ludwig-Maximillians-Universität München, 2015.

[314] Page, M. I.; Jencks, W. P. *Proc. Natl. Acad. Sci. USA* **1971**, *68*, 1678–1683.

[315] Wolters, L. P.; Bickelhaipt, F. M. *WIREs Comput Mol. Sci.* **2015**, *5*, 324–343.

[316] Williams, I. H. *J. Am. Chem. Soc.* **1987**, *109*, 6299–6307.

[317] Ćmikiewicz, A.; Gordon, A. J.; Berski, S. *Structural Chemistry* **2018**, *29*, 243–255.

[318] Hall, N. E.; Smith, B. J. *J. Phys. Chem. A* **1998**, *102*, 4930–4938.

[319] Kaufmann, E.; Schleyer, P. V. R.; Houk, K. N.; Wu, Y. D. *J. Am. Chem. Soc.* **1985**, *107*, 5560–5563.

[320] Nakamura, M.; Nakamura, E.; Koga, N.; Morokuma, K. *J. Am. Chem. Soc.* **1993**, *115*, 11016–11017.

[321] Strozier, R. W.; Caramella, P.; Houk, K. N. *J. Am. Chem. Soc.* **1979**, *101*, 1340–1343.

[322] Reppe, W. Vinylierung. *Liebigs Ann.* **1956***,* 601, 81–104.

[323] Trotuş, I.-T.; Zimmermann, T.; Schüth, F. *Chem. Rev.* 2014, **114**, 1761–1782.

[324] Choe, J. C. *Bull. Korean Chem. Soc.* **2019**, *40*, 205–206.

[325] Oro, J.; Kimball, A. P. *Arch. Biochem. Biophys.* **1961**, *94*, 217–227.

[326] Chen, J. H.; Baldi, P. *J. Chem. Inf. Model.* 2009, **49**, 2034–2043.

[327] Kayala, M. A.; Azencott, C.-A.; Chen, J. H.; Baldi, P. *J. Chem. Inf. Model.* **2011**, *51*, 2209–2222.

[328] Fooshee, D.; Mood, A.; Gutman, E.; Tavakoli, M.; Urban, G.; Liu, F.; Huynh, N.; Van Vranken, D.; Baldi, P. *Mol. Sys. Des. Eng.* **2018**, *3*, 442–452.

[329] Herman, Z.; Hierl, P.; Lee, A.; Wolfgang, R. *J. Chem. Phys.* **1969**, *51*, 454–455.

[330] Raksit, A. B.; Schiff, H. I.; Bohme, D. K. *Int. J. Mass Spectrom. Ion Process.* **1984**, *56*, 321–335.

[331] Snow, T. P.; Bierbaum, V. *Annu. Rev. Anal. Chem.* **2008**, *1*, 229–59.

[332] Smith, D. *Chem. Rev.* **1992**, *92*, 1473–1485.

[333] Olah, G. A.; Prakash, G. K. S.; Molnár, A.; Sommer, J. *Superacid Chemistry*, 2nd ed.; Wiley: Hoboken, NJ, 2008.

[334] Edwards, J. O. *J. Am. Chem. Soc.* **1954**, *76*, 1540-1547.

[335] Edwards, J. O. *J. Am. Chem. Soc.* **1956**, *78*, 1819–1820.

[336] Bordwell, F. G. *Acc. Chem. Res.* **1988**, 21, 456–463.

[337] Bordwell, F. G.; Algrim, D. J. *J. Am. Chem. Soc.* **1988**, *110*, 2964–2968.

[338] Breslow, R.; Grant, J. L. *J. Am. Chem. Soc.* **1977**, *99*, 7745–7746.

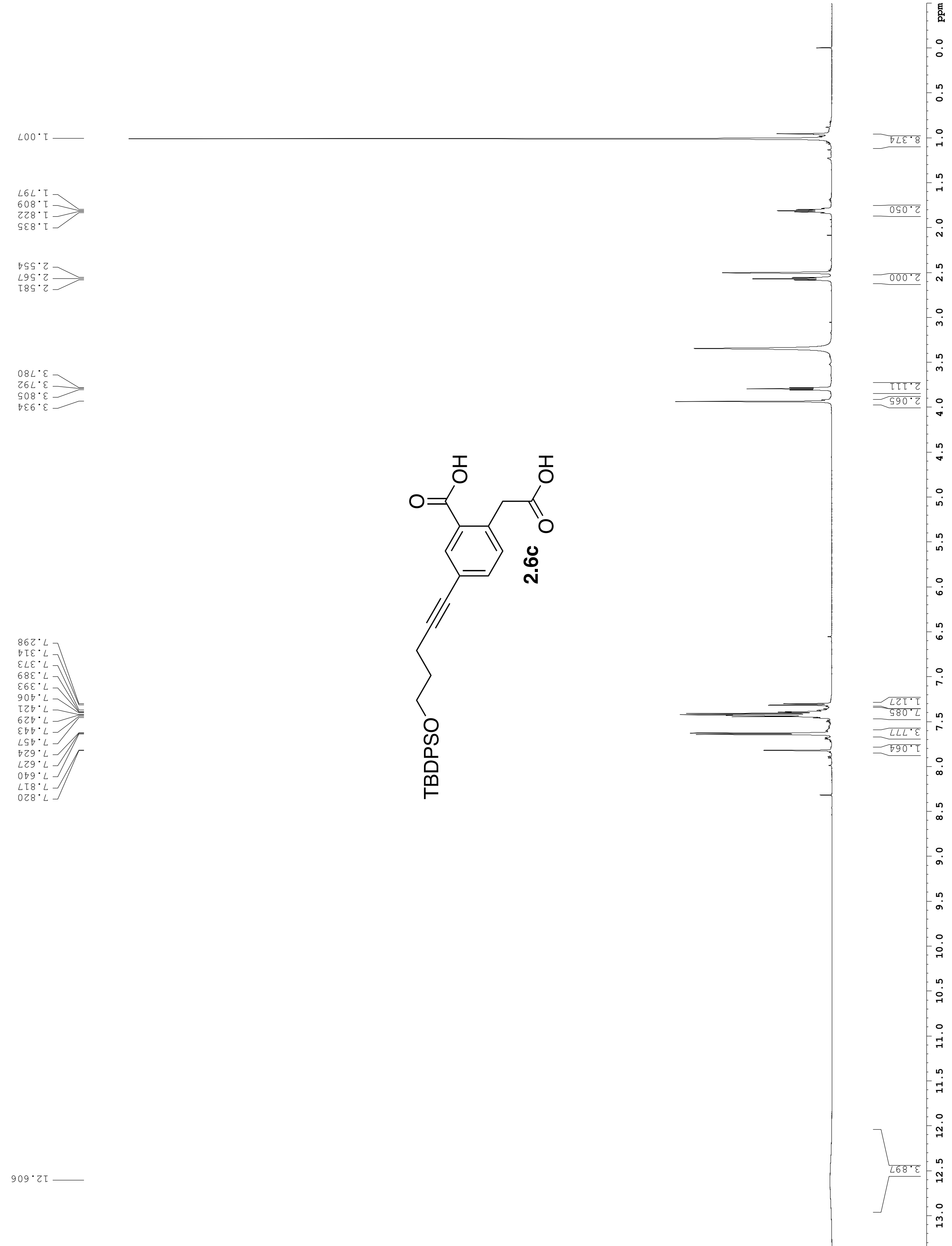
[339] Log *k* for nucleophilic addition was determined using the Mayr equation for a diverse set of nucleophiles.

[340] Brotzel, F.; Cheung, Y.; Chu, C.; Mayr, H. *J. Org. Chem.* **2007**, *72*, 3679–3688.
[341] Phan, T. B.; Breugst, M.; Mayr, H. *Angew. Chem. Int. Ed.* **2006**, *45*, 3869–3874.
[342] Mayr, H.; Ofial, A. R. *J. Phys. Org. Chem.* **2008**, *21*, 584–595.
[343] Ofial, A. R. Mayr's Database of Reactivity Parameters. https://www.cup.lmu.de/oc/mayr/reaktionsdatenbank2/ (accessed April 8, 2019).
[344] Hine, J.; Weimer, R. J. *J. Am. Chem. Soc*. **1965**, *103*, 3387–3396.
[345] Pellerite, M. J.; Brauman, J. I. *J. Am. Chem. Soc.* **1983**, *105*, 2672–2680.
[346] Deakyne, C. A.; Meot-Ner, M. *J. Phys. Chem.* **1990**, *94*, 232–239.
[347] Wei, Y.; Singer, T.; Mayr, H.; Sastry, G. N.; Zipse; H. *J. Comput. Chem.* **2008***, 29,* 291–297.
[348] Lindner, C.; Maryasin, B.; Richter, F.; Zipse, H. *J. Phys. Org. Chem.* **2010**, *23*, 1036–1042.
[349] Lindner, C.; Tandon, R.; Maryasin, B.; Larionov, E.; Zipse, H. *Beilstein J. Org. Chem.* **2012**, *8*, 1406–1442.
[350] Follet, E.; Zipse, H.; Lakhdar, S.; Ofial, A. R.; Berionni, G. *Synthesis* **2017**, *49*, 3495–3504.
[351] Wei, Y.; Sastry, G. N.; Zipse, H. *J. Am. Chem. Soc.* **2008**, *130*, 3473–3477.
[352] Hill, J. S.; Isaacs, N. S. *J. Phys. Org. Chem.* **1990**, *3*, 285–288.
[353] Aggarwal, V. K.; Mereu, A. *Chem. Commun*. **1999**, 2311–2312.
[354] Maji, B.; Breugst, M.; Mayr, H. *Angew. Chem. Int. Ed.* **2011**, *50*, 6915–6919.
[355] Levens, A.; An, F.; Breugst, M.; Mayr, H.; Lupton, D. W. *Org. Lett*. **2016**, *18*, 3566–3569.
[356] Maji, B.; Breugst, M.; Mayr, H. *Angew. Chem. Int. Ed*. **2011**, *50*, 6915–6919.
[357] Mayr, H.; Lakhdar, S.; Maji, B.; Ofial, A. R. *Beilstein J. Org. Chem.* **2012**, *8*, 1458–1478.
[358] Mayr, H. *Angew. Chem. Int. Ed.* **2011**, *50*, 3612–3618.
[359] Mahiuddin, B.; Horn, M.; Zipse, H.; Mayr, H. *J. Org. Chem.* **2009**, *74*, 7157–7164.
[360] Ofial, A. R. Mayr's Database of Reactivity Parameters. https://www.cup.lmu.de/oc/mayr/reaktionsdatenbank2/ (accessed April 8, 2019).
[361] DePalma, V. M.; Arnett, E. M. *J. Am. Chem. Soc.* **1978**, *100*, 3514–3525.
[362] Allgäuer, D. S.; Mayer, P.; Mayr, H. *J. Am. Chem. Soc.* **2013**, *135*, 15216–15224.
[363] Brotzel, F.; Chu, Y. C.; Mayr, H. *J. Org. Chem.* **2007**, *72*, 3679–3688.
[364] Mayer, R. J.; Breugst, M.; Hampel, N.; Ofial, A. R.; Mayr, H. J. Org. Chem. **2019**, 84, 8837–8858.
[365] Seegerer, A.; Hioe, J.; Hammer, M. M.; Morana, F.; Fuchs, P. J. W.; Gschwing, R. M. *J. Am. Chem. Soc.* **2016**, *138*, 9864–9873.
[366] Marenich, A. V.; Cramer, C. J.; Truhlar, D. G. *J. Phys. Chem. B* **2009***, 113,* 6378–6396.
[367] Klamt, A. *WIREs Comput. Mol. Sci*. **2018**, *8*, e1338.
[368] Klamt, A.; Jonas, V.; Bürger, T.; Lohrenz, J. C. W. *J. Phys. Chem. A* **1998**, *102*, 5074–5085.
[369] TURBOMOLE V7.3 2018, a development of University of Karlsruhe and Forschungszentrum Karlsruhe GmbH, 1989-2007,TURBOMOLE GmbH, since 2007; available from http://www.turbomole.com.
[370] Marenich, A. V.; Cramer, C. J.; Truhlar, D. G. *J. Phys. Chem. B* **2009***, 113,* 6378–6396.
[371] Schmidt, M. W.; Baldridge, K. K.; Boatz, J. A.; Elbert, S. T.; Gordon, M. S.; Jensen, J. H.; Koseki, S; Matsunaga, N.; Nguyen, K. A.; Su, S.; Windus*,* T. L. *J. Comput. Chem.* **1993**, *14*, 1347–1363.
[372] Gordon, M. S.; Schmidt, M. W. Advances in Electronic Structure Theory: GAMESS a Decade Later. In *Theory and Applications of Computational Chemistry, the first forty years*;

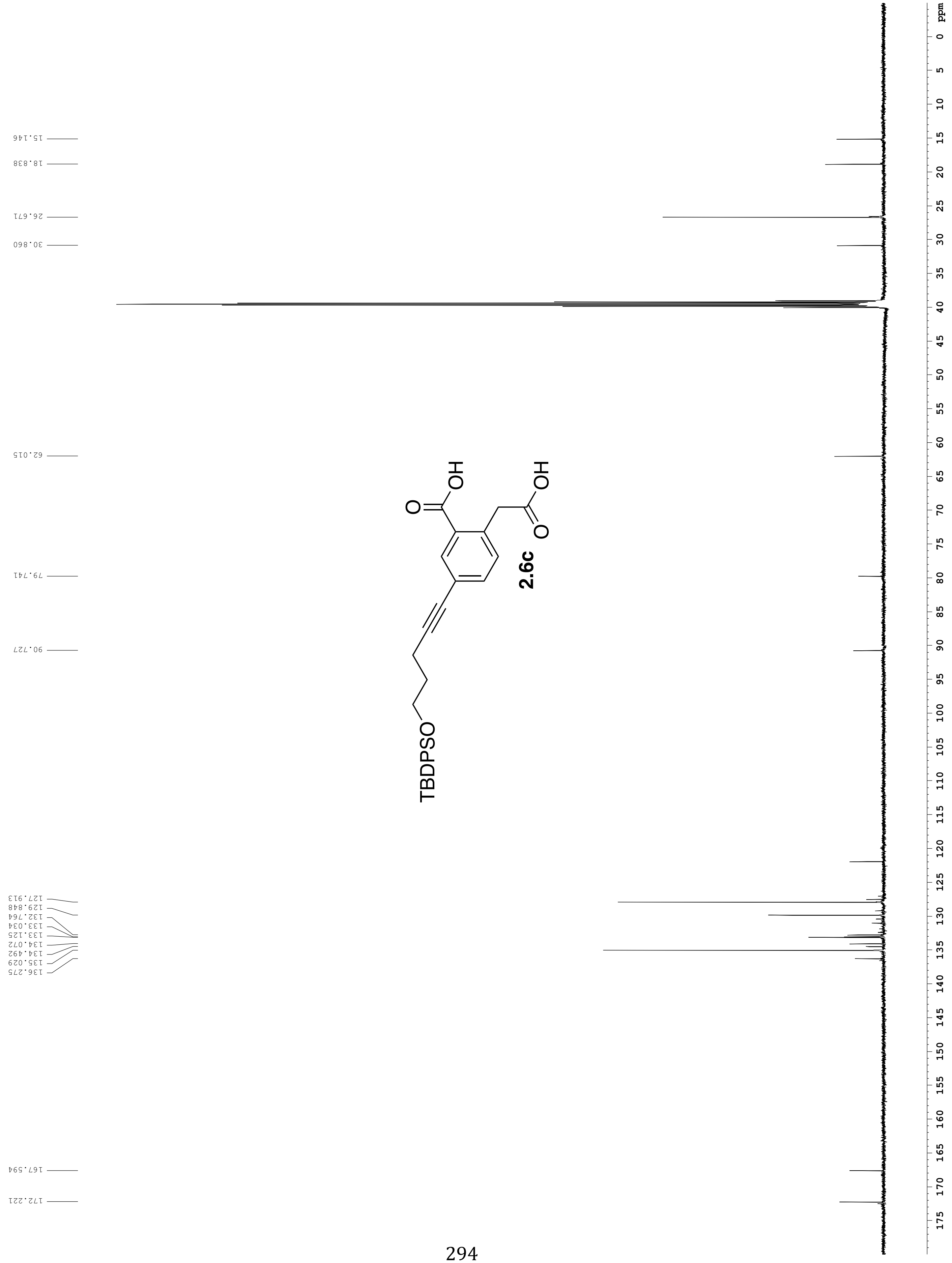
Dykstra, C. E.; Frenking, G.; Kim, K. S.; Scuseria, G. E., Eds.; Elsevier: Amsterdam, 2005; pp. 1167–1189.

[373] Grimme, S.; Ehrlich, S.; Goerigk, L. *J. Comput. Chem.* **2011**, *32*, 1456–1465.

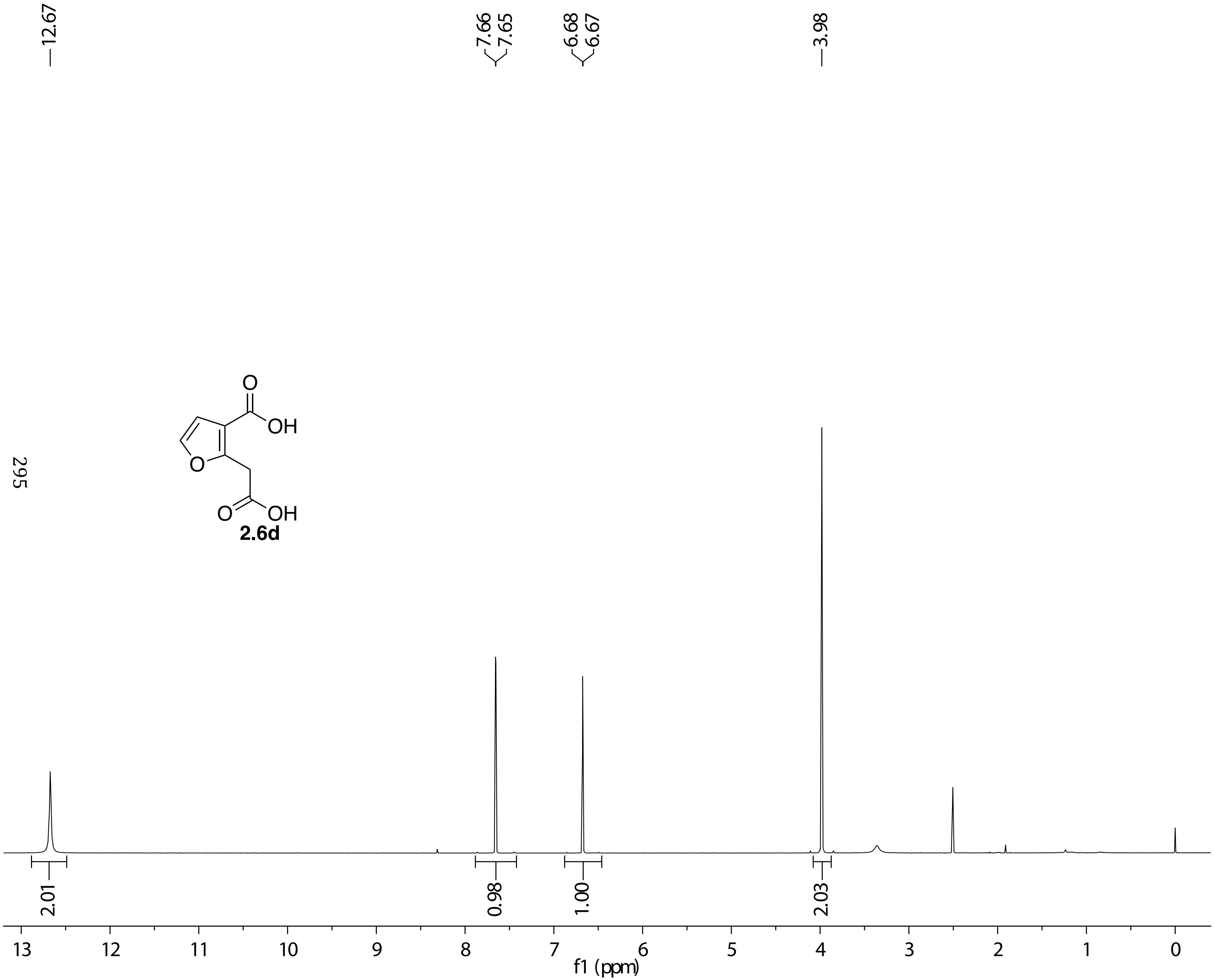
# Appendix A: NMR Spectra for Chapters 2 and 3


1.007
1.797
1.809
1.822
1.835
2.554
2.567
2.581
3.780
3.792
3.805
3.934
7.298
7.314
7.373
7.389
7.393
7.406
7.421
7.429
7.443
7.457
7.624
7.627
7.640
7.817
7.820
12.606
8.374
2.050
2.000
2.111
2.065
1.127
7.085
3.777
1.064
3.897
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
O
OH
OH
O
TBDPSO

**2.6c**

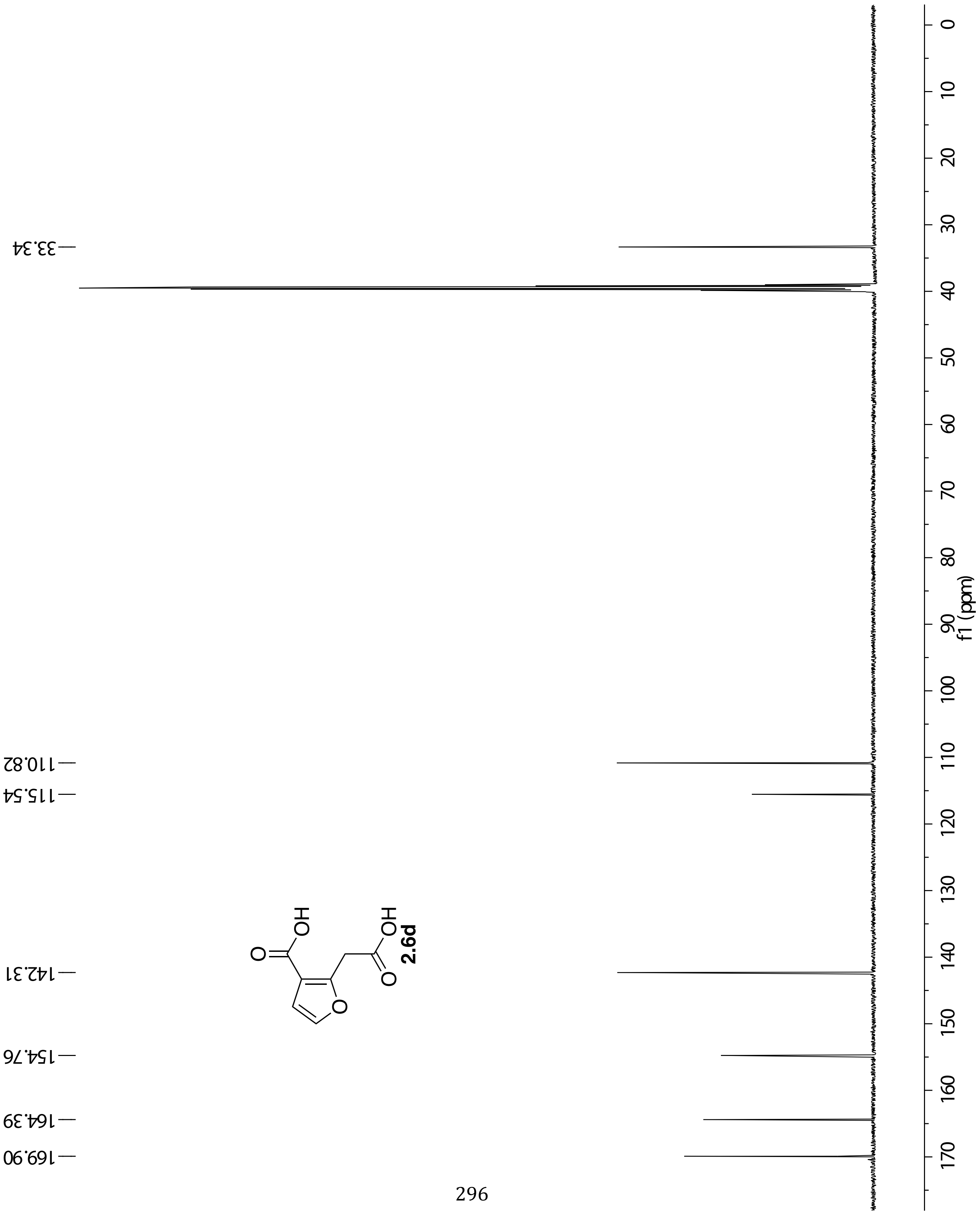

15.146
18.838
26.671
30.860
62.015
79.741
90.727
127.913
129.848
132.764
133.034
133.125
134.072
134.492
135.029
136.275
167.594
172.221
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
O
OH
OH
O
TBDPSO

**2.6c**

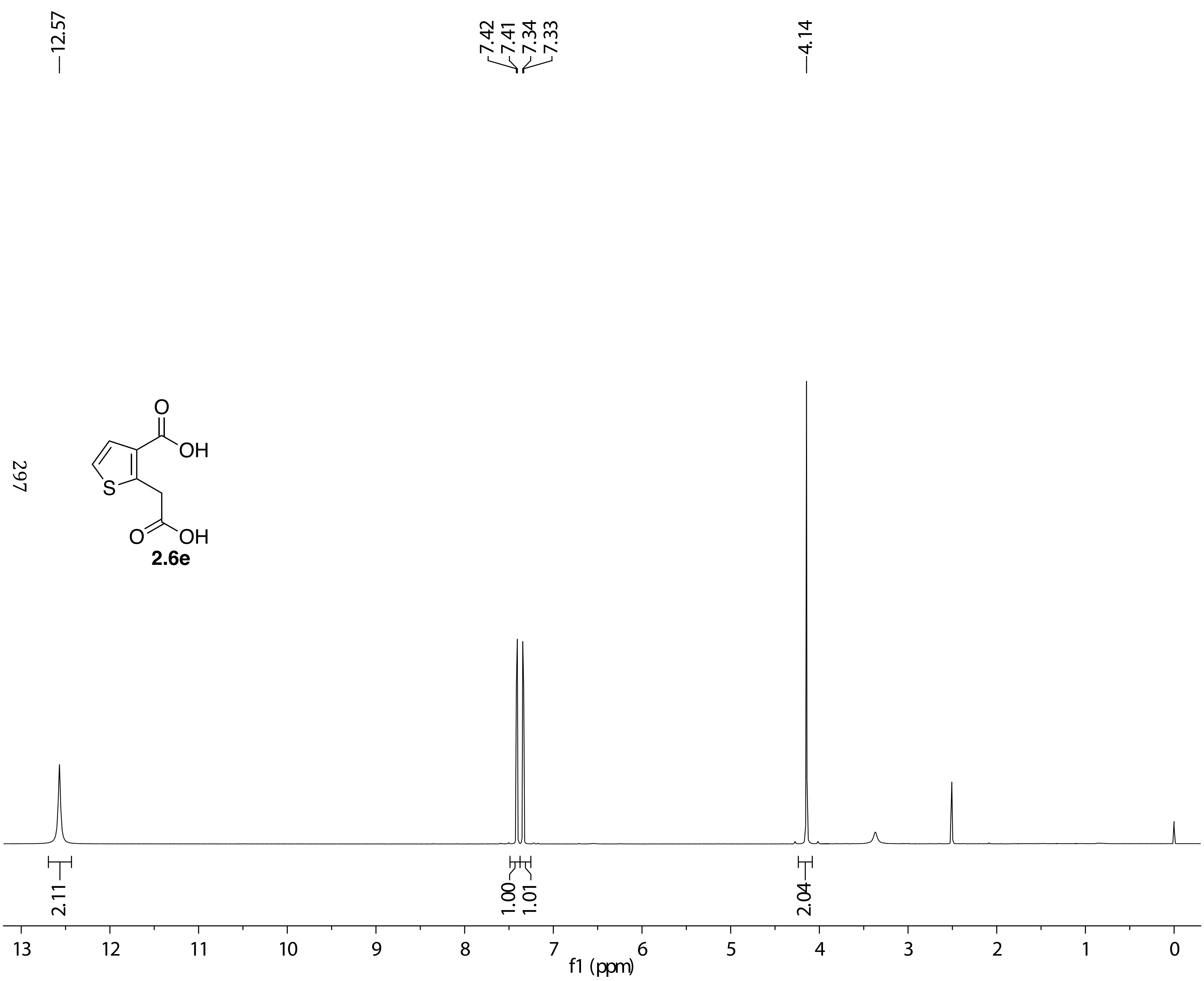


**2.6d**

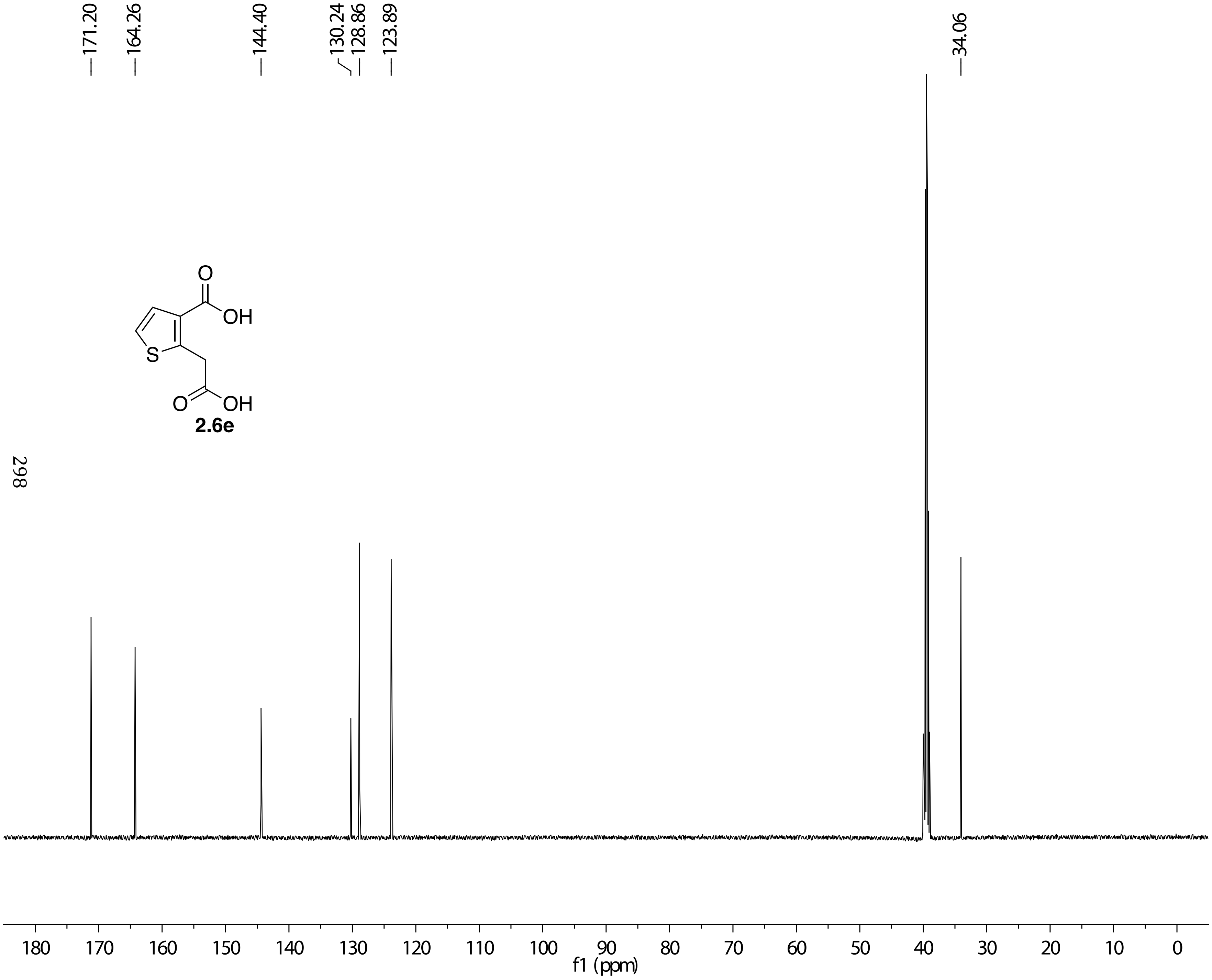
12.67
7.66
7.65
6.68
6.67
3.98
OH
O
OH
O
2.01
0.98
1.00
2.03
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)



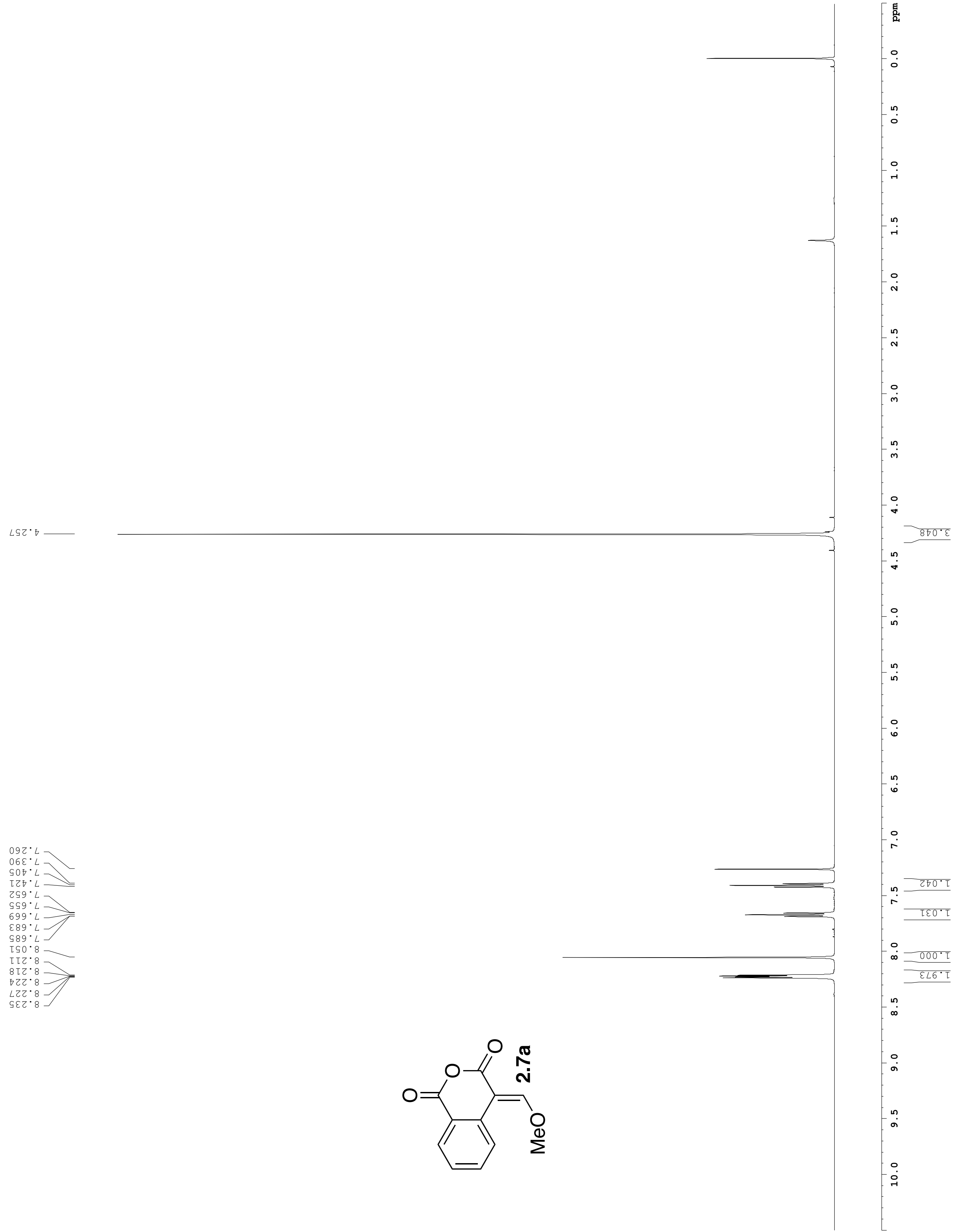
33.34
110.82
115.54
142.31
154.76
164.39
169.90
O
HO
O
OH
O
2.6d
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
f1 (ppm)


**2.6e**

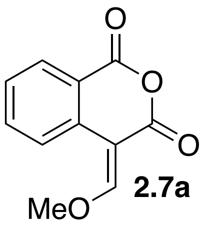
12.57
7.42
7.41
7.34
7.33
4.14
2.11
1.00
1.01
2.04
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)
S
O
OH
O
OH


171.20
164.26
144.40
130.24
128.86
123.89
34.06
O
OH
S
O
OH
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

**2.6e**

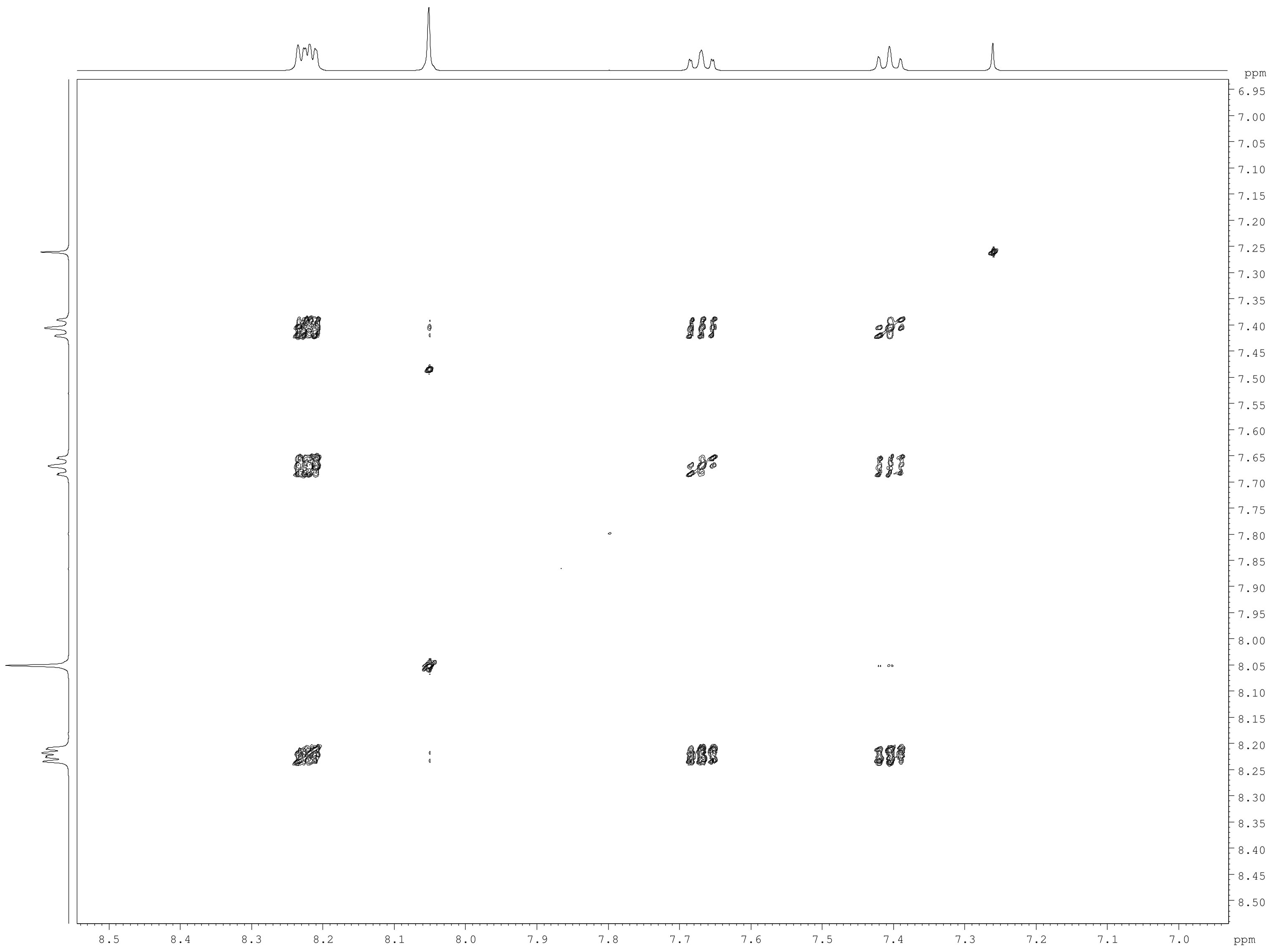


4.257
7.260
7.390
7.405
7.421
7.652
7.655
7.669
7.683
7.685
8.051
8.211
8.218
8.224
8.227
8.235
3.048
1.042
1.031
1.000
1.973
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
O
O
MeO
2.7a

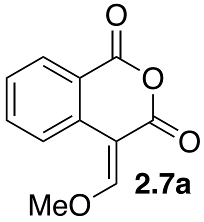


**2.7a**

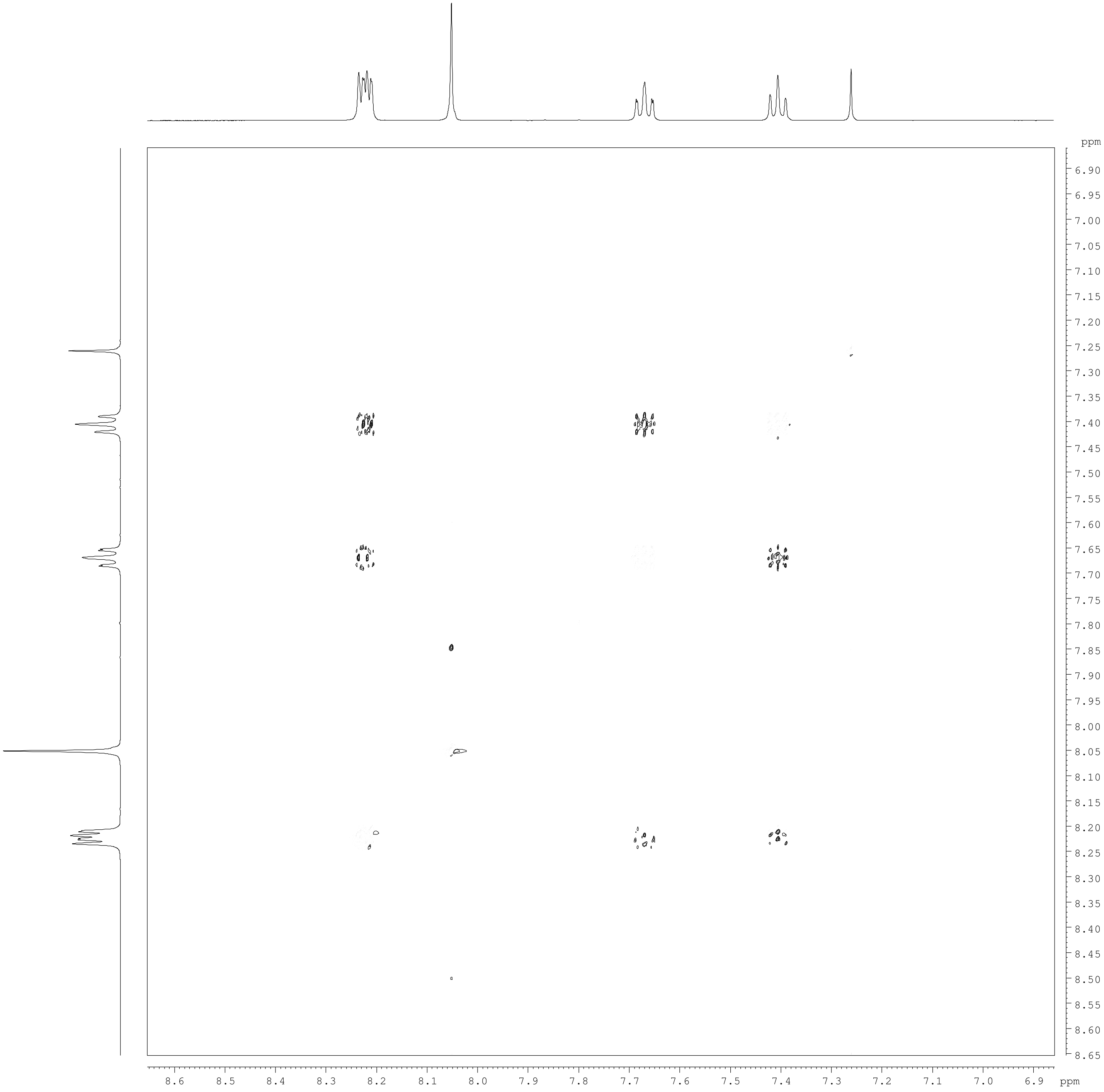
# COSY

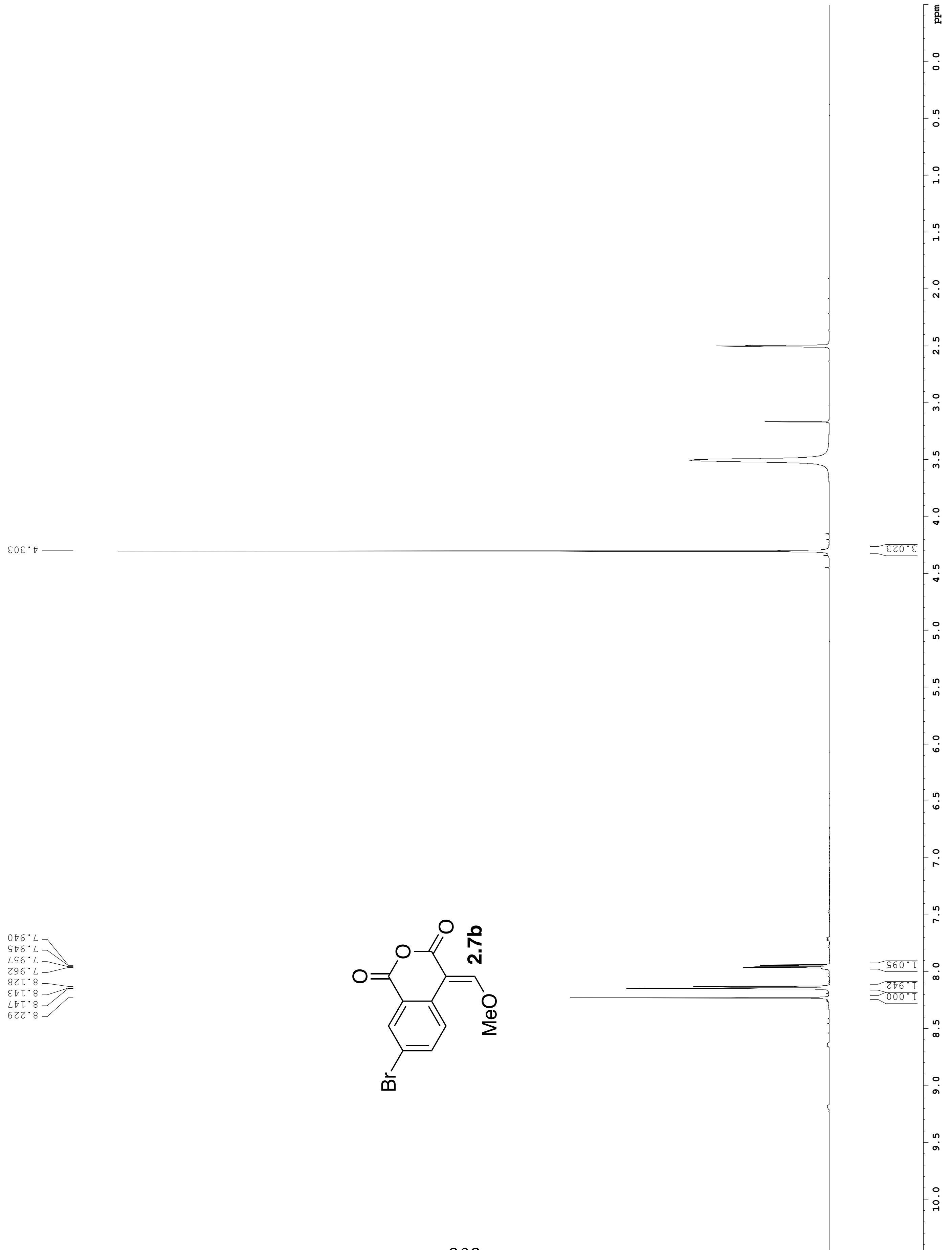

ppm
6.95
7.00
7.05
7.10
7.15
7.20
7.25
7.30
7.35
7.40
7.45
7.50
7.55
7.60
7.65
7.70
7.75
7.80
7.85
7.90
7.95
8.00
8.05
8.10
8.15
8.20
8.25
8.30
8.35
8.40
8.45
8.50
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
ppm

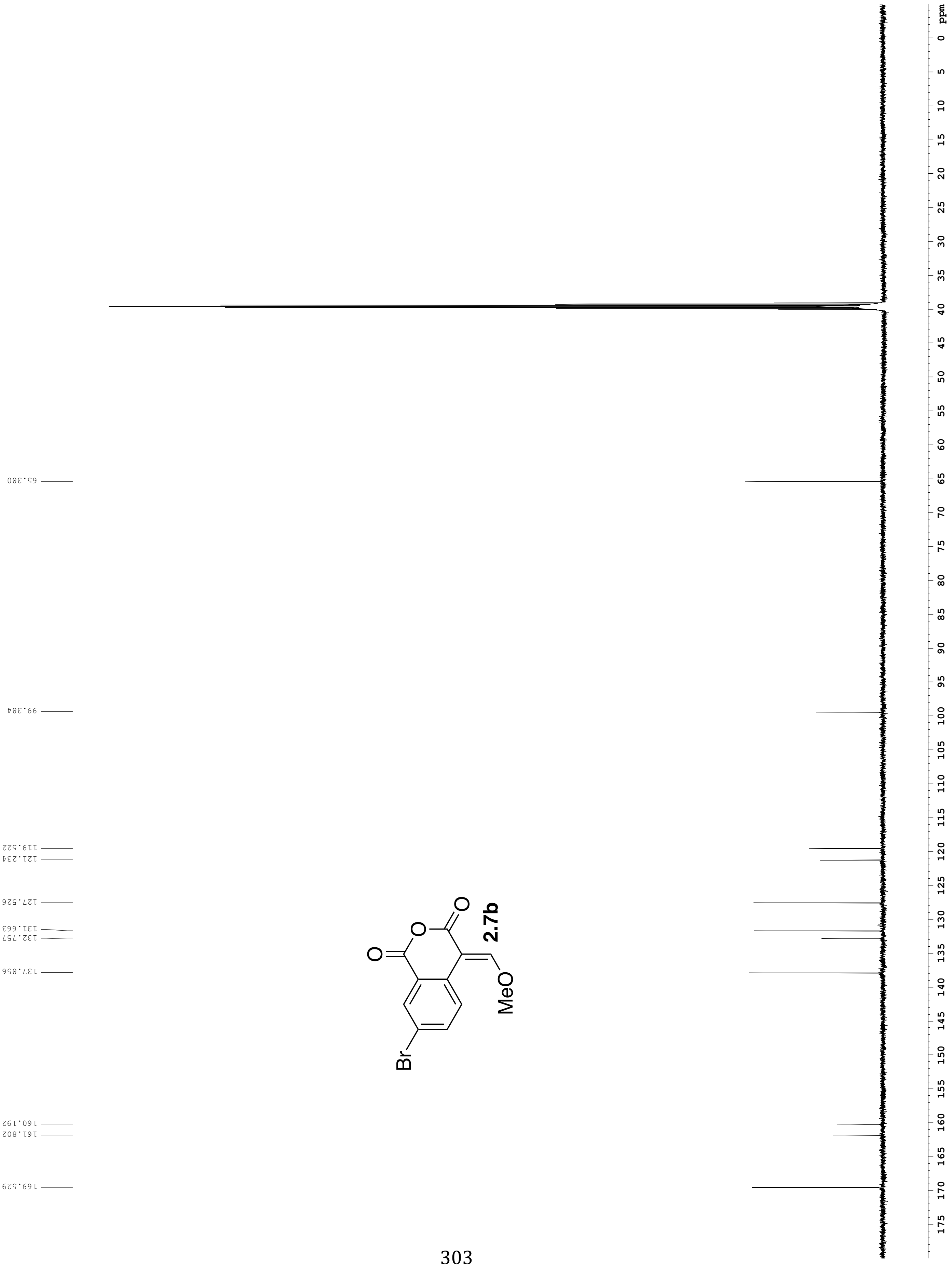
NOESY


O
O
O
MeO

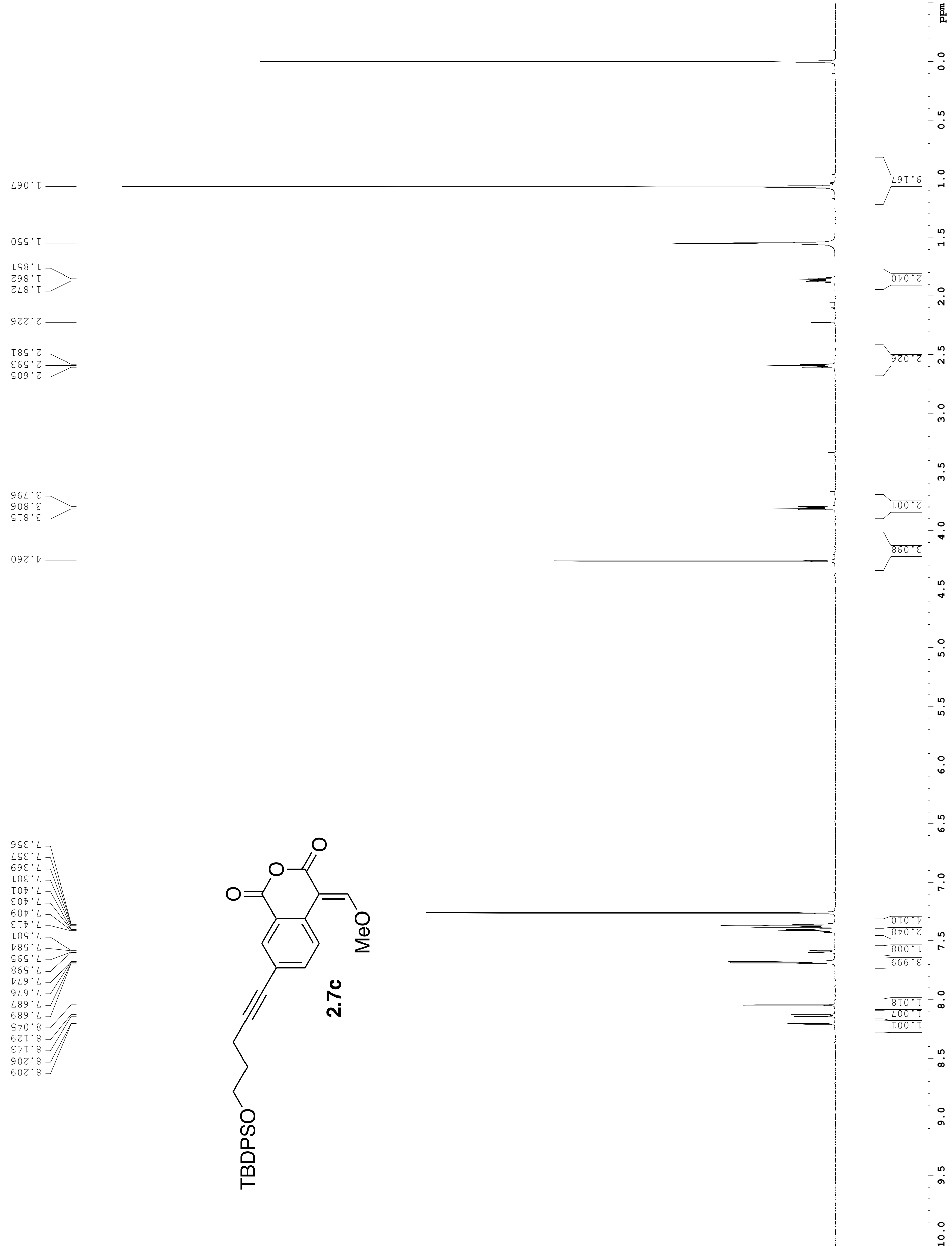
**2.7a**


ppm
6.90
6.95
7.00
7.05
7.10
7.15
7.20
7.25
7.30
7.35
7.40
7.45
7.50
7.55
7.60
7.65
7.70
7.75
7.80
7.85
7.90
7.95
8.00
8.05
8.10
8.15
8.20
8.25
8.30
8.35
8.40
8.45
8.50
8.55
8.60
8.65
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
6.9
ppm

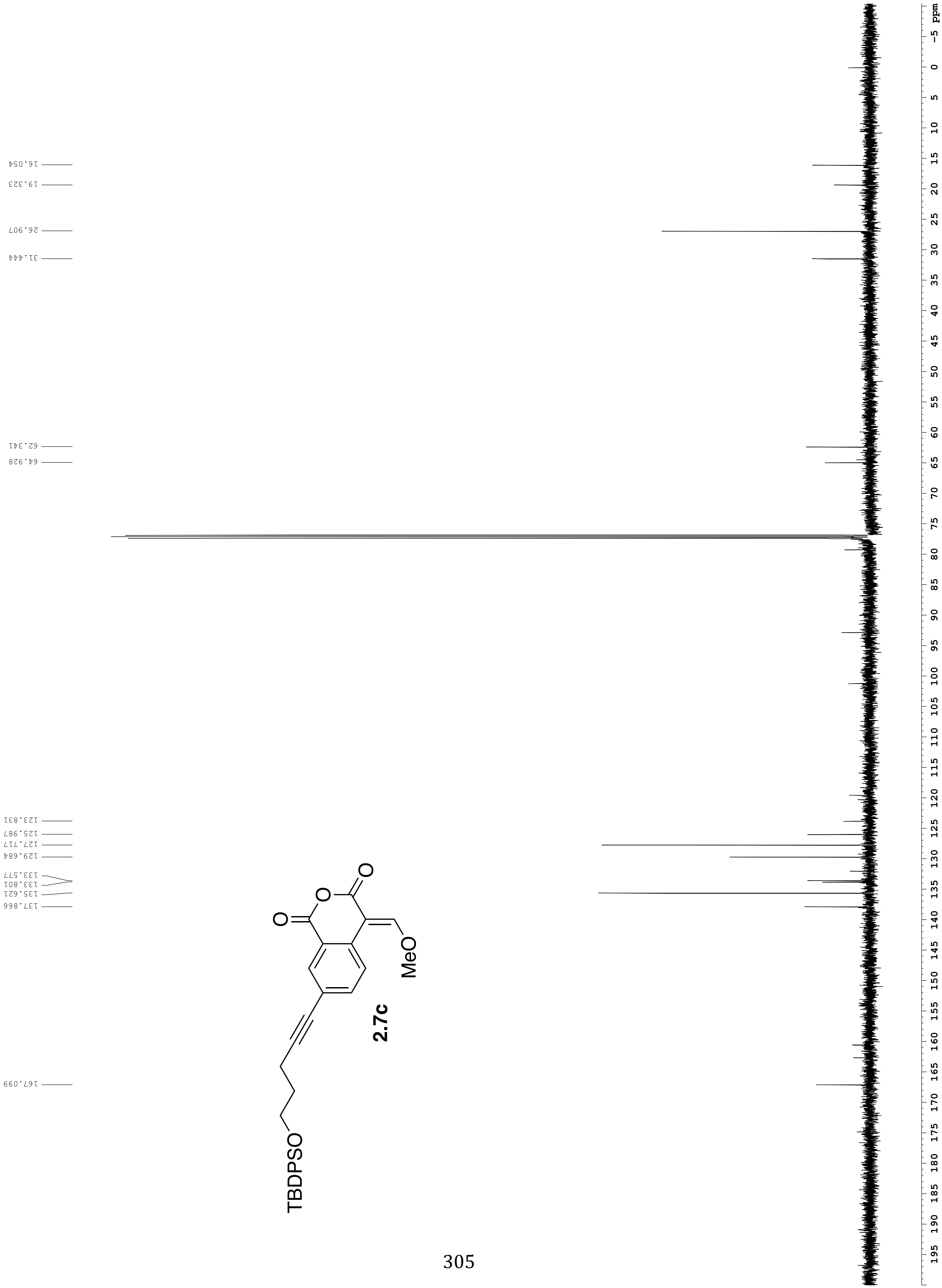

4.303
7.940
7.945
7.957
7.962
8.128
8.143
8.147
8.229
3.023
1.095
1.942
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
O
O
MeO
Br
2.7b


65.380
99.384
119.522
121.234
127.526
131.663
132.757
137.856
160.192
161.802
169.529
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
O
O
O
MeO
Br

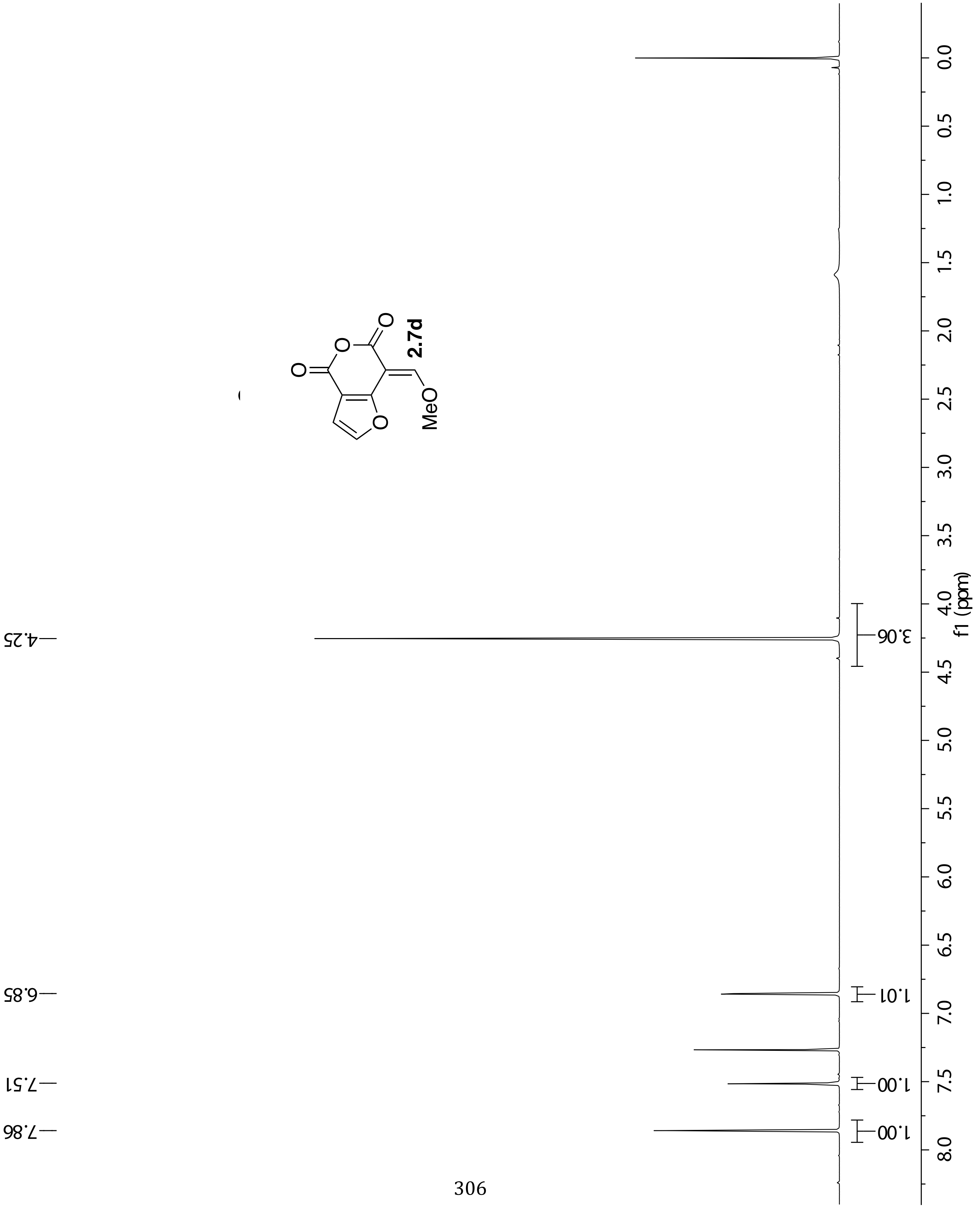
**2.7b**

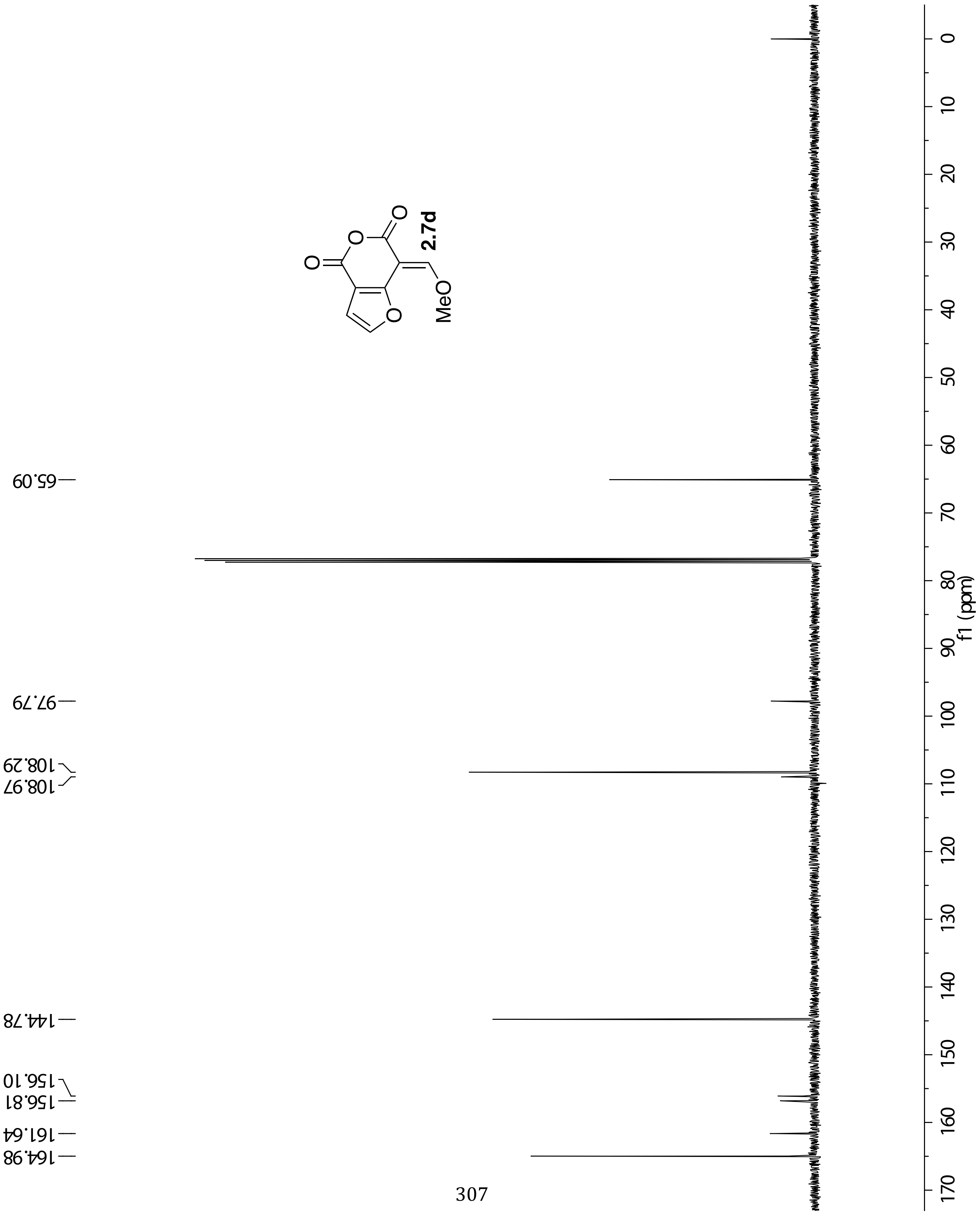

**2.7c**

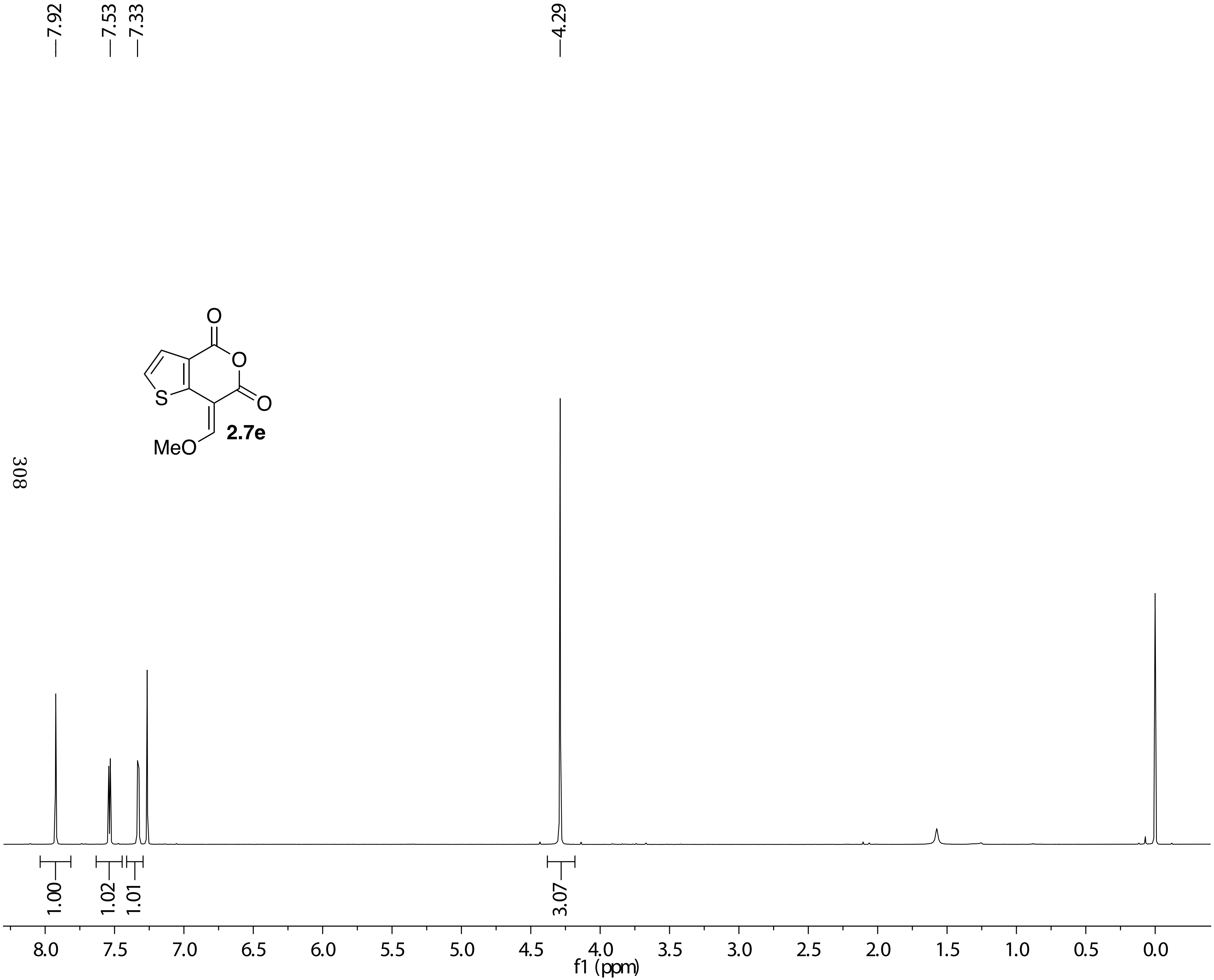
TBDPSO
MeO
O
O
O
1.067
1.550
1.851
1.862
1.872
2.226
2.581
2.593
2.605
3.796
3.806
3.815
4.260
7.356
7.357
7.369
7.381
7.401
7.403
7.409
7.413
7.581
7.584
7.595
7.598
7.674
7.676
7.687
7.689
8.045
8.129
8.143
8.206
8.209
9.167
2.040
2.026
2.001
3.098
4.010
2.048
1.008
3.999
1.018
1.007
1.001
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0


16.054
19.323
26.907
31.444
62.341
64.928
123.831
125.987
127.717
129.684
133.577
133.801
135.621
137.866
167.099
O
O
O
MeO
TBDPSO
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195

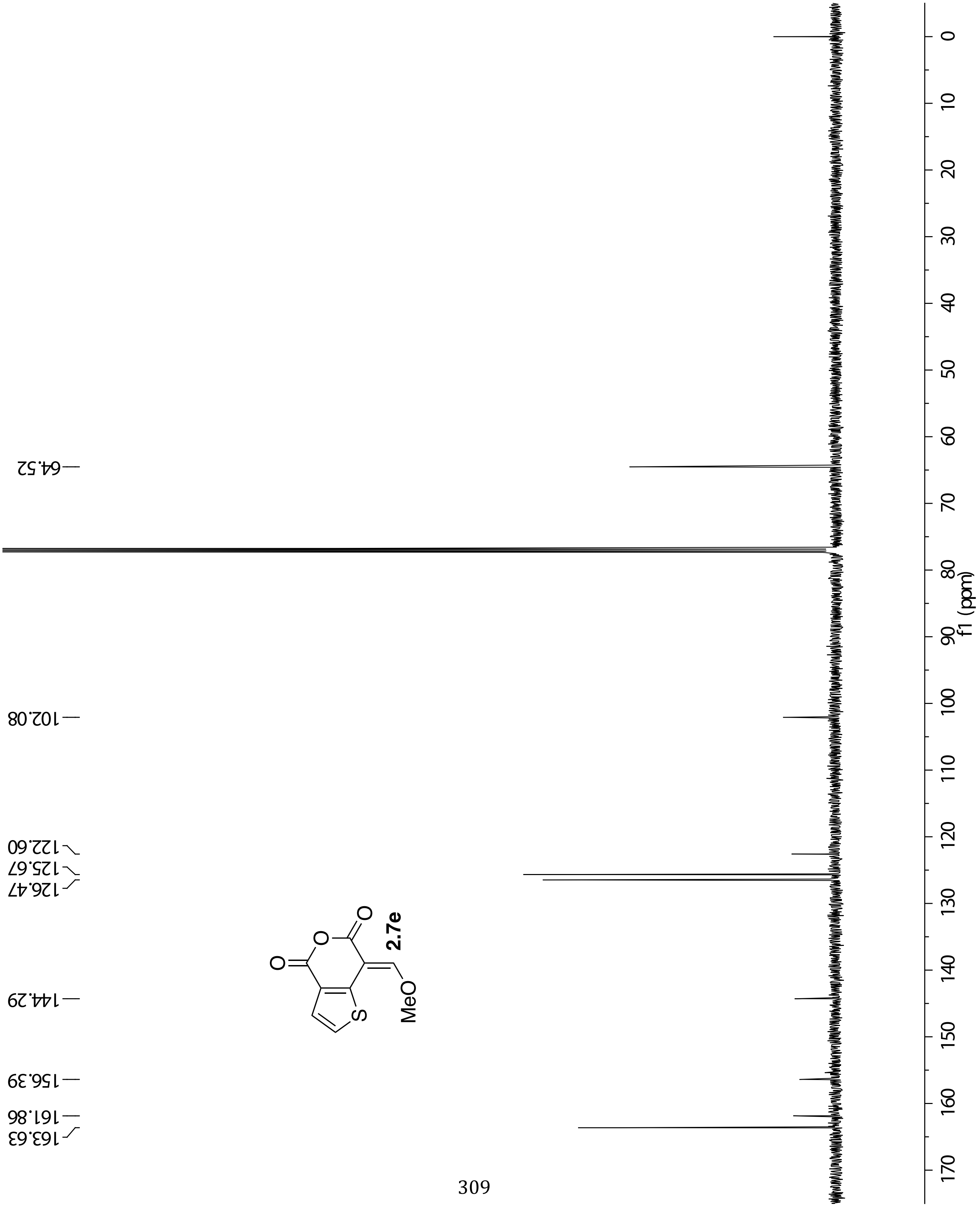
**2.7c**


2.7d
MeO
O
O
O
O
7.86
7.51
6.85
4.25
1.00
1.00
1.01
3.06
f1 (ppm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0

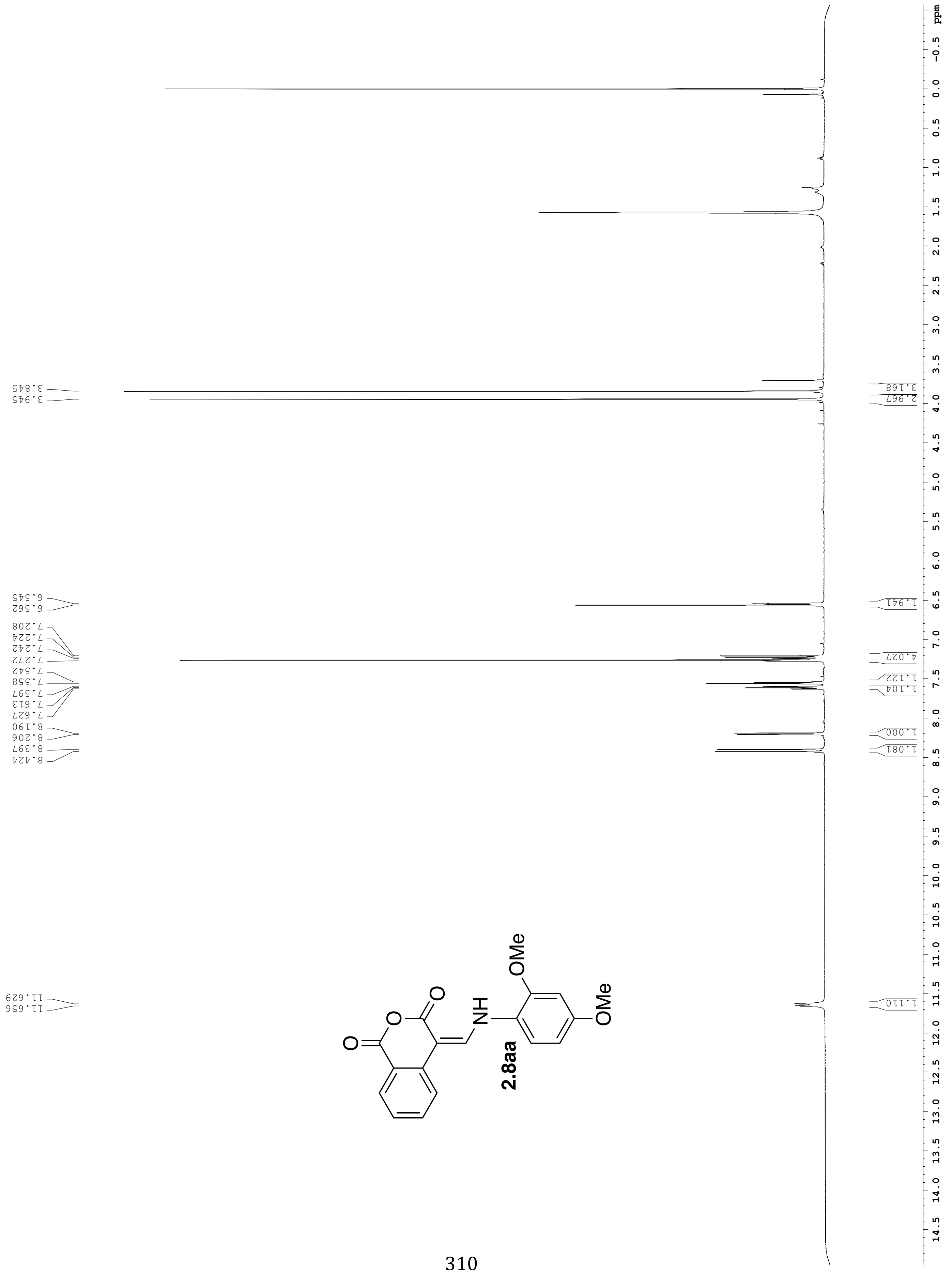

2.7d
MeO
O
65.09
97.79
108.29
108.97
144.78
156.10
156.81
161.64
164.98
f1 (ppm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170

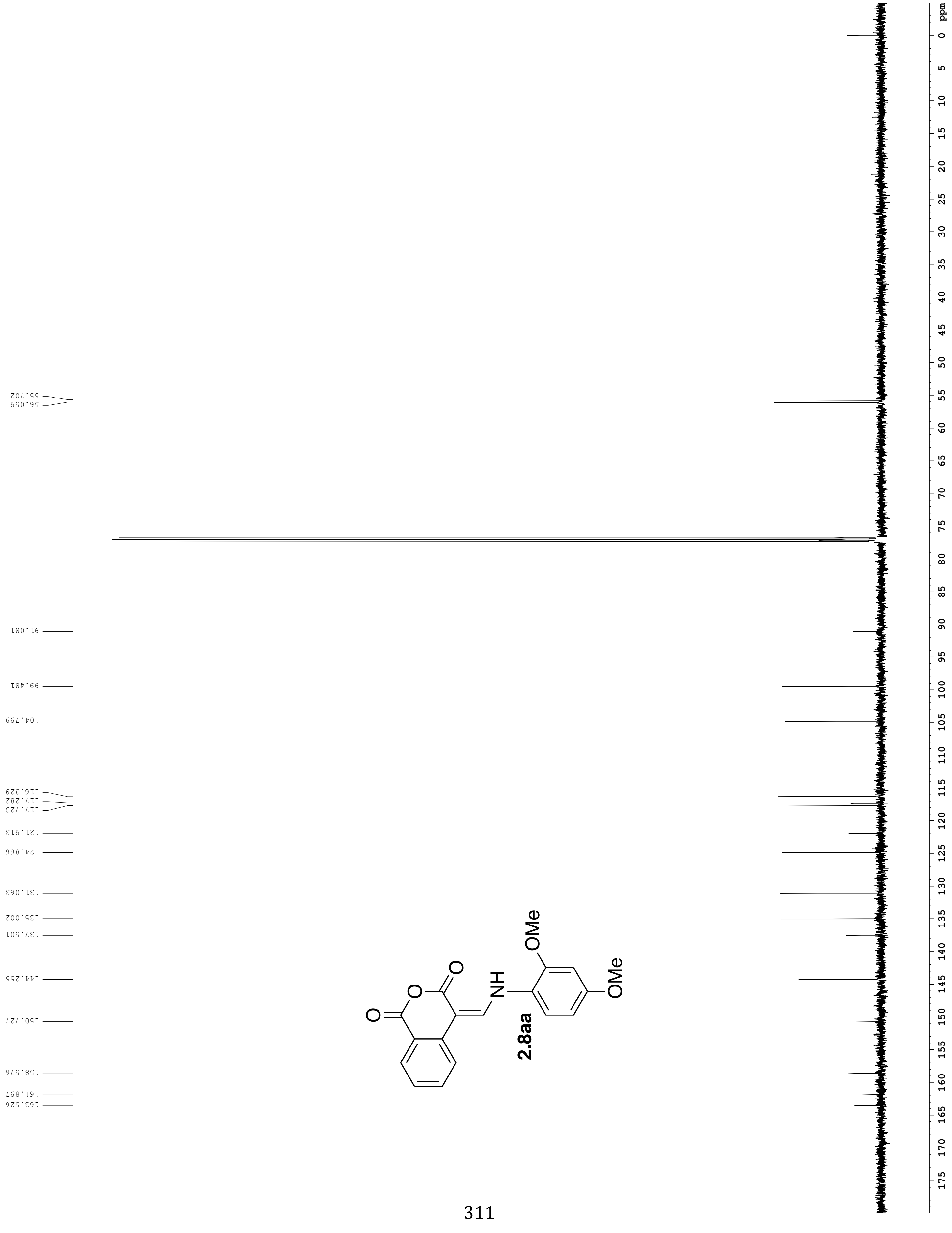

7.92
7.53
7.33
4.29
S
O
O
O
MeO
1.00
1.02
1.01
3.07
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

**2.7e**

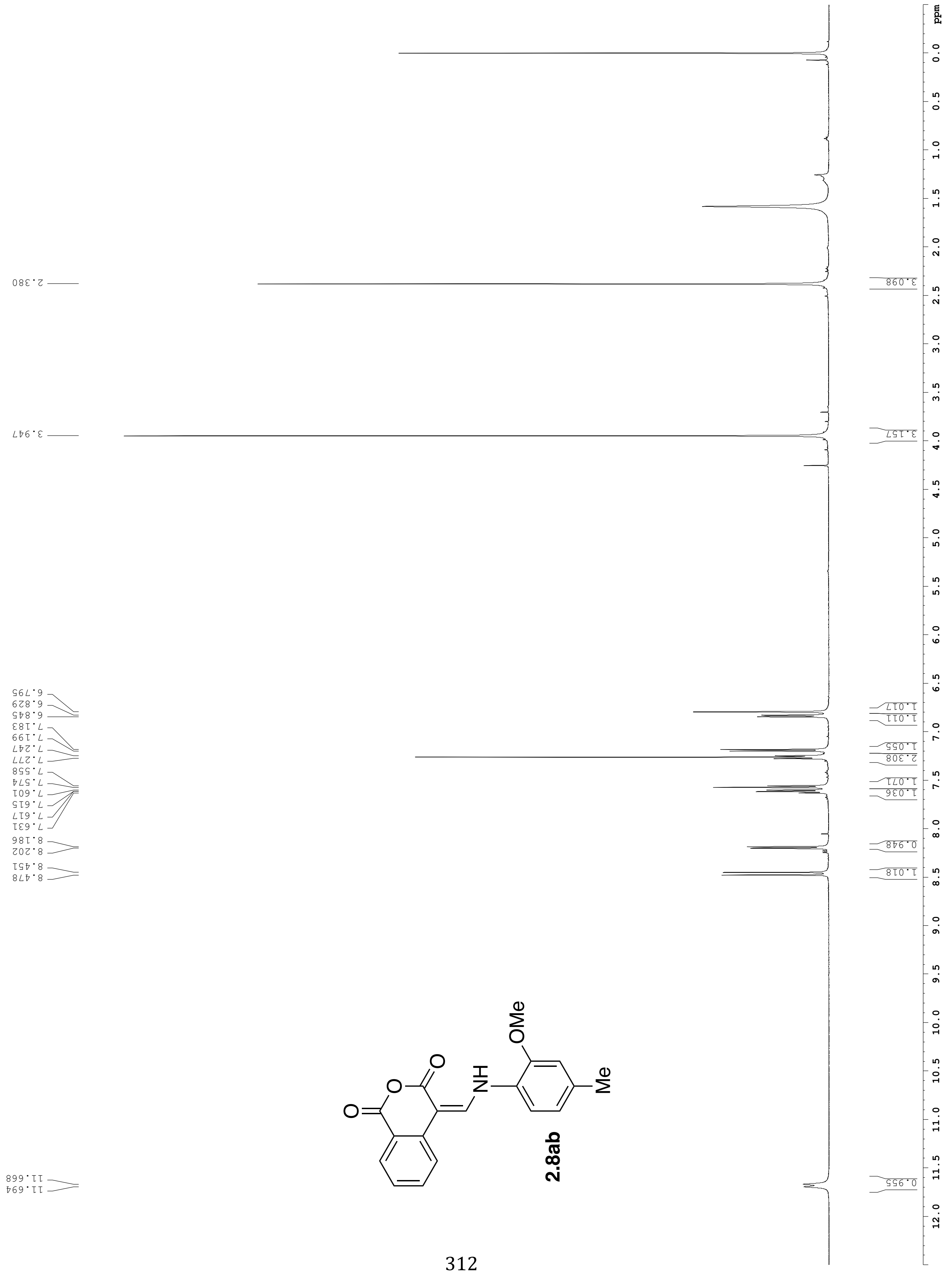


64.52
102.08
122.60
125.67
126.47
144.29
156.39
161.86
163.63
O
O
O
S
MeO
2.7e
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
f1 (ppm)


3.845
3.945
6.545
6.562
7.208
7.224
7.242
7.272
7.542
7.558
7.597
7.613
7.627
8.190
8.206
8.397
8.424
11.629
11.656
3.168
2.967
1.941
4.027
1.122
1.104
1.000
1.081
1.110
ppm
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
O
O
O
NH
OMe
OMe
2.8aa

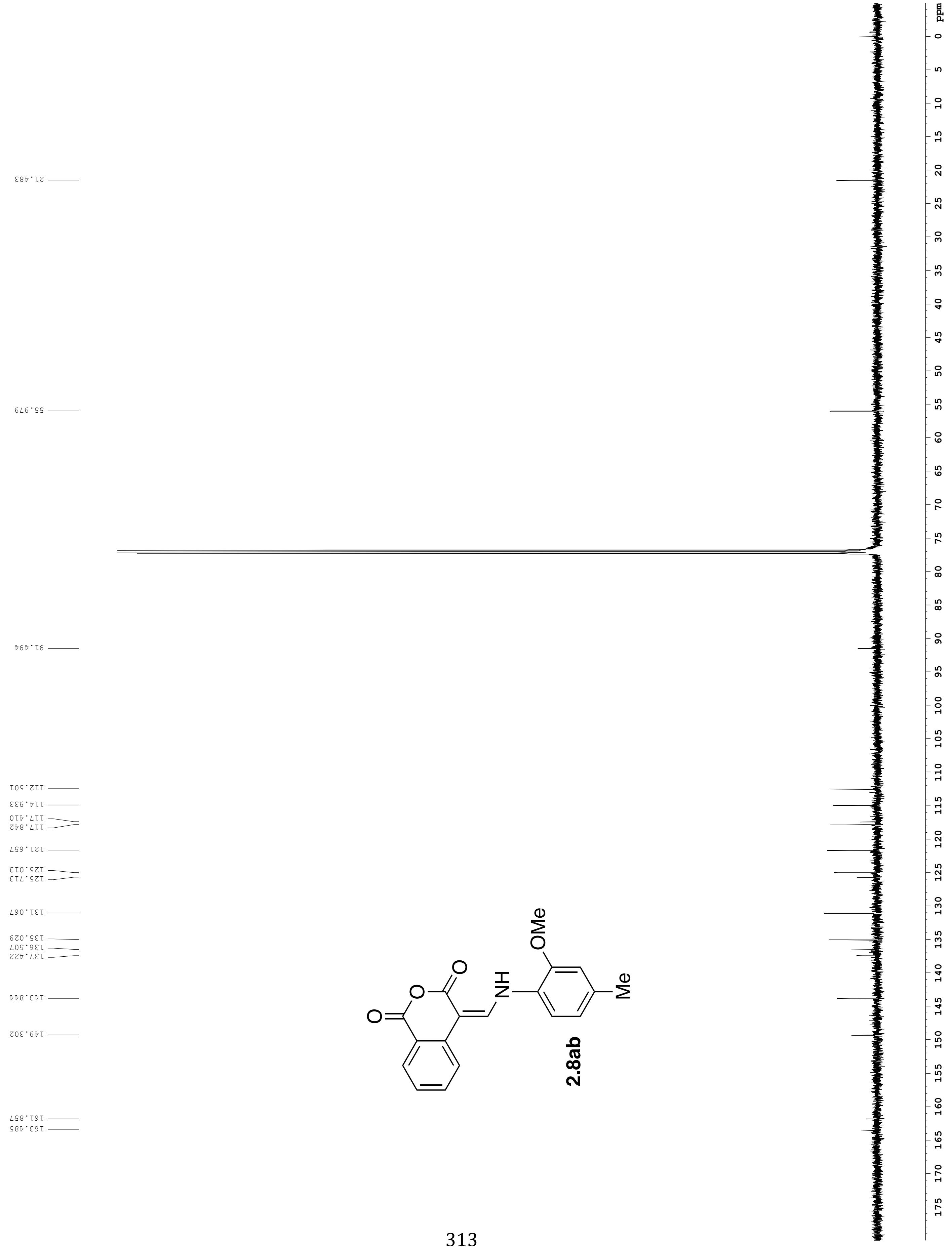

**2.8aa**

55.702
56.059
91.081
99.481
104.799
116.329
117.282
117.723
121.913
124.866
131.063
135.002
137.501
144.255
150.727
158.576
161.897
163.526
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
O
O
O
NH
OMe
OMe



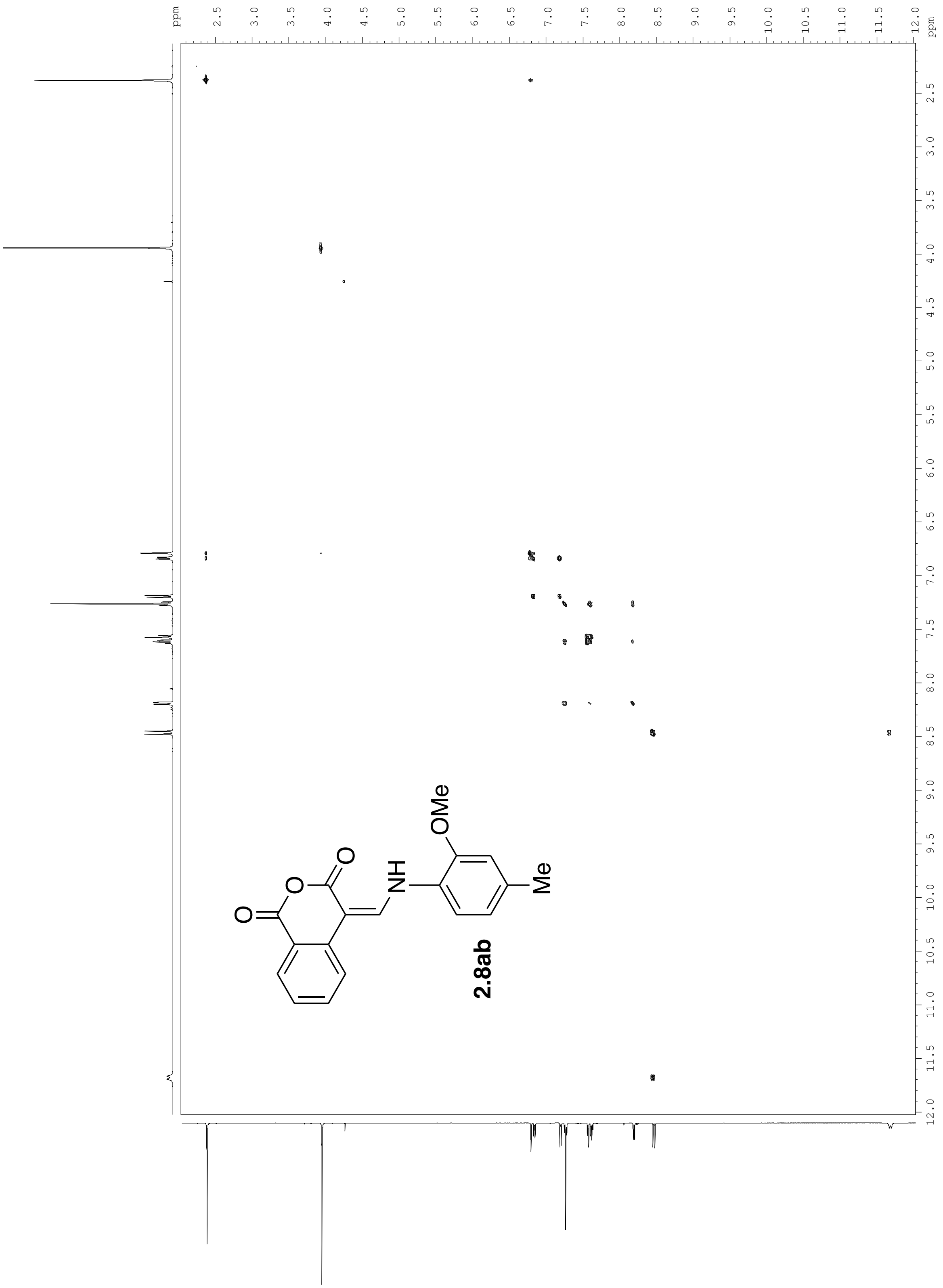
2.380
3.947
6.795
6.829
6.845
7.183
7.199
7.247
7.277
7.558
7.574
7.601
7.615
7.617
7.631
8.186
8.202
8.451
8.478
11.668
11.694
3.098
3.157
1.017
1.011
1.055
2.308
1.071
1.036
0.948
1.018
0.955
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
OMe
NH
Me
O

**2.8ab**


21.483
55.979
91.494
112.501
114.933
117.410
117.842
121.657
125.013
125.713
131.067
135.029
136.507
137.422
143.844
149.302
161.857
163.485
OMe
NH
Me
O
O
O
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

**2.8ab**

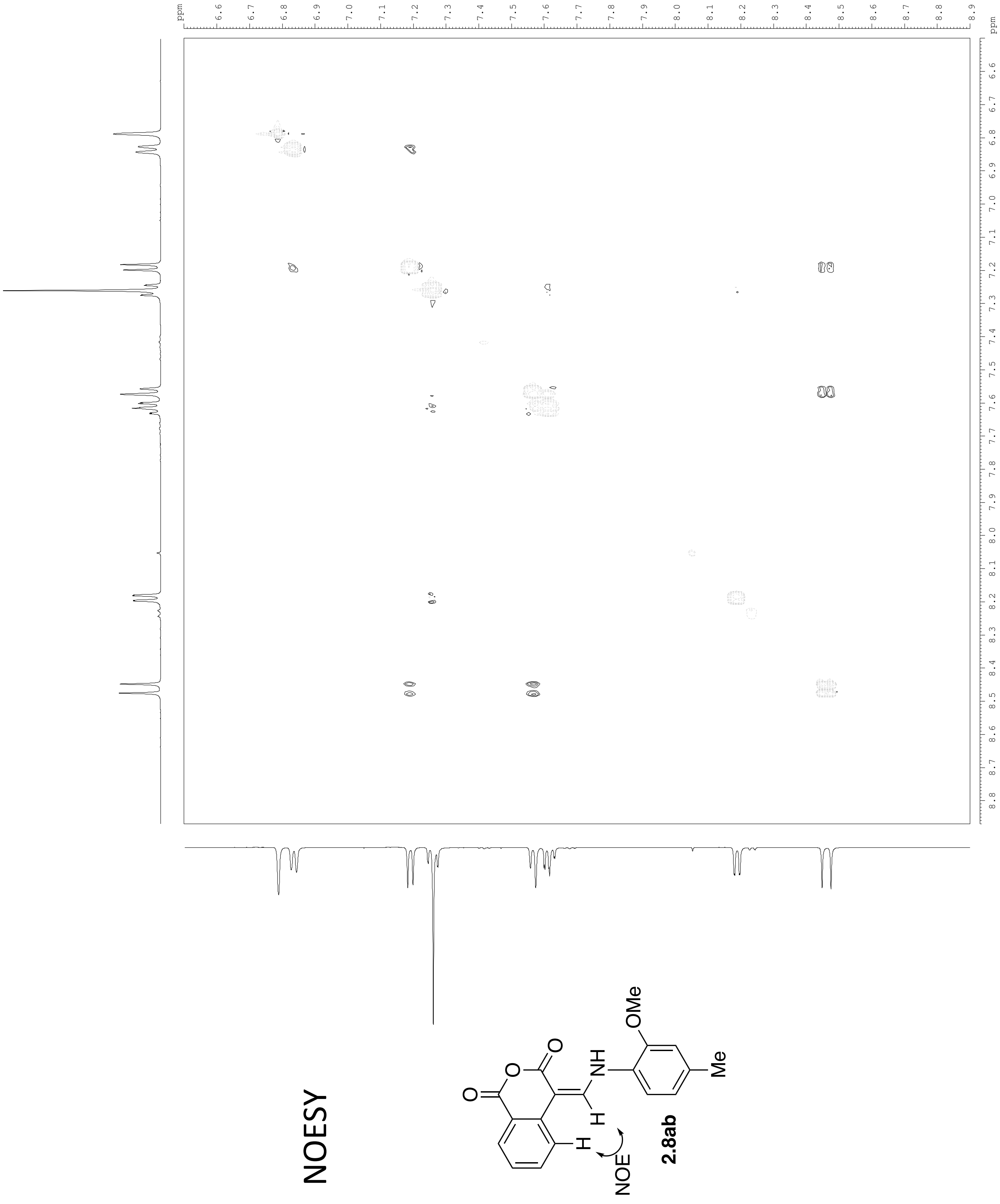
# COSY



**2.8ab**

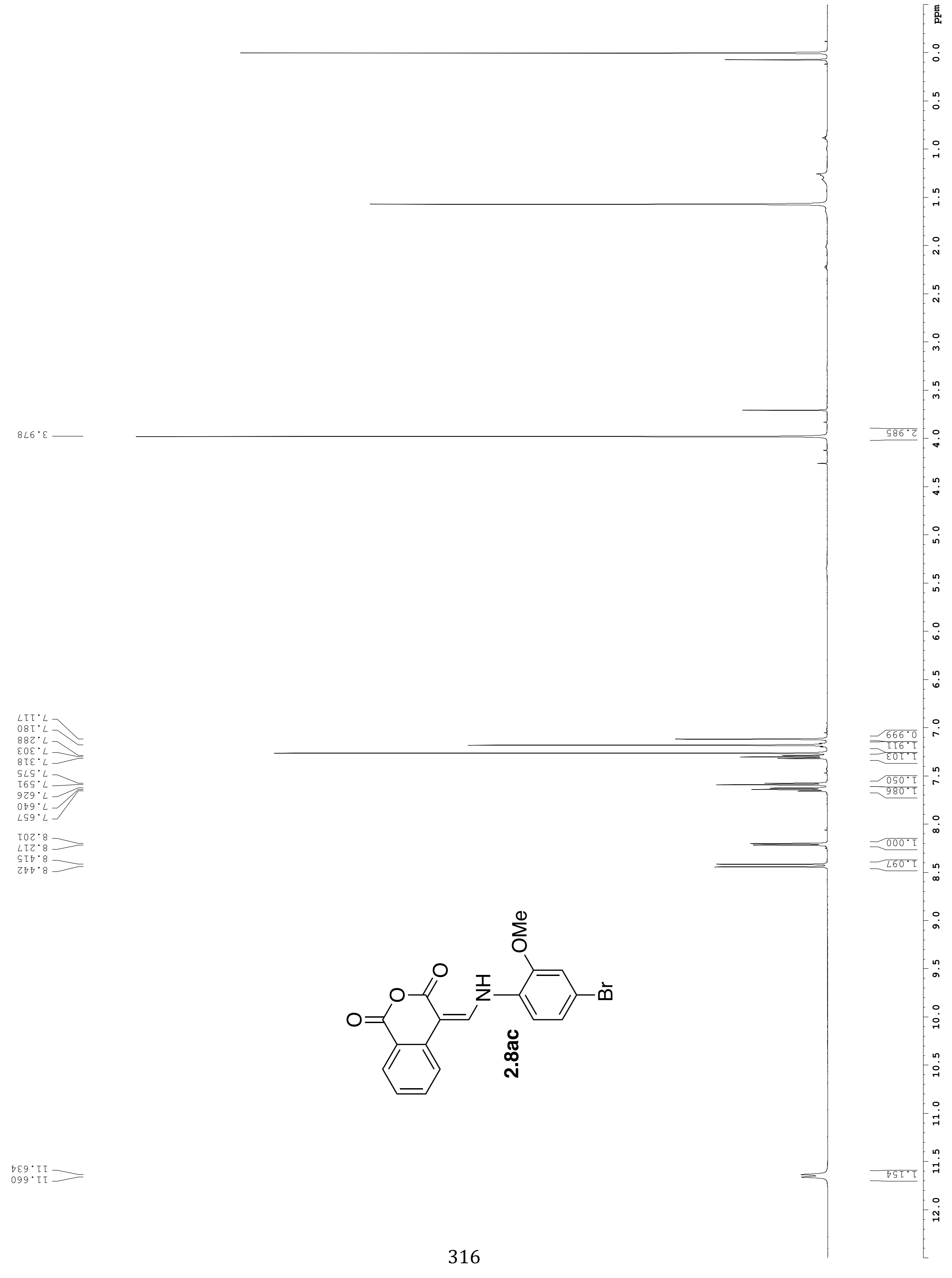
ppm
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
ppm
O
O
O
NH
OMe
Me

NOESY



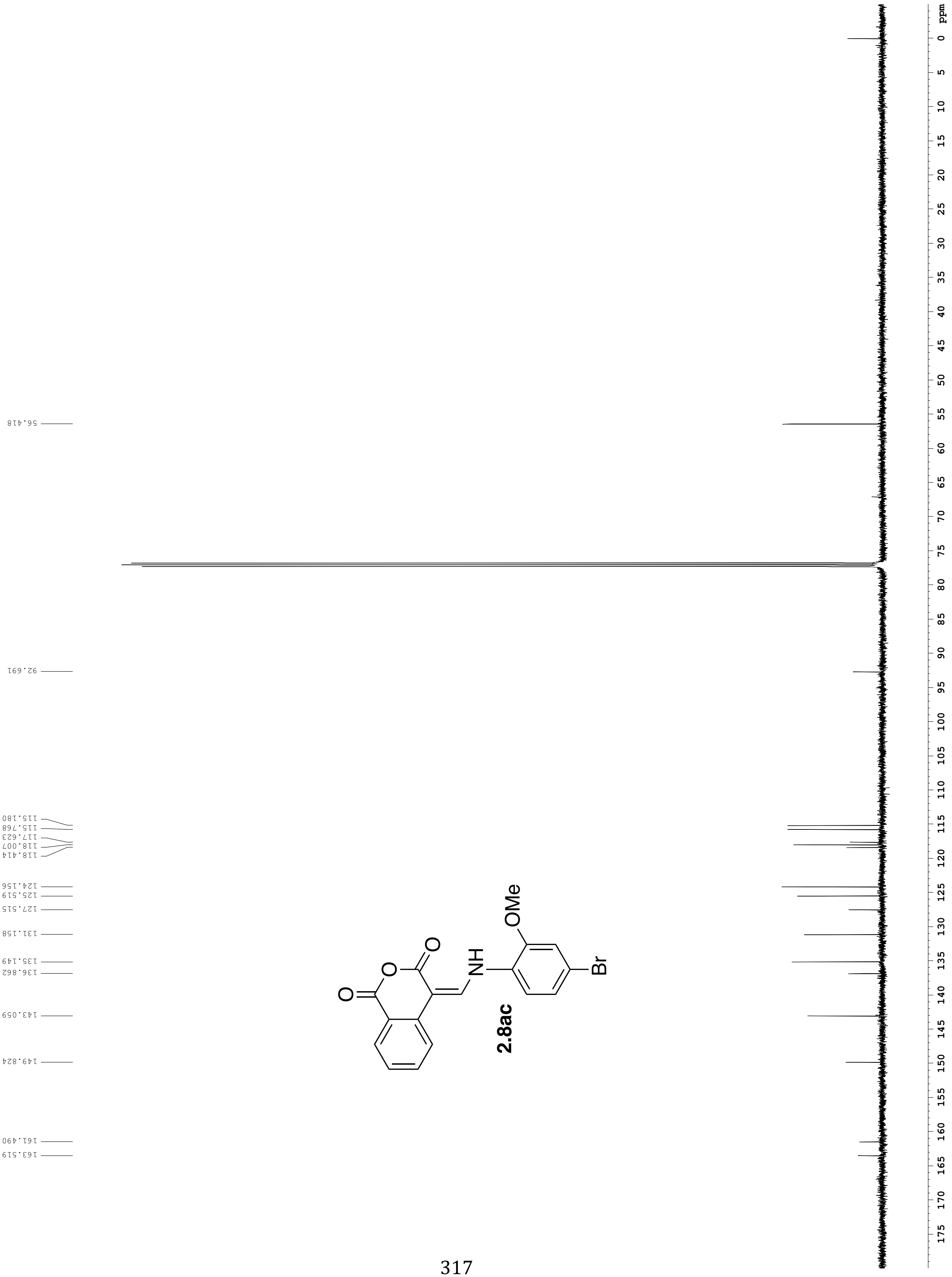
ppm
6.6
6.7
6.8
6.9
7.0
7.1
7.2
7.3
7.4
7.5
7.6
7.7
7.8
7.9
8.0
8.1
8.2
8.3
8.4
8.5
8.6
8.7
8.8
8.9
O
O
O
NH
OMe
Me
H
H
NOE

**2.8ab**



3.978
7.117
7.180
7.288
7.303
7.318
7.575
7.591
7.626
7.640
7.657
8.201
8.217
8.415
8.442
11.634
11.660
2.985
0.999
1.911
1.103
1.050
1.086
1.000
1.097
1.154
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
O
O
O
NH
OMe
Br

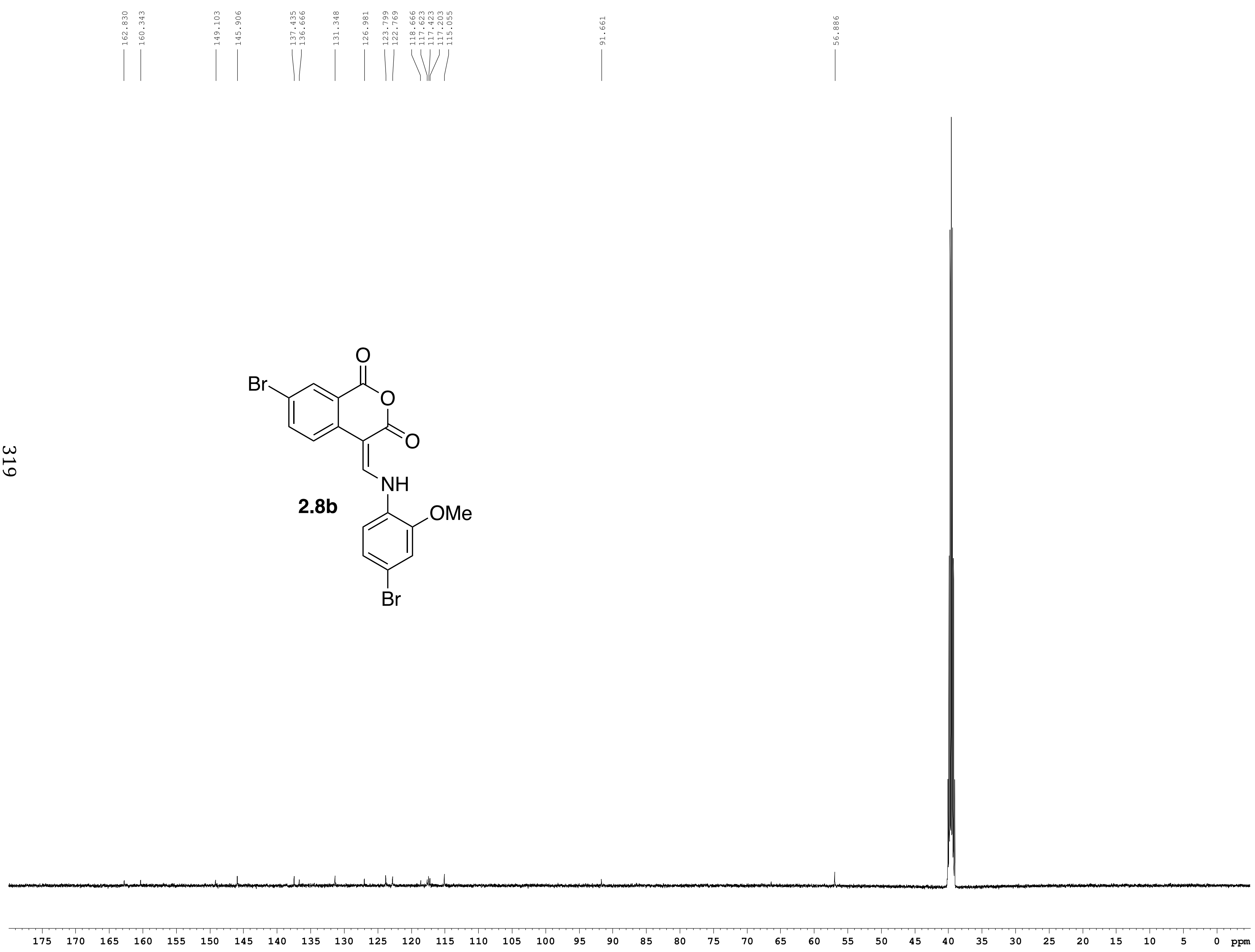
**2.8ac**


56.418
92.691
115.180
115.768
117.623
118.007
118.414
124.156
125.519
127.515
131.158
135.149
136.862
143.059
149.824
161.490
163.519
O
O
O
NH
OMe
Br
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

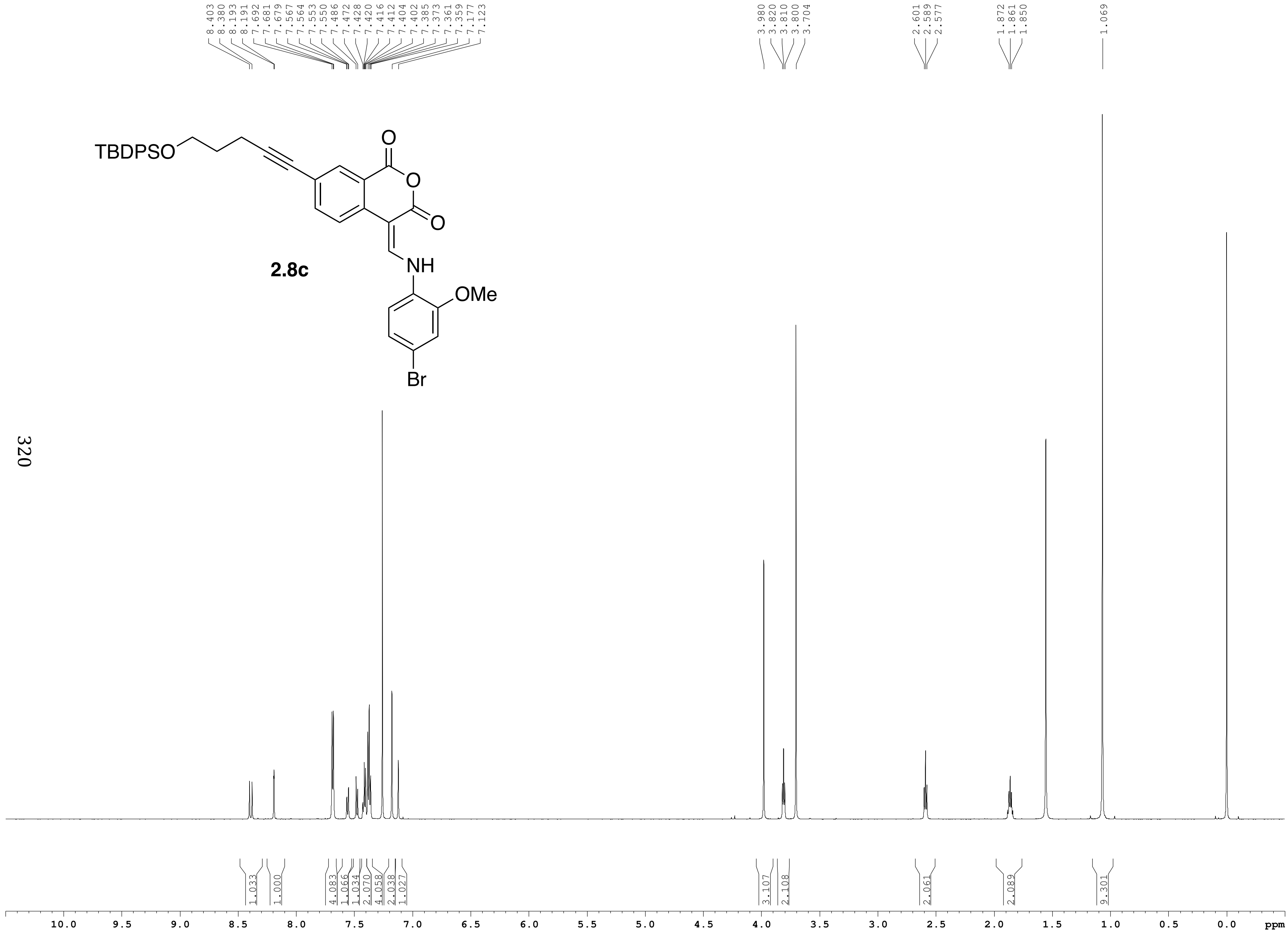
**2.8ac**


3.969
7.274
7.371
7.883
7.943
8.061
8.169
9.054
9.074
2.922
2.064
3.937
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
O
O
NH
OMe
Br
Br

**2.8b**


162.830
160.343
149.103
145.906
137.435
136.666
131.348
126.981
123.799
122.769
118.666
117.623
117.423
117.203
115.055
91.661
56.886
Br
O
O
O
NH
OMe
Br
175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 ppm

**2.8b**

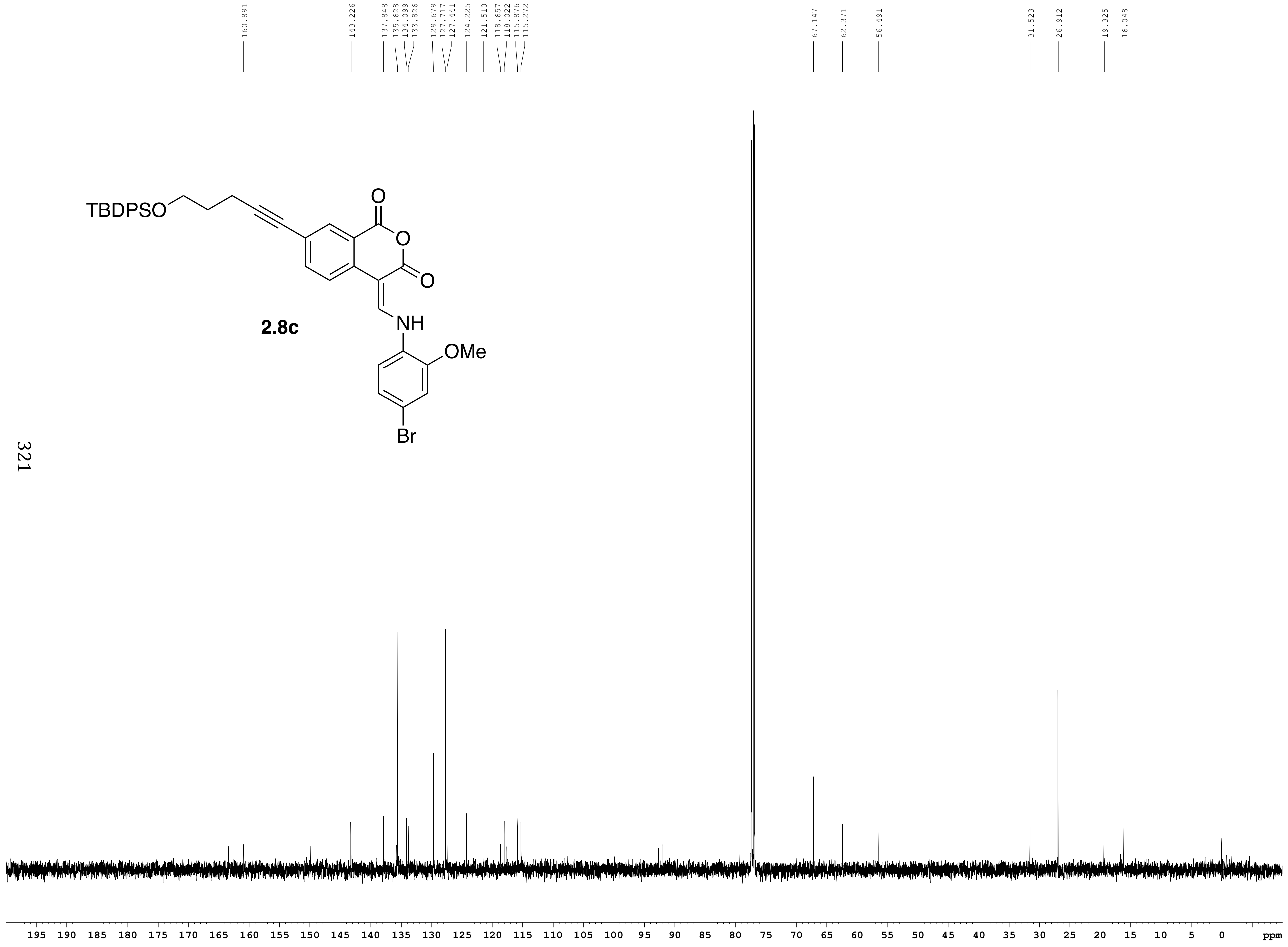


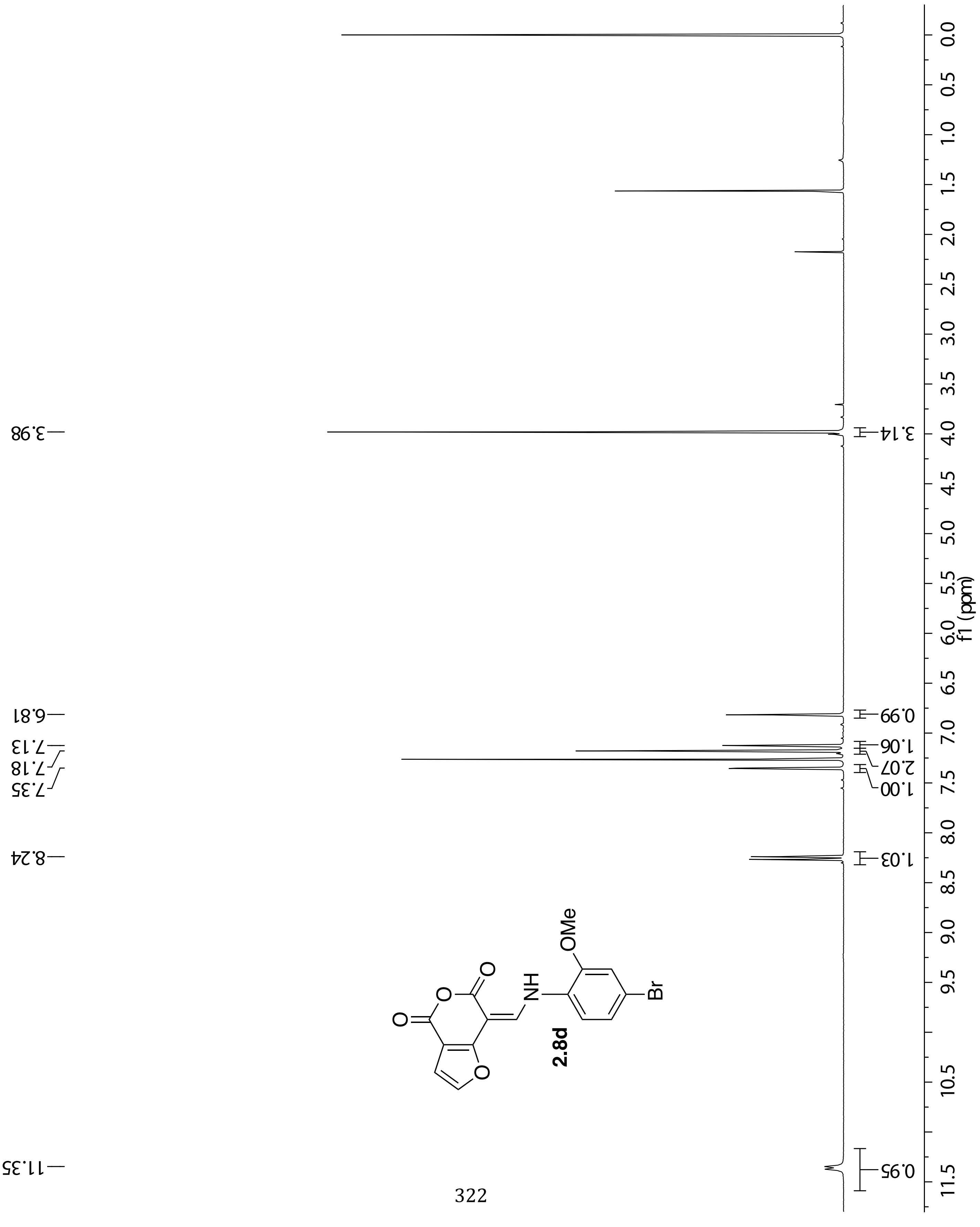
**2.8c**

8.403
8.380
8.193
8.191
7.692
7.681
7.679
7.567
7.564
7.553
7.550
7.486
7.472
7.428
7.420
7.416
7.412
7.404
7.402
7.385
7.373
7.361
7.359
7.177
7.123
3.980
3.820
3.810
3.800
3.704
2.601
2.589
2.577
1.872
1.861
1.850
1.069
TBDPSO
O
O
O
NH
OMe
Br
1.033
1.000
4.083
1.066
1.034
2.070
4.058
2.038
1.027
3.107
2.108
2.061
2.089
9.301
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

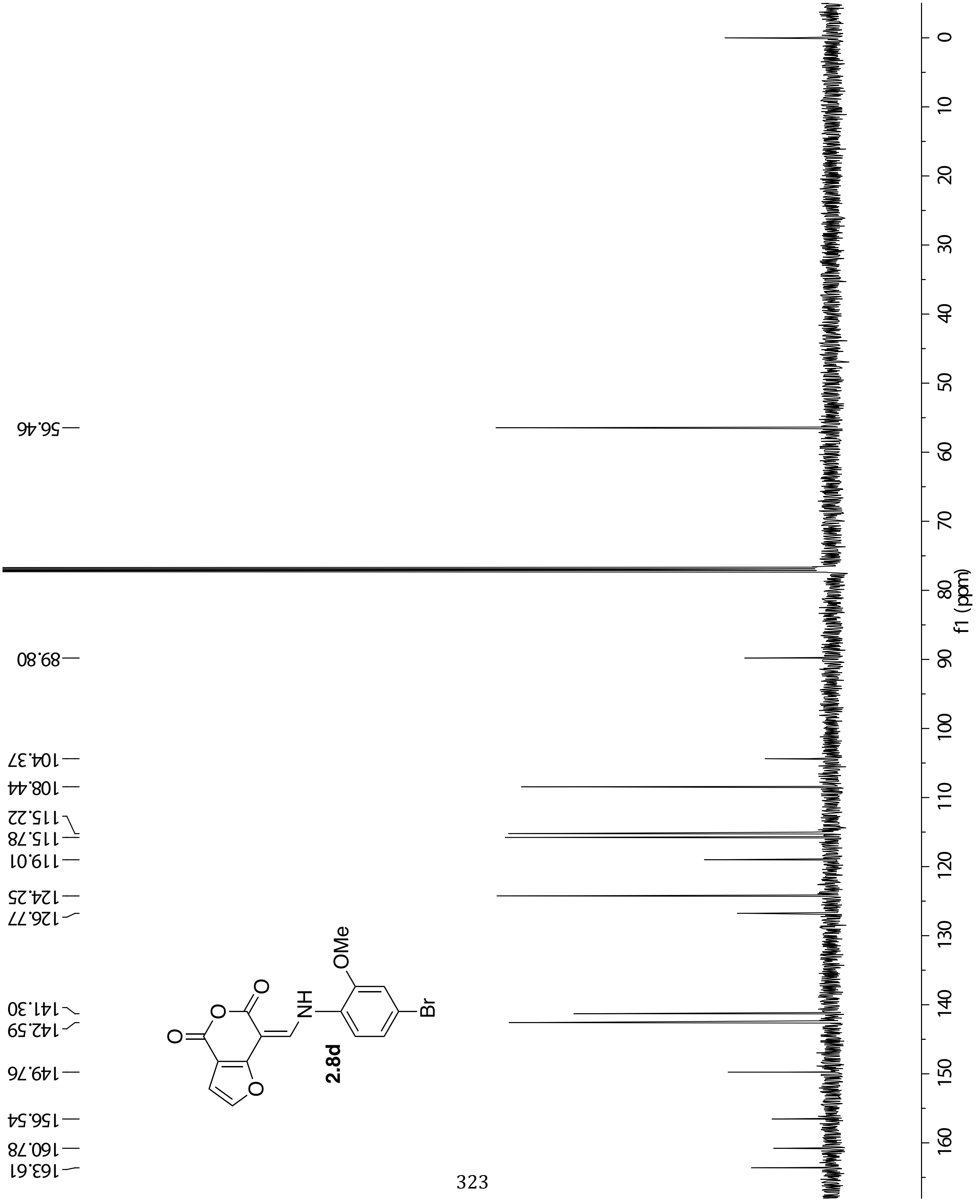
TBDPSO
O
O
O
NH
OMe
Br

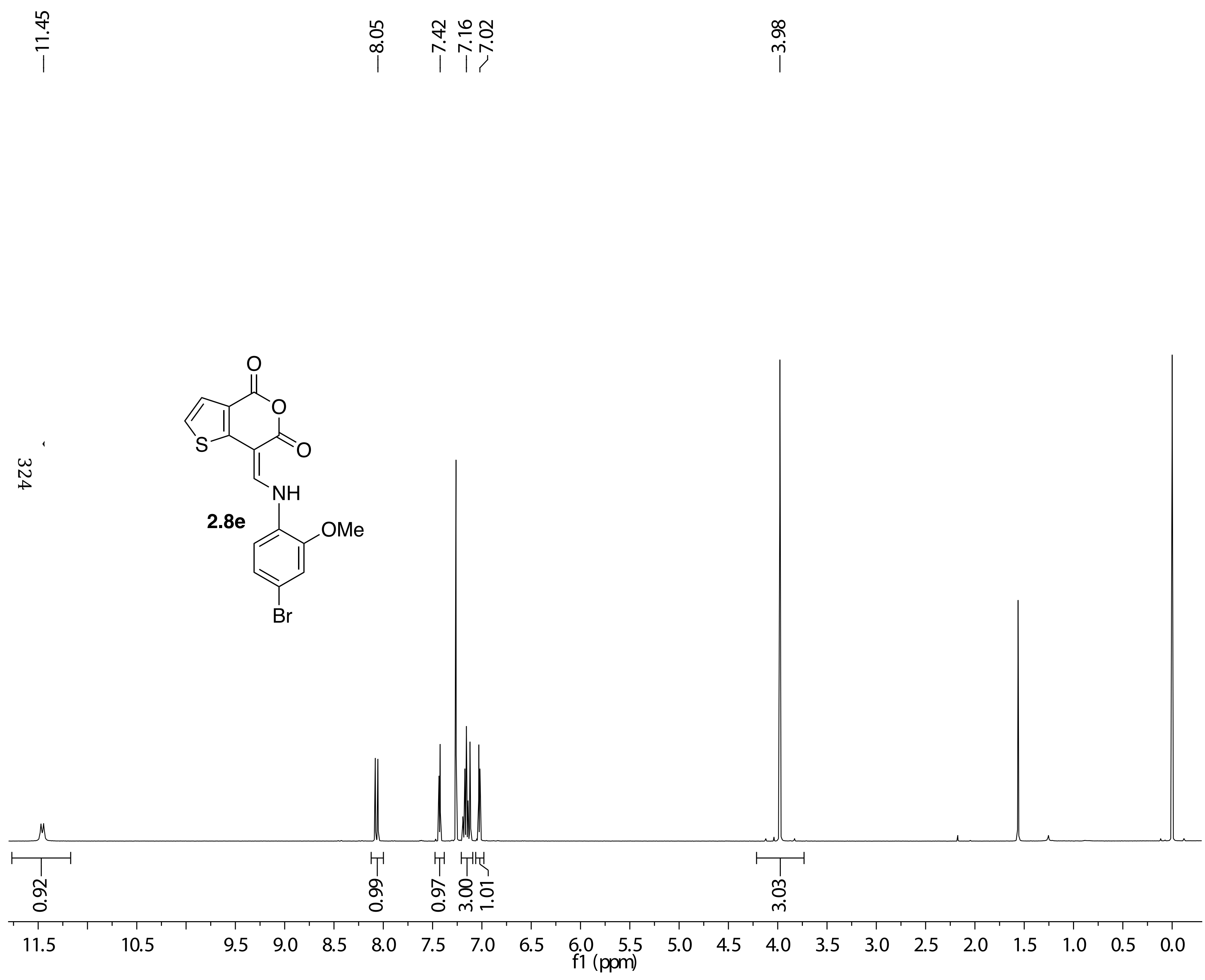
**2.8c**

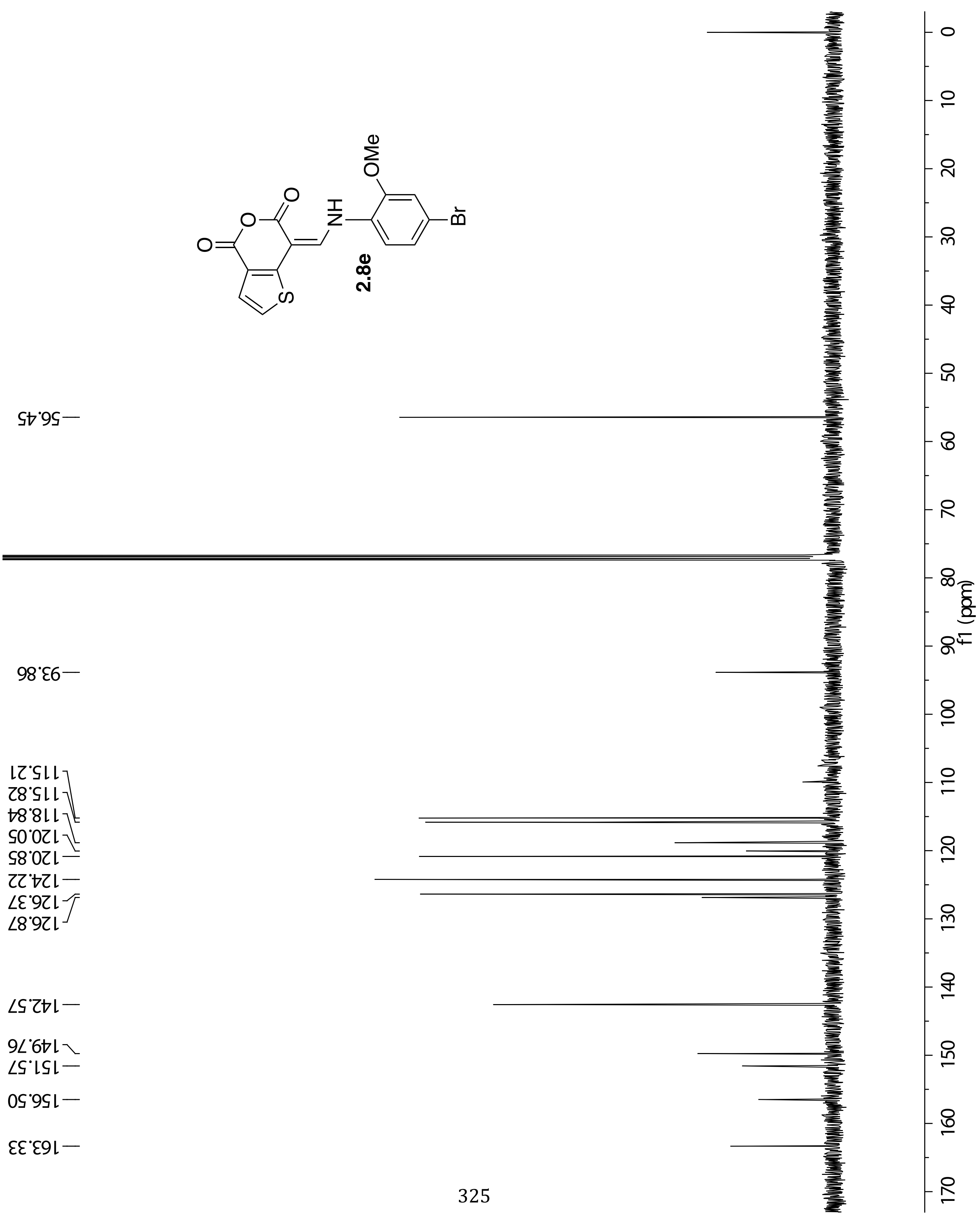

160.891
143.226
137.848
135.628
134.099
133.826
129.679
127.717
127.441
124.225
121.510
118.657
118.022
115.876
115.272
67.147
62.371
56.491
31.523
26.912
19.325
16.048
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
ppm

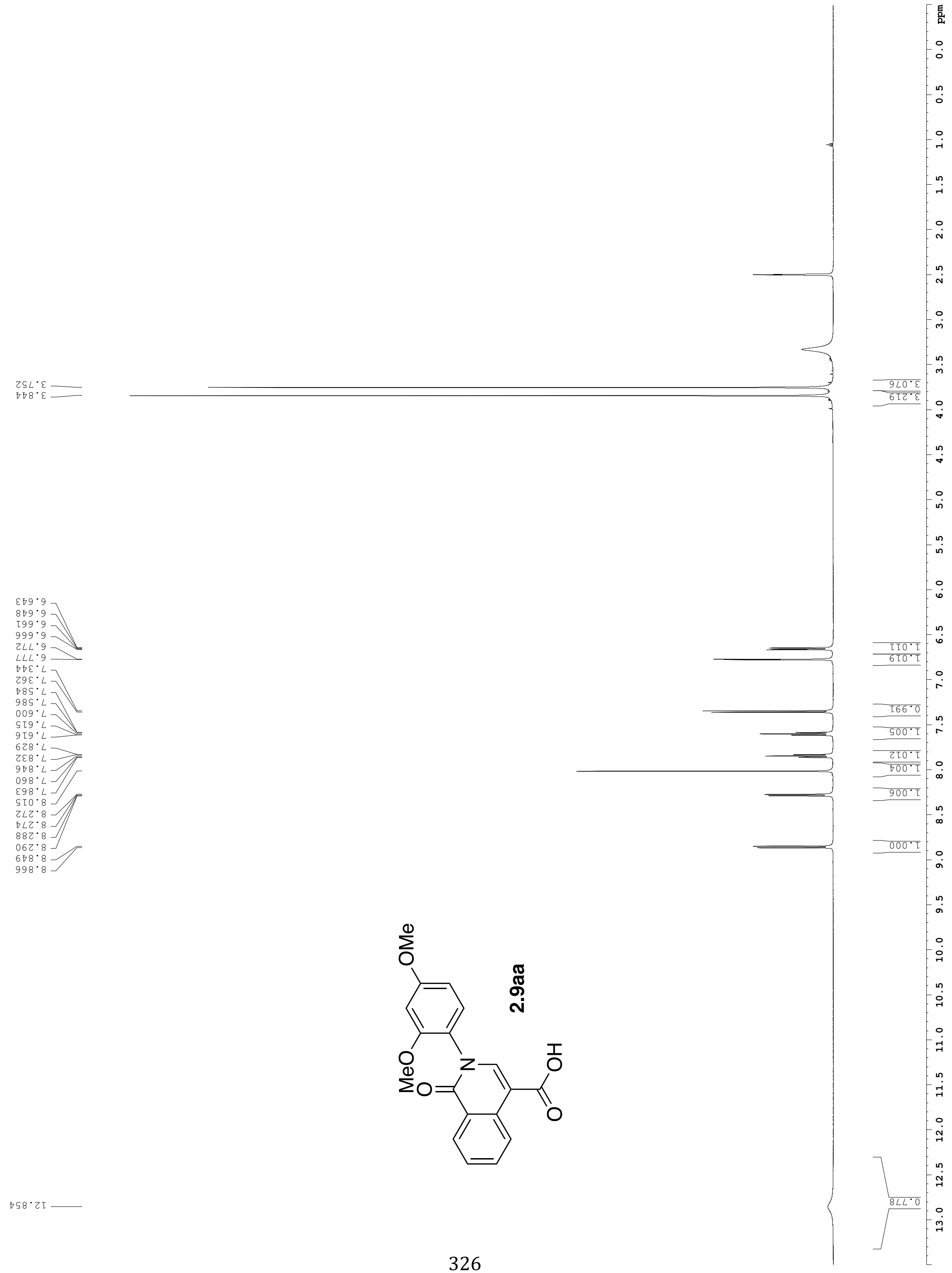

3.98
6.81
7.13
7.18
7.35
8.24
11.35
3.14
0.99
1.06
2.07
1.00
1.03
0.95
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.5
11.5
f1 (ppm)
O
O
O
O
NH
OMe
Br

**2.8d**

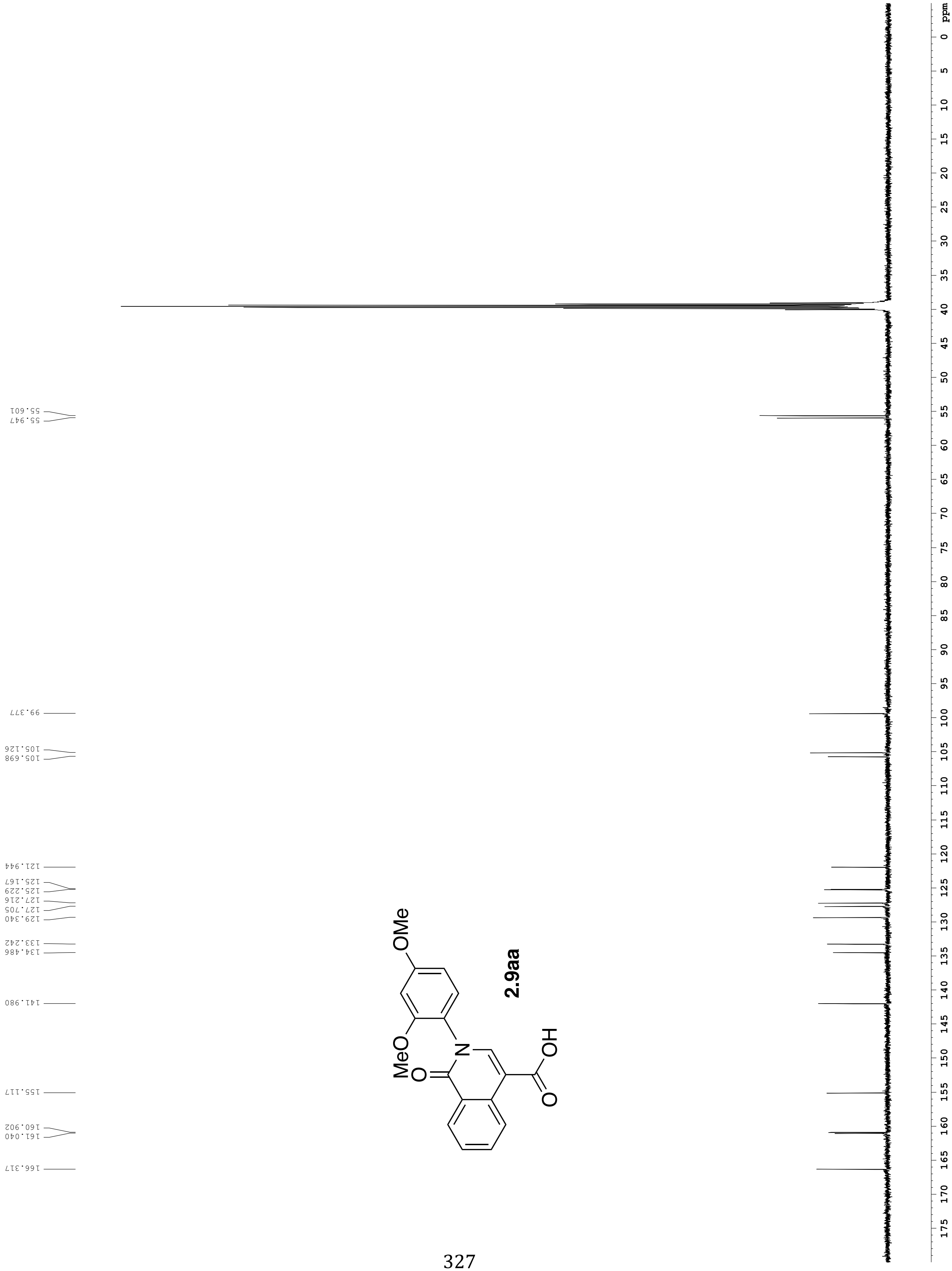

**2.8d**
163.61
160.78
156.54
149.76
142.59
141.30
126.77
124.25
119.01
115.78
115.22
108.44
104.37
89.80
56.46
OMe
NH
Br
O
f1 (ppm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160


11.45
8.05
7.42
7.16
7.02
3.98
O
O
O
S
NH
OMe
Br
2.8e
0.92
0.99
0.97
3.00
1.01
3.03
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

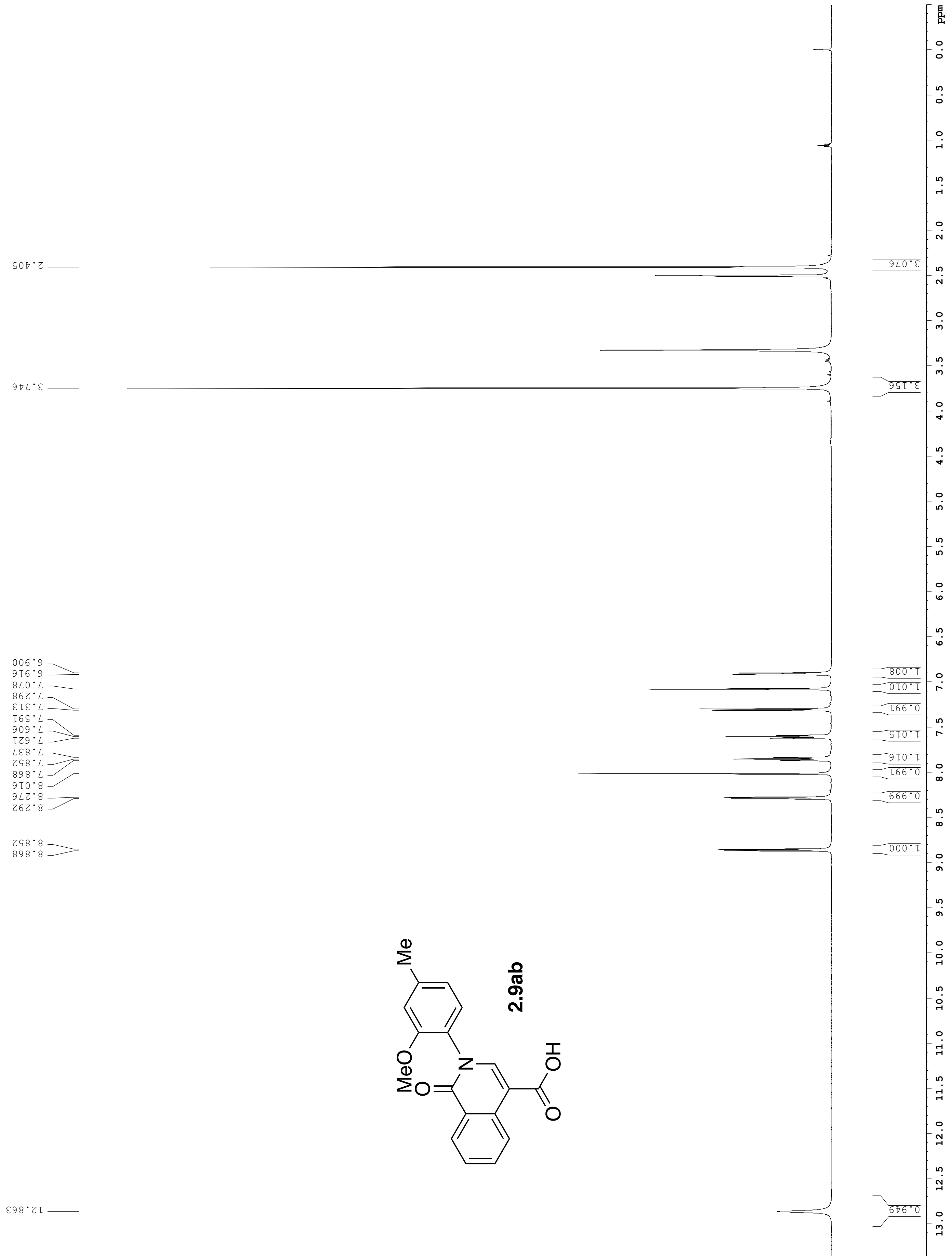

2.8e
OMe
NH
O
O
O
S
Br
163.33
156.50
151.57
149.76
142.57
126.87
126.37
124.22
120.85
120.05
118.84
115.82
115.21
93.86
56.45
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
f1 (ppm)


3.752
3.844
6.643
6.648
6.661
6.666
6.772
6.777
7.344
7.362
7.584
7.586
7.600
7.615
7.616
7.829
7.832
7.846
7.860
7.863
8.015
8.272
8.274
8.288
8.290
8.849
8.866
12.854
3.076
3.219
1.011
1.019
0.991
1.005
1.012
1.004
1.006
1.000
0.778
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
OMe
MeO
N
O
OH
O

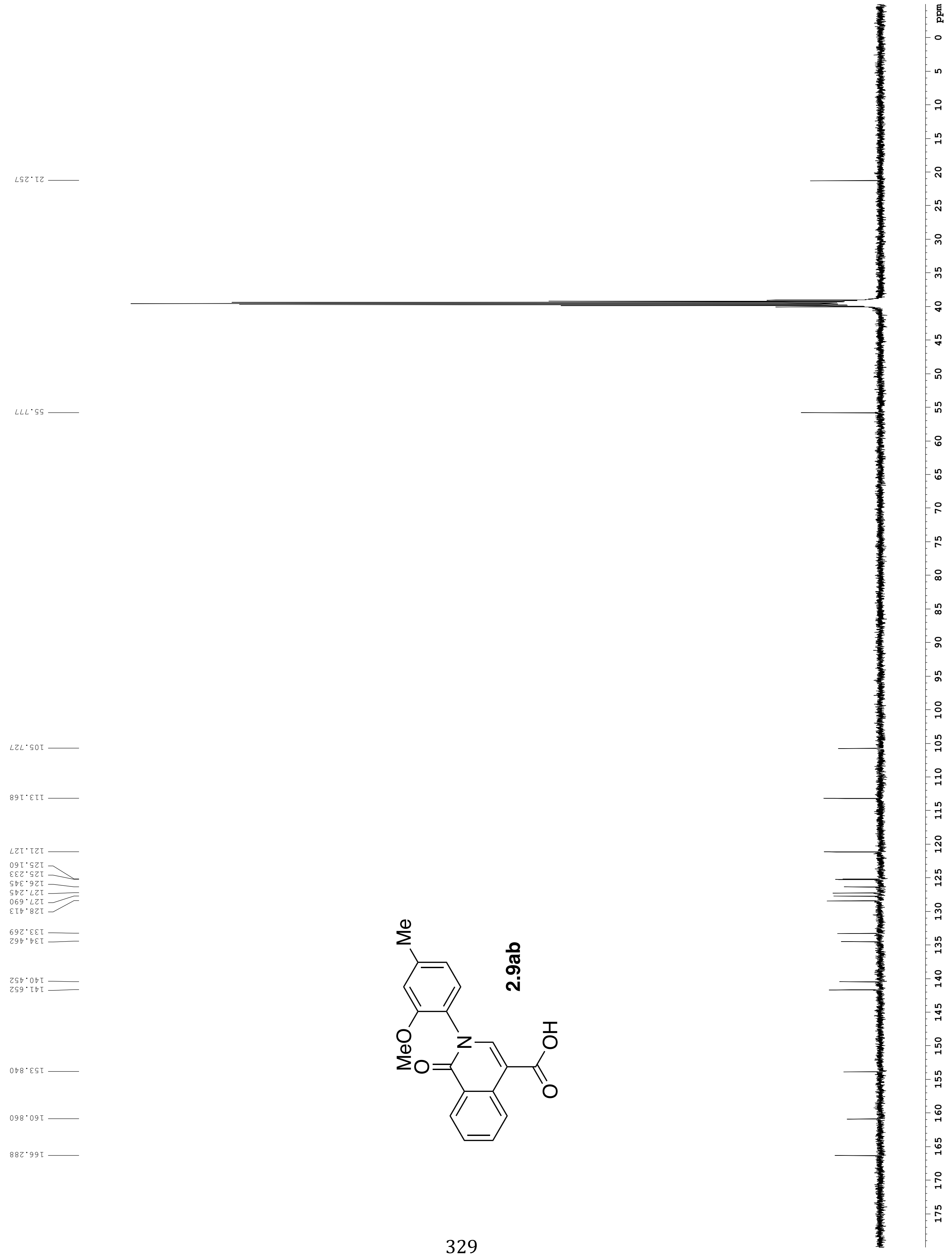
**2.9aa**


55.601
55.947
99.377
105.126
105.698
121.944
125.167
125.229
127.216
127.705
129.340
133.242
134.486
141.980
155.117
160.902
161.040
166.317
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
OMe
MeO
O
N
OH
O

**2.9aa**

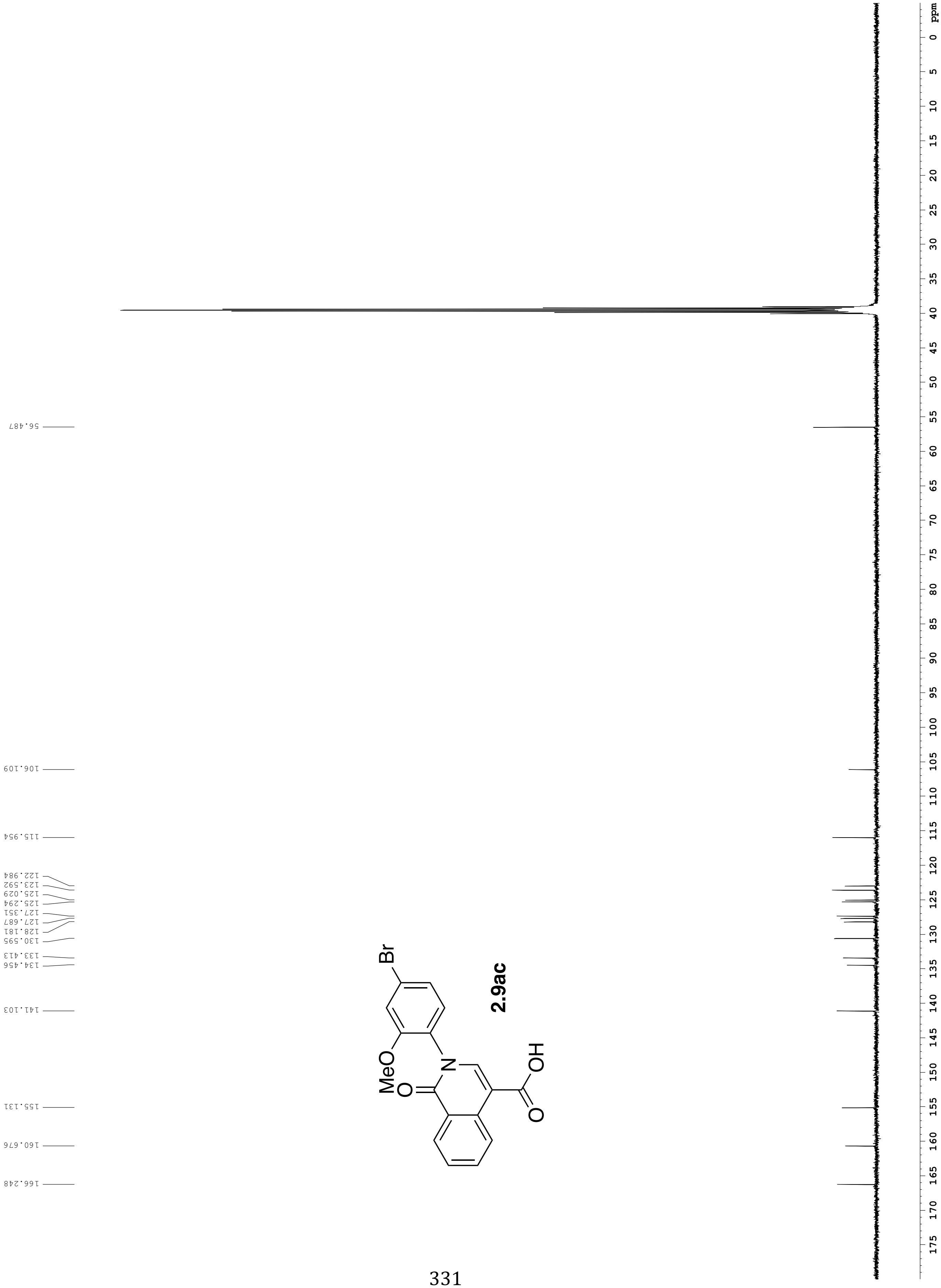

2.405
3.746
6.900
6.916
7.078
7.298
7.313
7.591
7.606
7.621
7.837
7.852
7.868
8.016
8.276
8.292
8.852
8.868
12.863
3.076
3.156
1.008
1.010
0.991
1.015
1.016
0.991
0.999
1.000
0.949
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
Me
MeO
O
N
OH
O

**2.9ab**

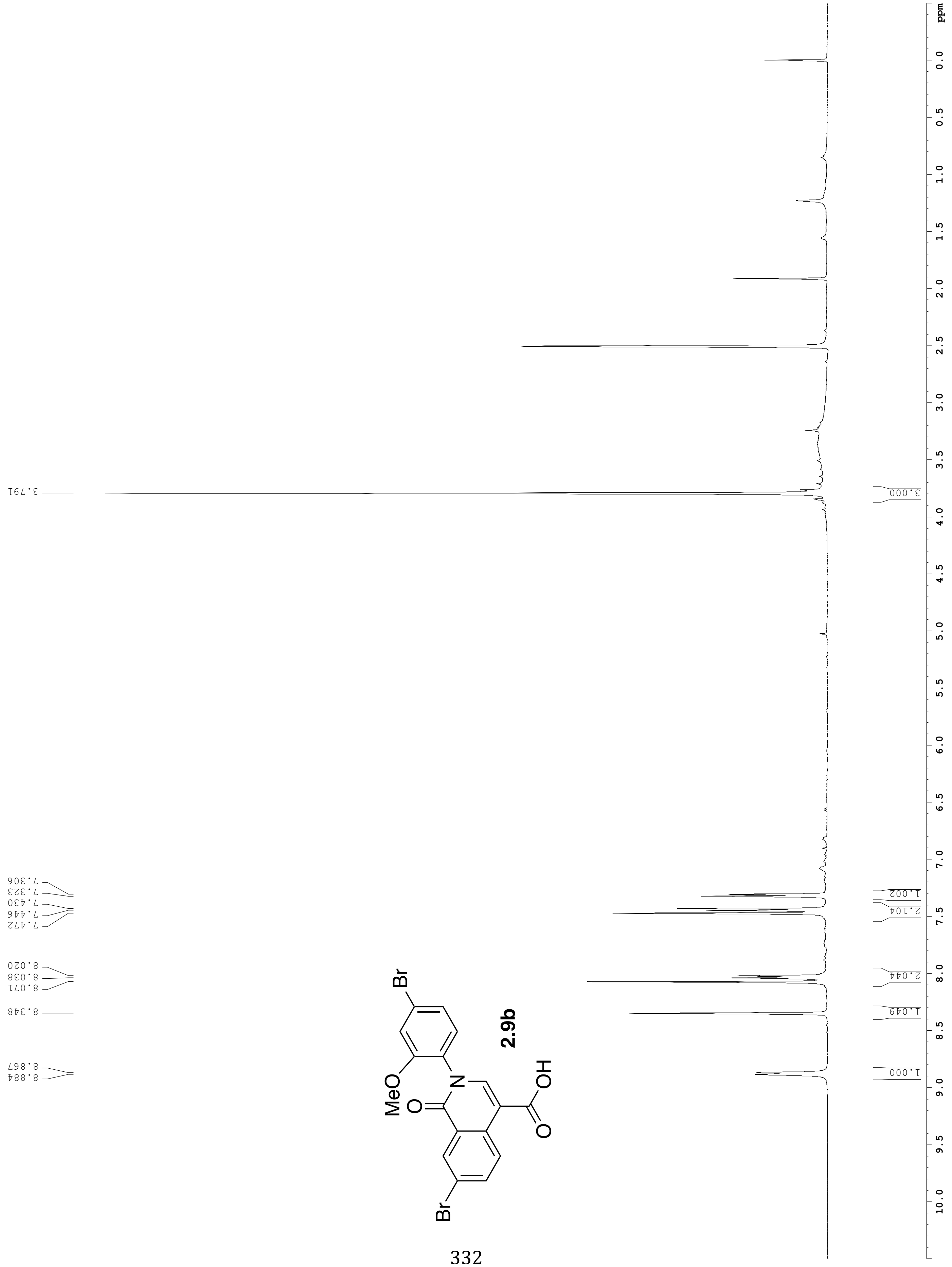

21.257
55.777
105.727
113.168
121.127
125.160
125.233
126.345
127.245
127.690
128.413
133.269
134.462
140.452
141.652
153.840
160.860
166.288
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
Me
MeO
N
O
OH
O

**2.9ab**

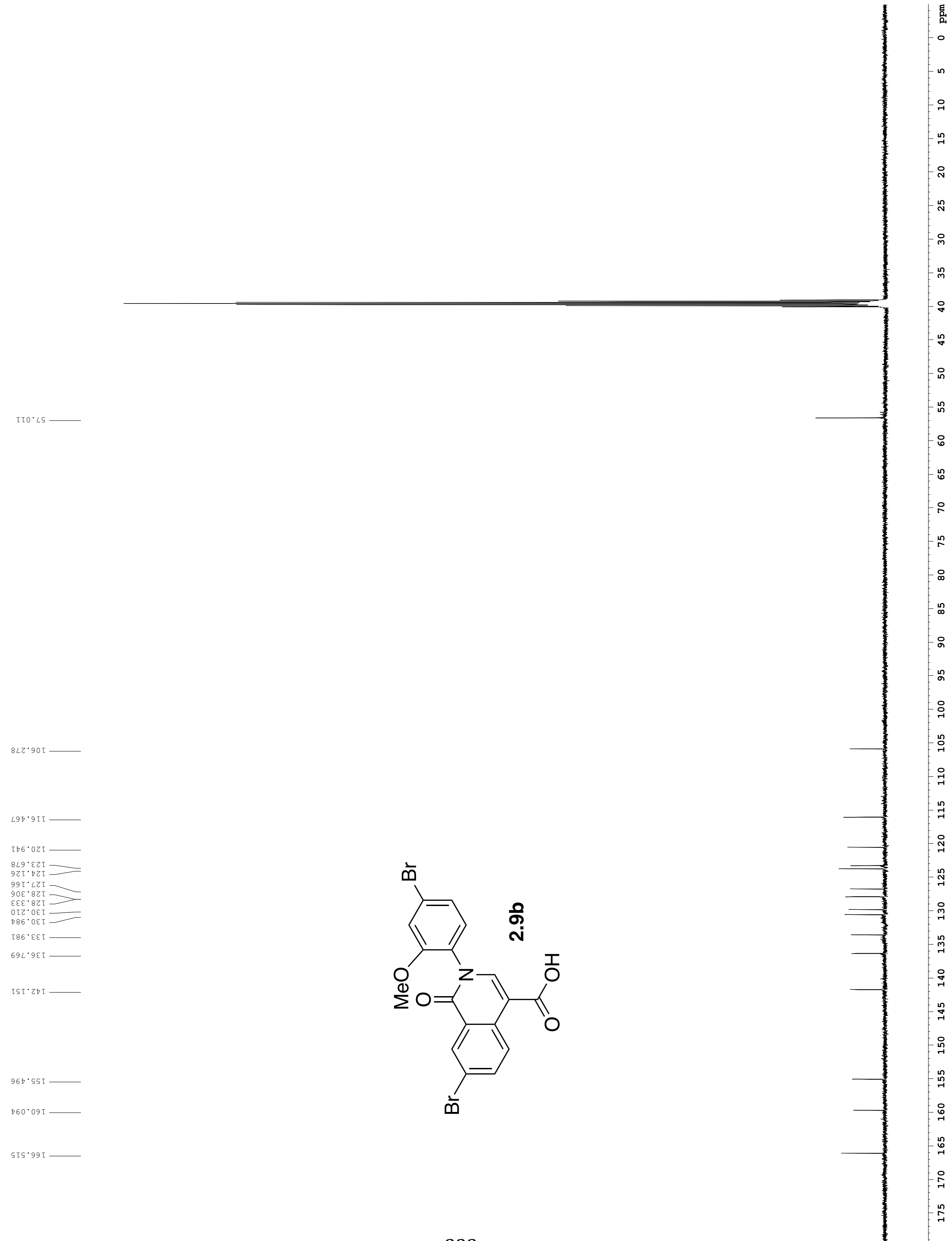

3.794
7.301
7.304
7.318
7.321
7.431
7.448
7.465
7.468
7.598
7.613
7.629
7.846
7.861
7.876
8.055
8.275
8.291
8.847
8.864
12.897
3.106
1.011
2.027
1.035
1.011
0.989
1.002
1.000
0.874
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
Br
MeO
N
O
OH
O
2.9ac

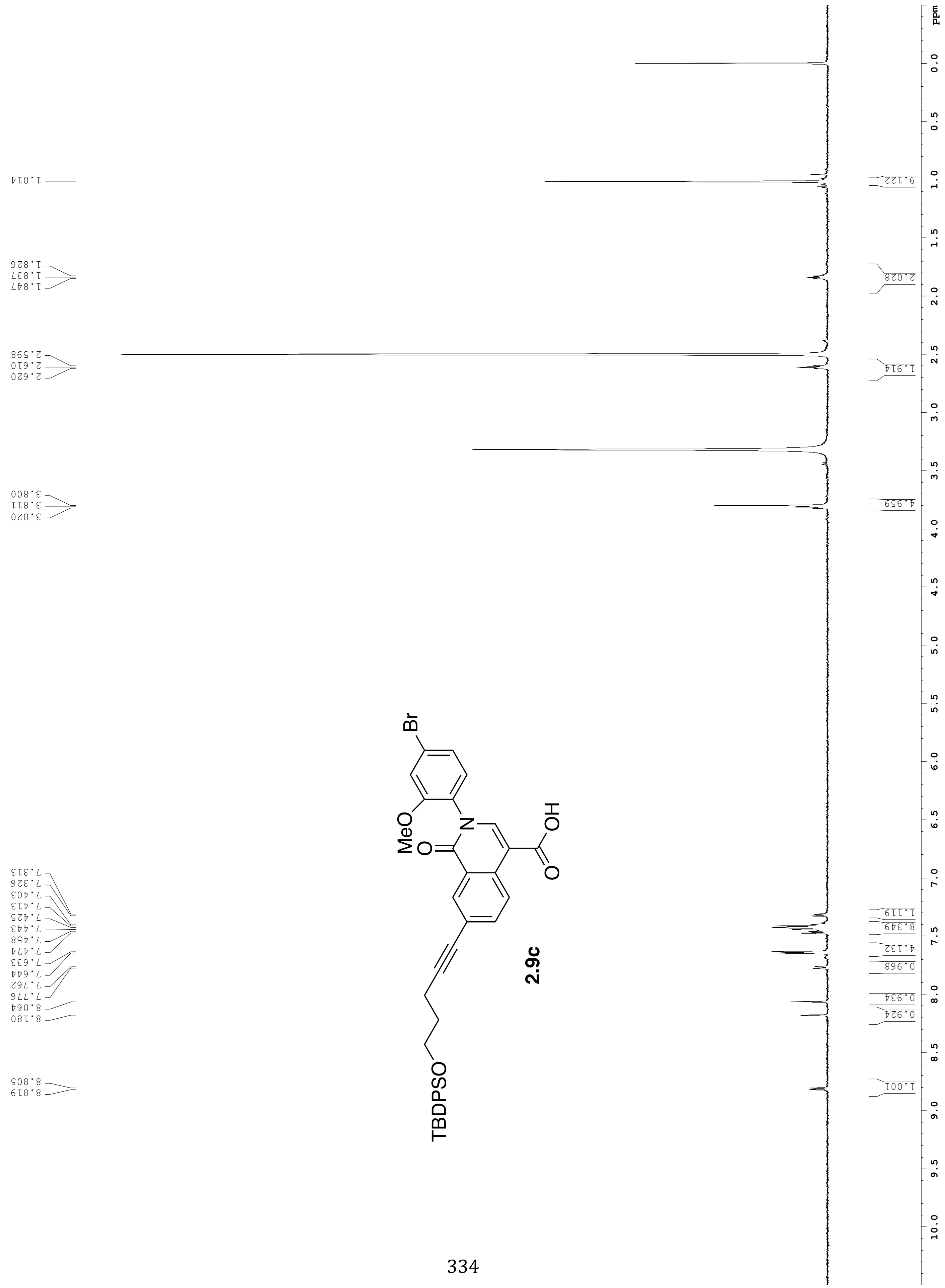

56.487
106.109
115.954
122.984
123.592
125.029
125.294
127.351
127.687
128.181
130.595
133.413
134.456
141.103
155.131
160.676
166.248
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
Br
MeO
O
N
OH
O

**2.9ac**

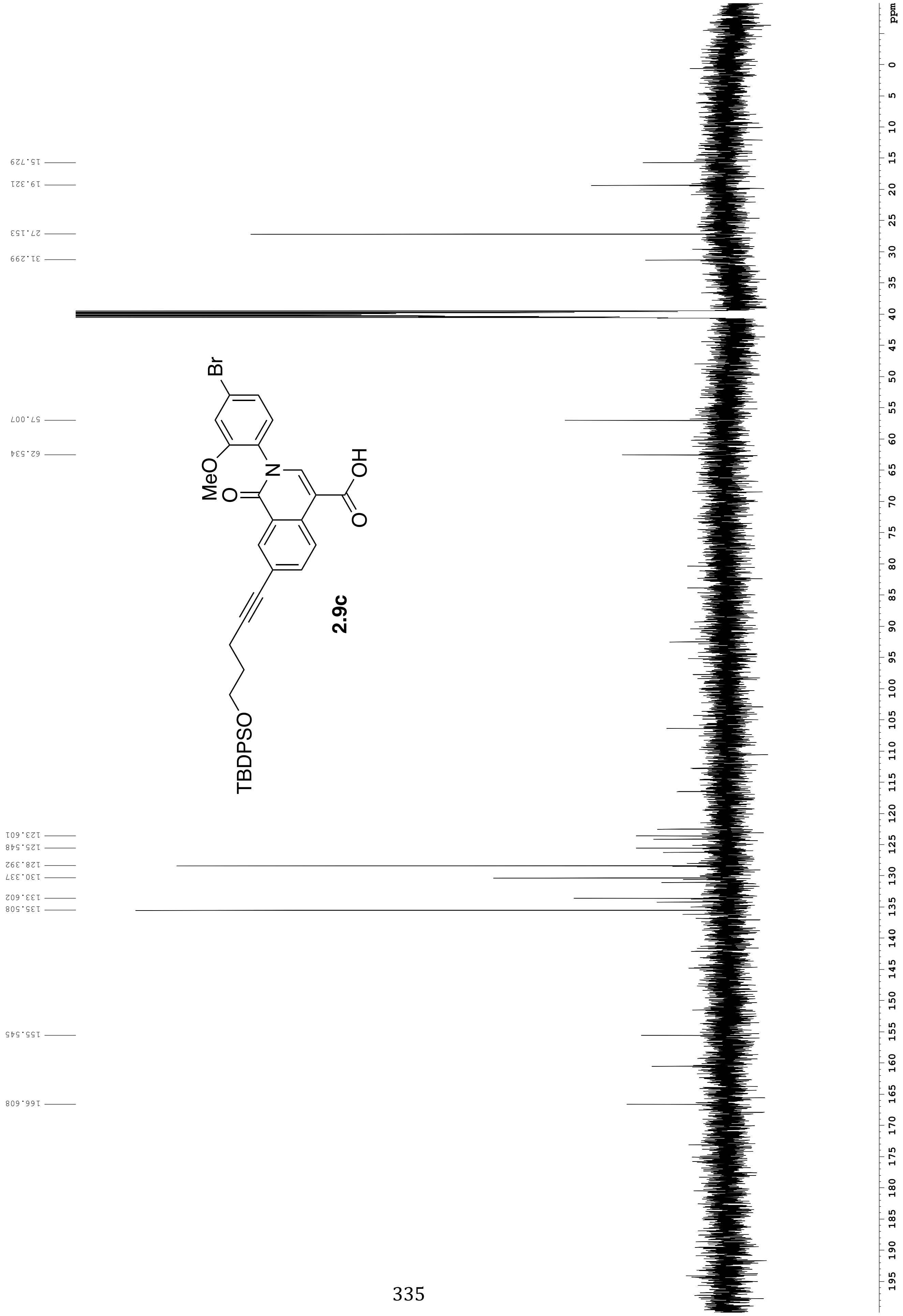

ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
3.791
7.306
7.323
7.430
7.446
7.472
8.020
8.038
8.071
8.348
8.867
8.884
3.000
1.002
2.104
2.044
1.049
1.000
Br
MeO
N
O
OH
O
Br

**2.9b**

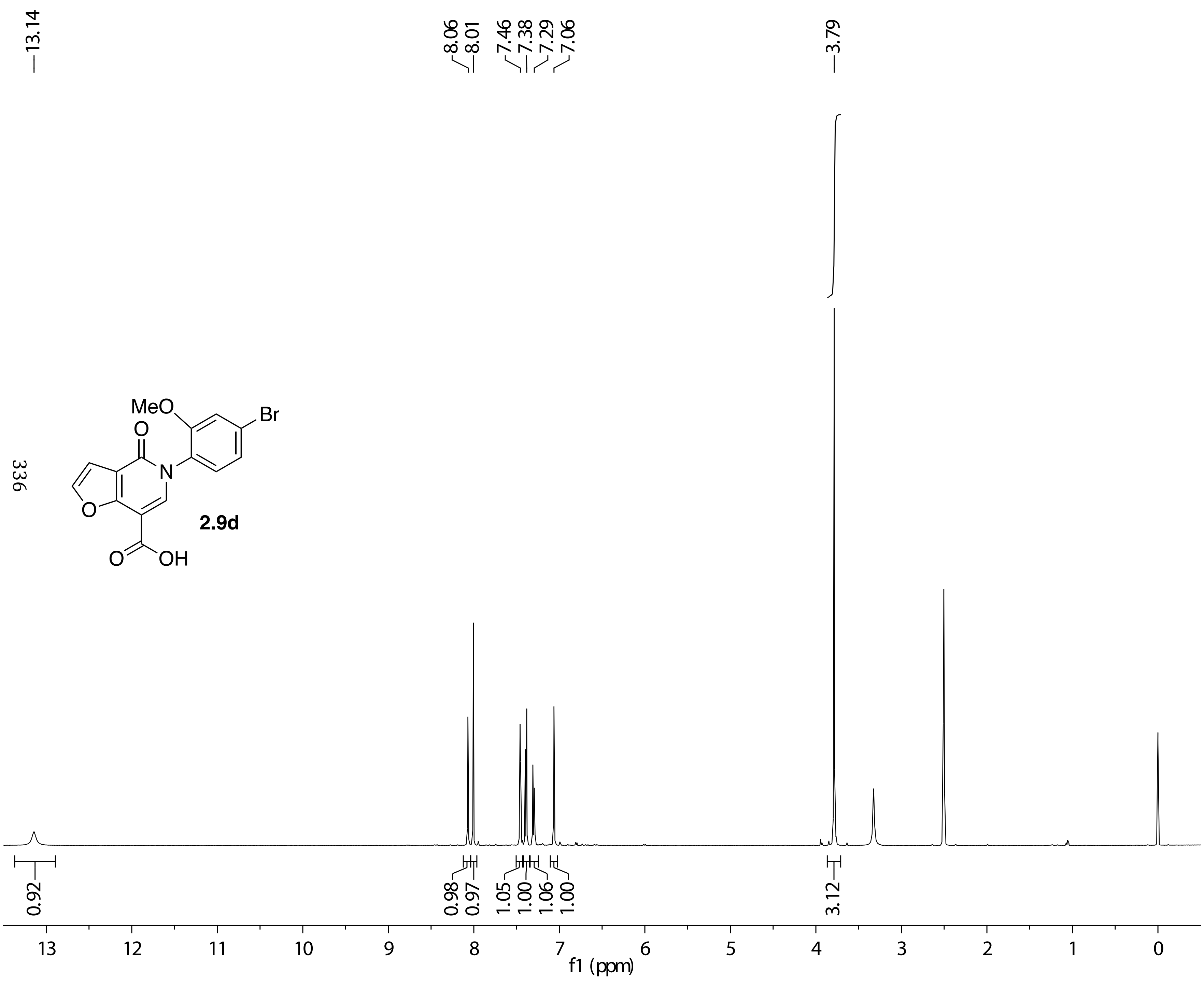

57.011
106.278
116.467
120.941
123.678
124.126
127.166
128.306
128.333
130.210
130.984
133.981
136.769
142.151
155.496
160.094
166.515
Br
MeO
N
O
OH
O
Br
2.9b
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175


1.014
1.826
1.837
1.847
2.598
2.610
2.620
3.800
3.811
3.820
7.313
7.326
7.403
7.413
7.425
7.443
7.458
7.474
7.633
7.644
7.762
7.776
8.064
8.180
8.805
8.819
9.122
2.028
1.914
4.959
1.119
8.349
4.132
0.968
0.934
0.924
1.001
Br
MeO
O
N
OH
O
TBDPSO
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0

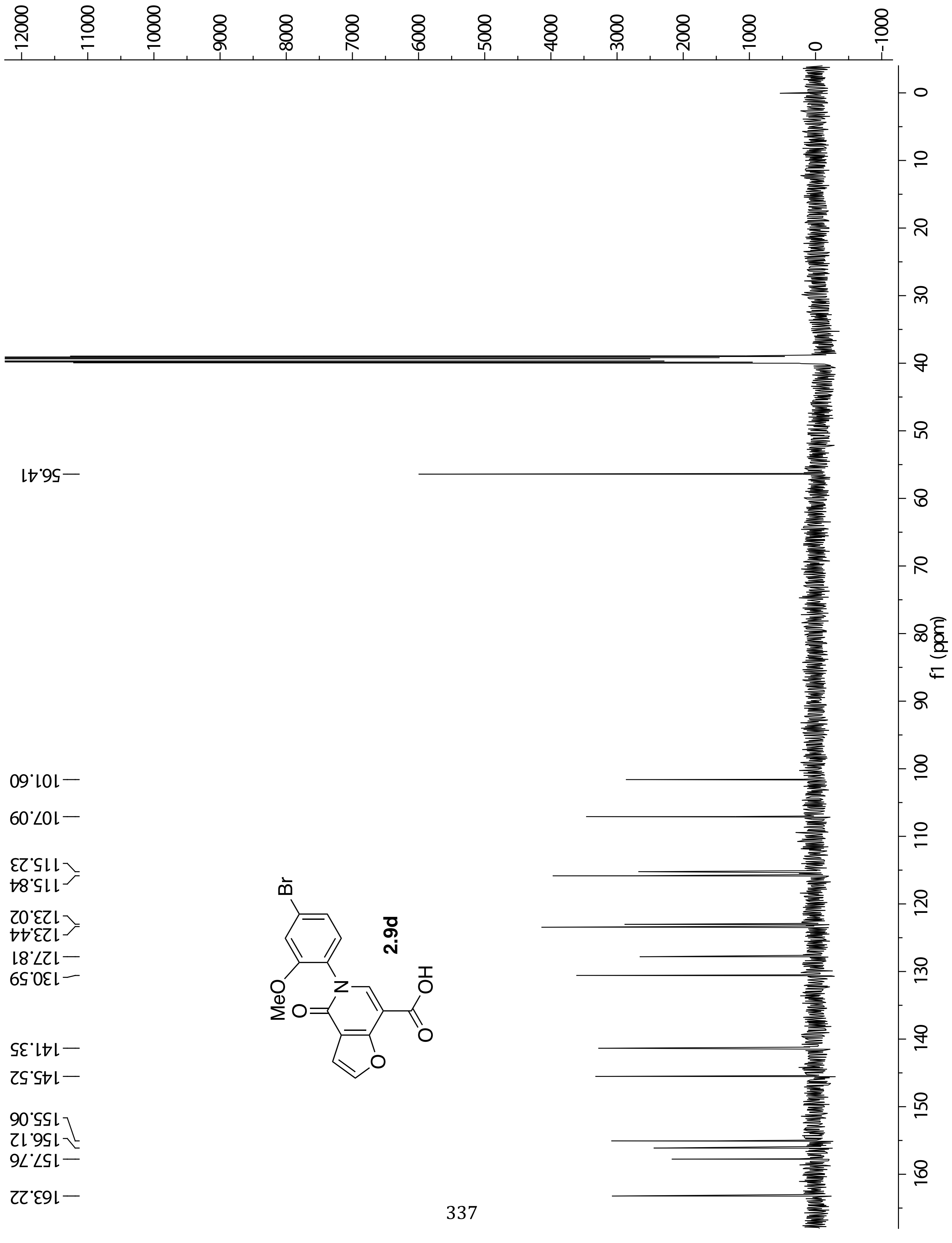
**2.9c**

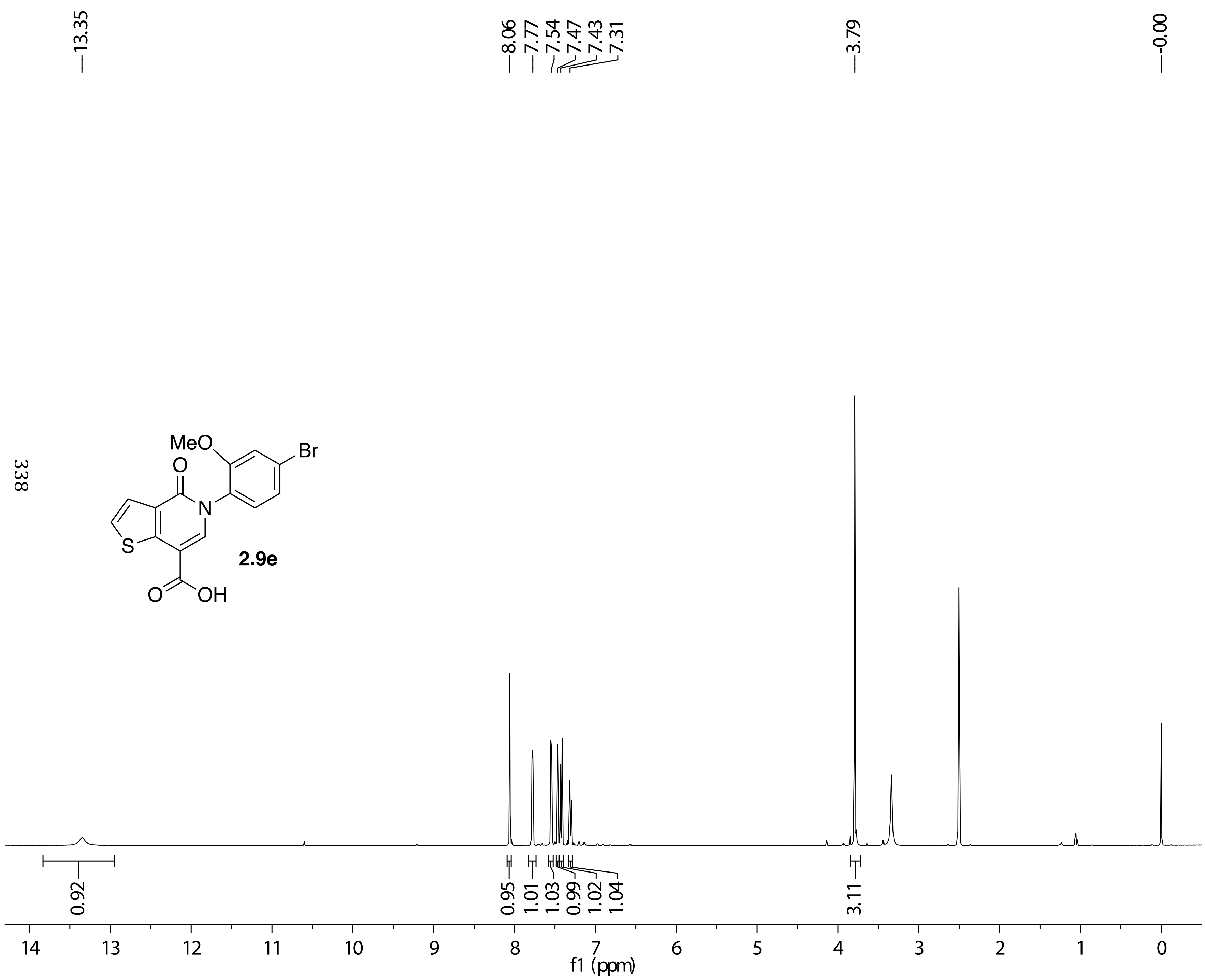


15.729
19.321
27.153
31.299
57.007
62.534
123.601
125.548
128.392
130.337
133.602
135.508
155.545
166.608
Br
MeO
O
N
OH
O
TBDPSO
2.9c
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195

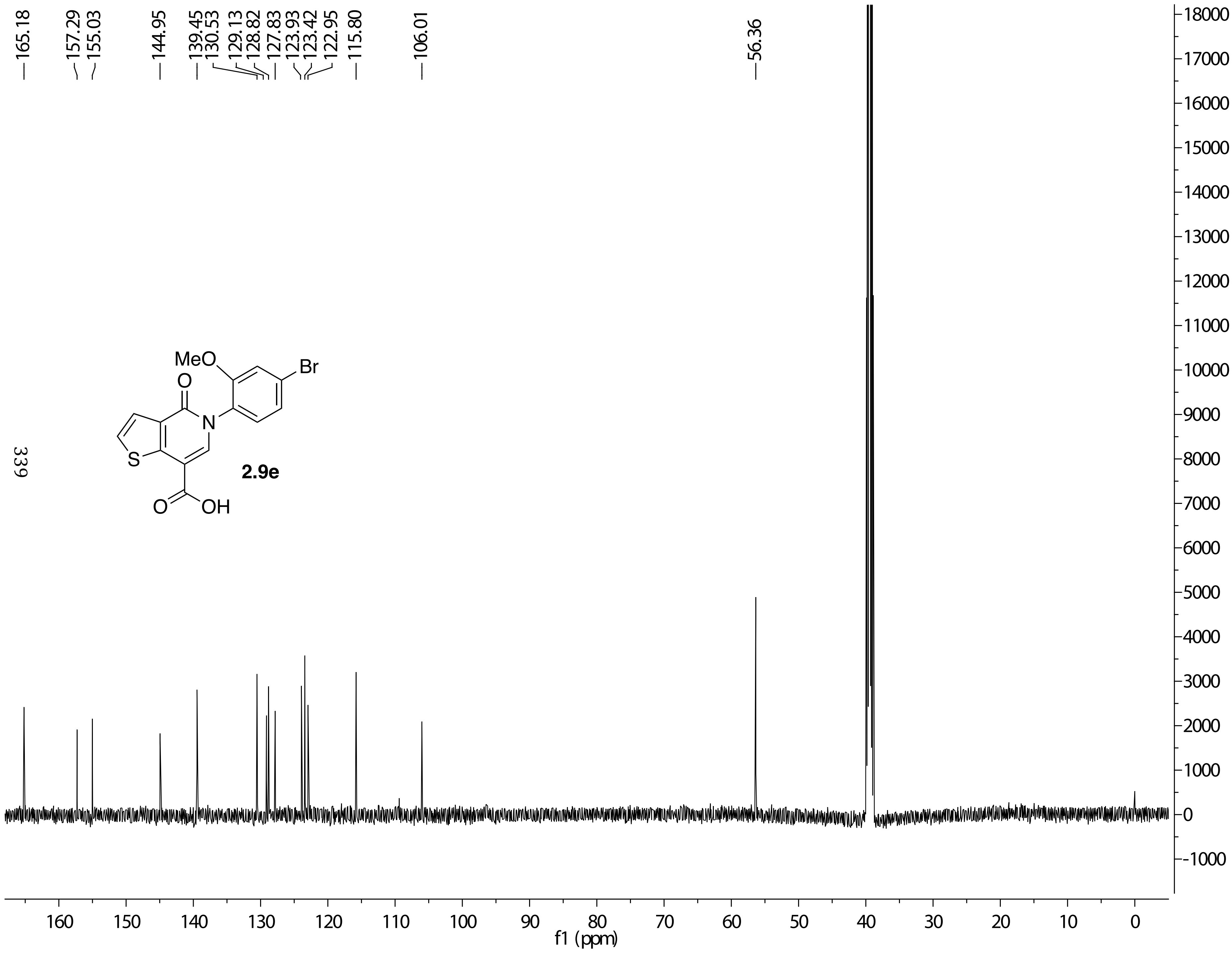

13.14
8.06
8.01
7.46
7.38
7.29
7.06
3.79
0.92
0.98
0.97
1.05
1.00
1.06
1.00
3.12
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)
MeO
O
Br
N
O
O
OH

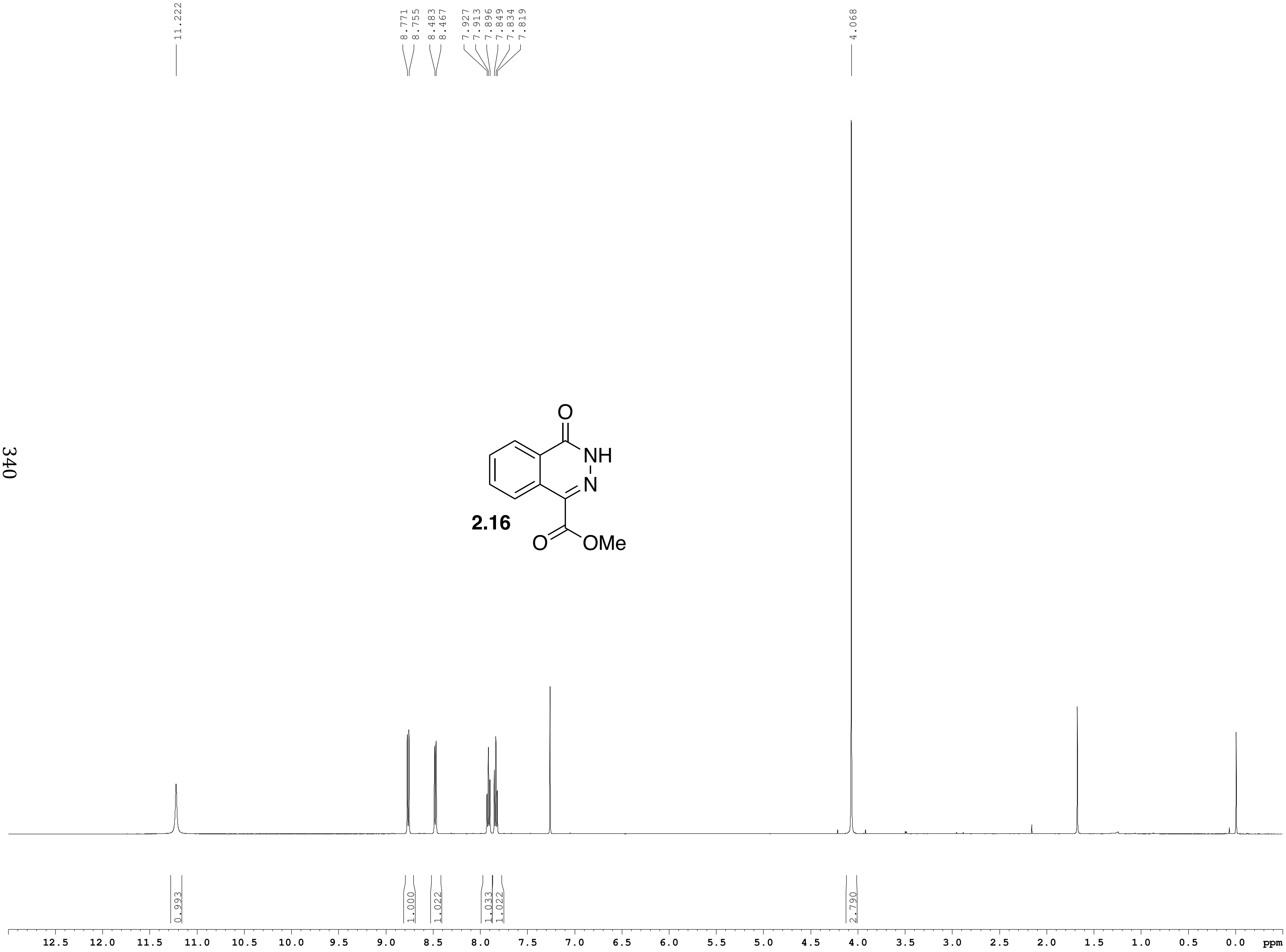
**2.9d**


163.22
157.76
156.12
155.06
145.52
141.35
130.59
127.81
123.44
123.02
115.84
115.23
107.09
101.60
56.41
Br
MeO
O
N
OH
O
O
2.9d
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
f1 (ppm)



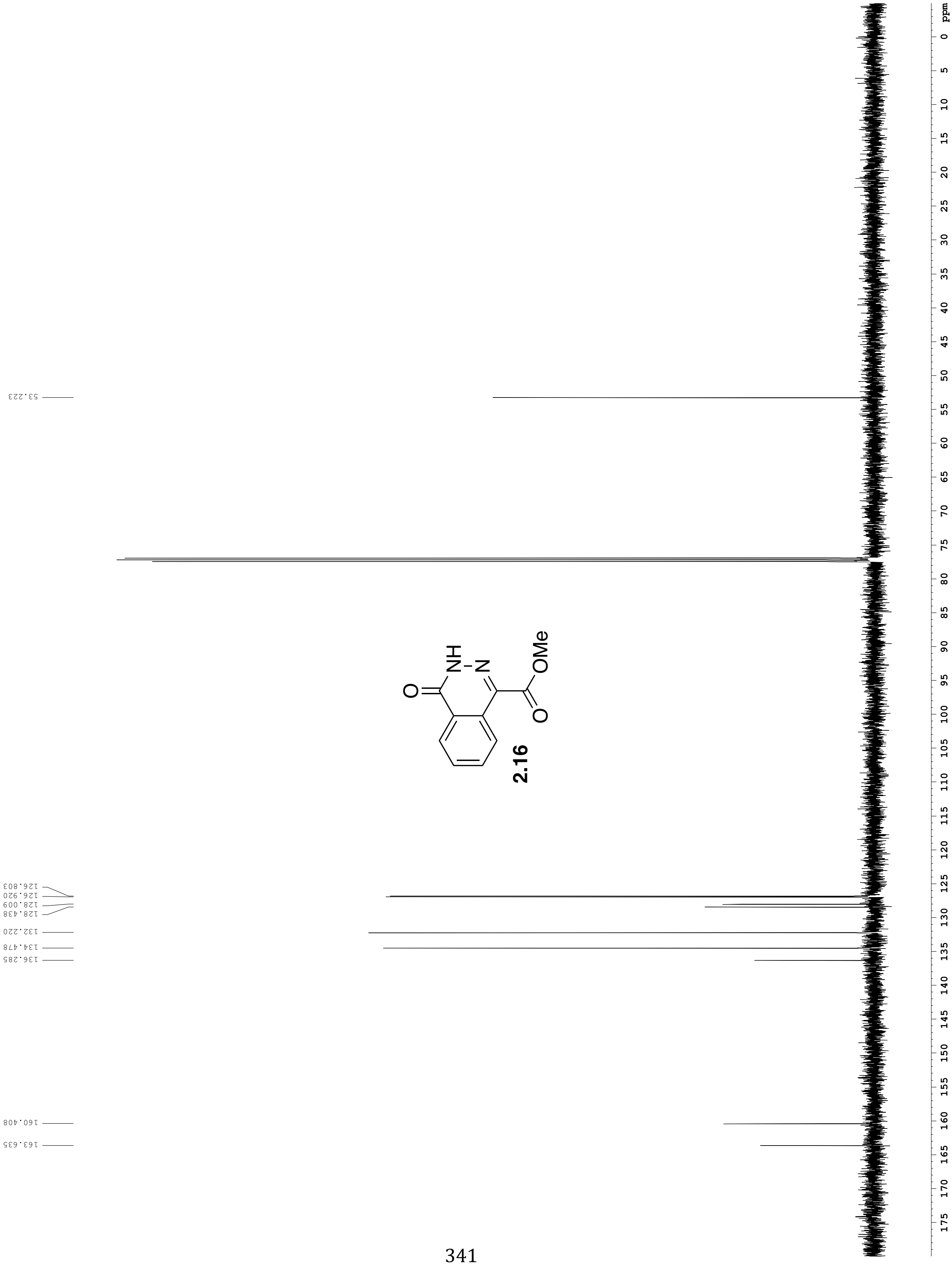
13.35
8.06
7.77
7.54
7.47
7.43
7.31
3.79
-0.00
MeO
O
N
Br
S
O
OH
2.9e
0.92
0.95
1.01
1.03
0.99
1.02
1.04
3.11
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)


165.18
157.29
155.03
144.95
139.45
130.53
129.13
128.82
127.83
123.93
123.42
122.95
115.80
106.01
56.36
MeO
O
Br
N
S
O
OH
2.9e
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

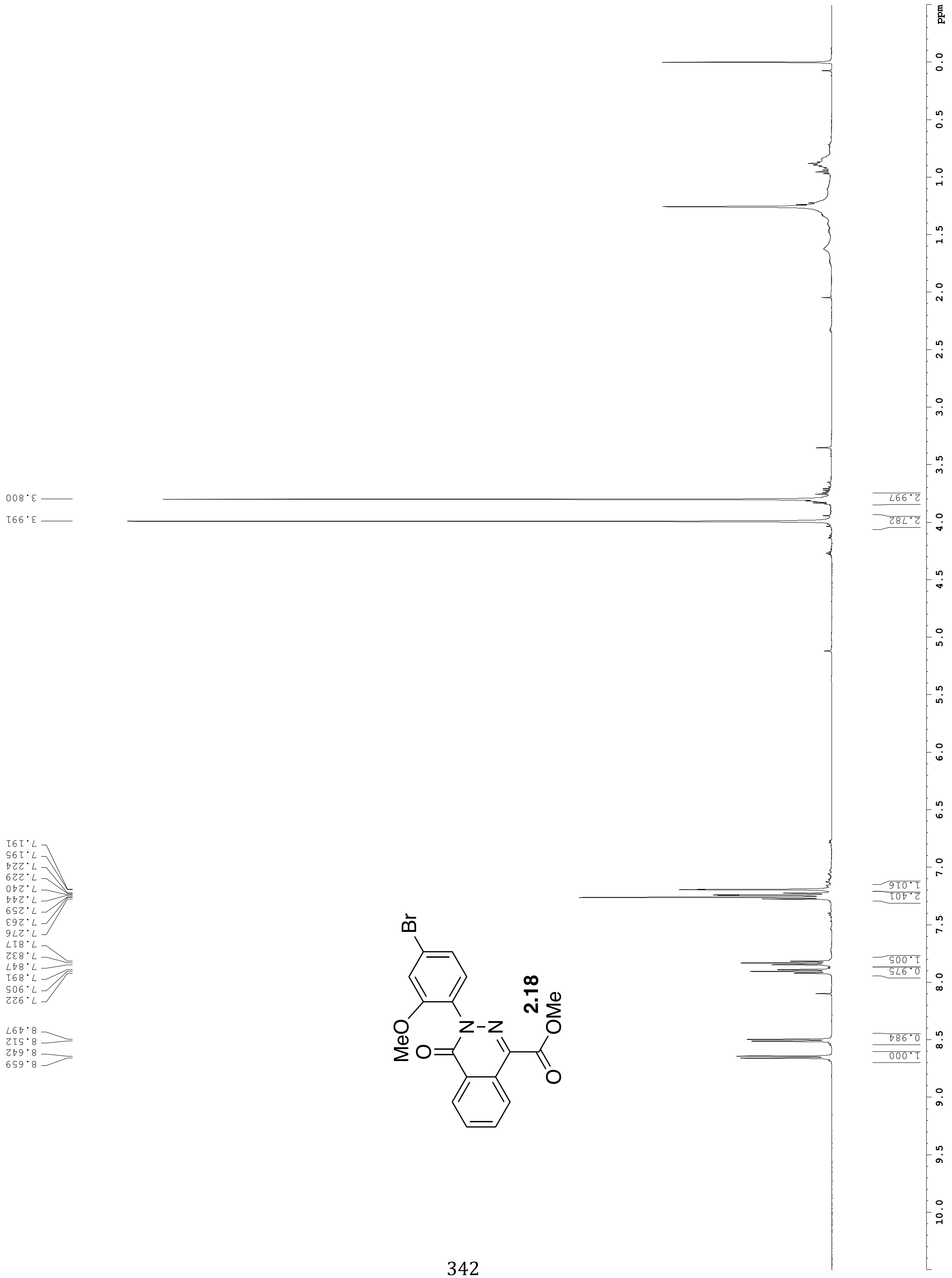


**2.16**

11.222
8.771
8.755
8.483
8.467
7.927
7.913
7.896
7.849
7.834
7.819
4.068
O
NH
N
O
OMe
0.993
1.000
1.022
1.033
1.022
2.790
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm



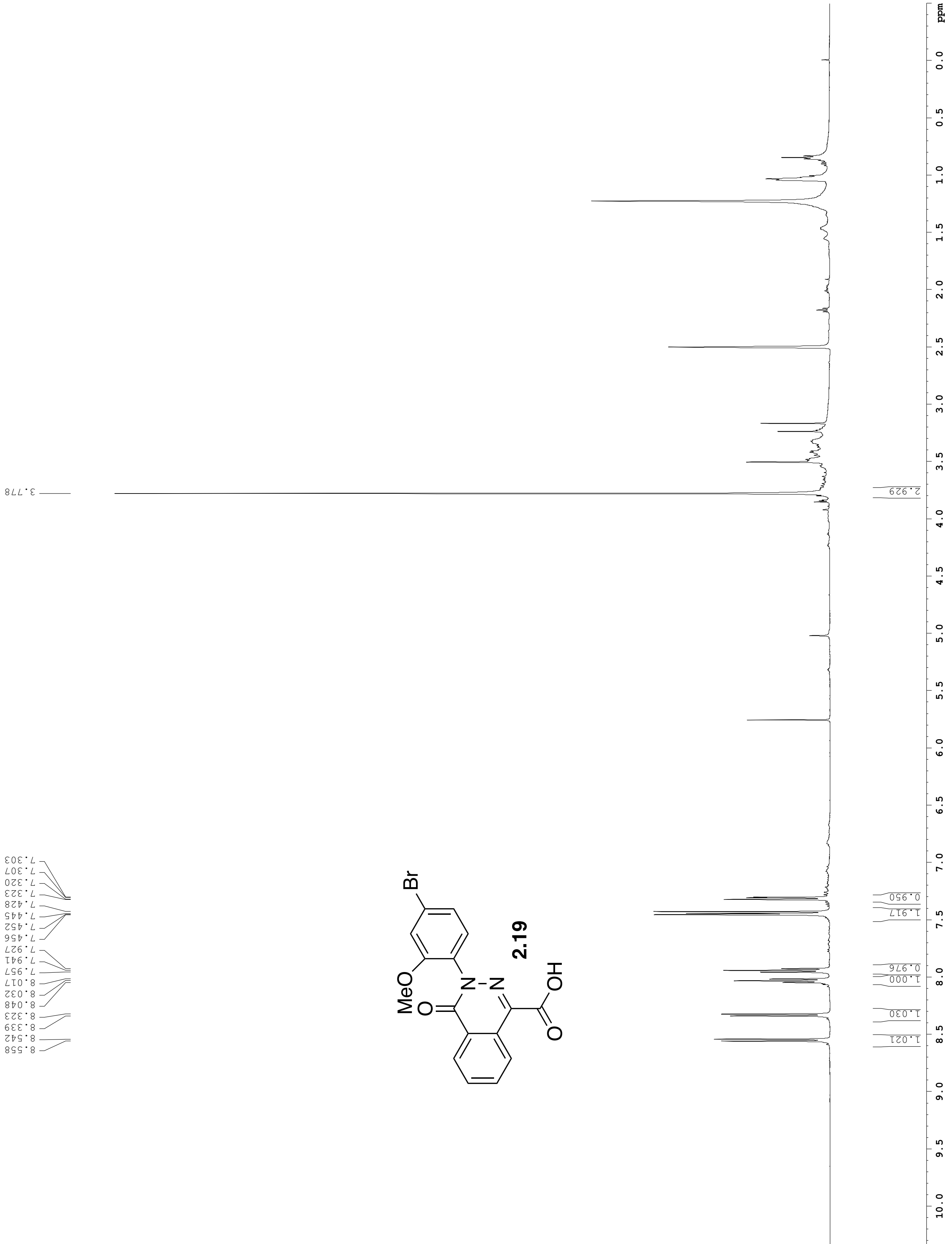
163.635
160.408
136.285
134.478
132.220
128.438
128.009
126.920
126.803
53.223
O
NH
N
OMe
O
2.16
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

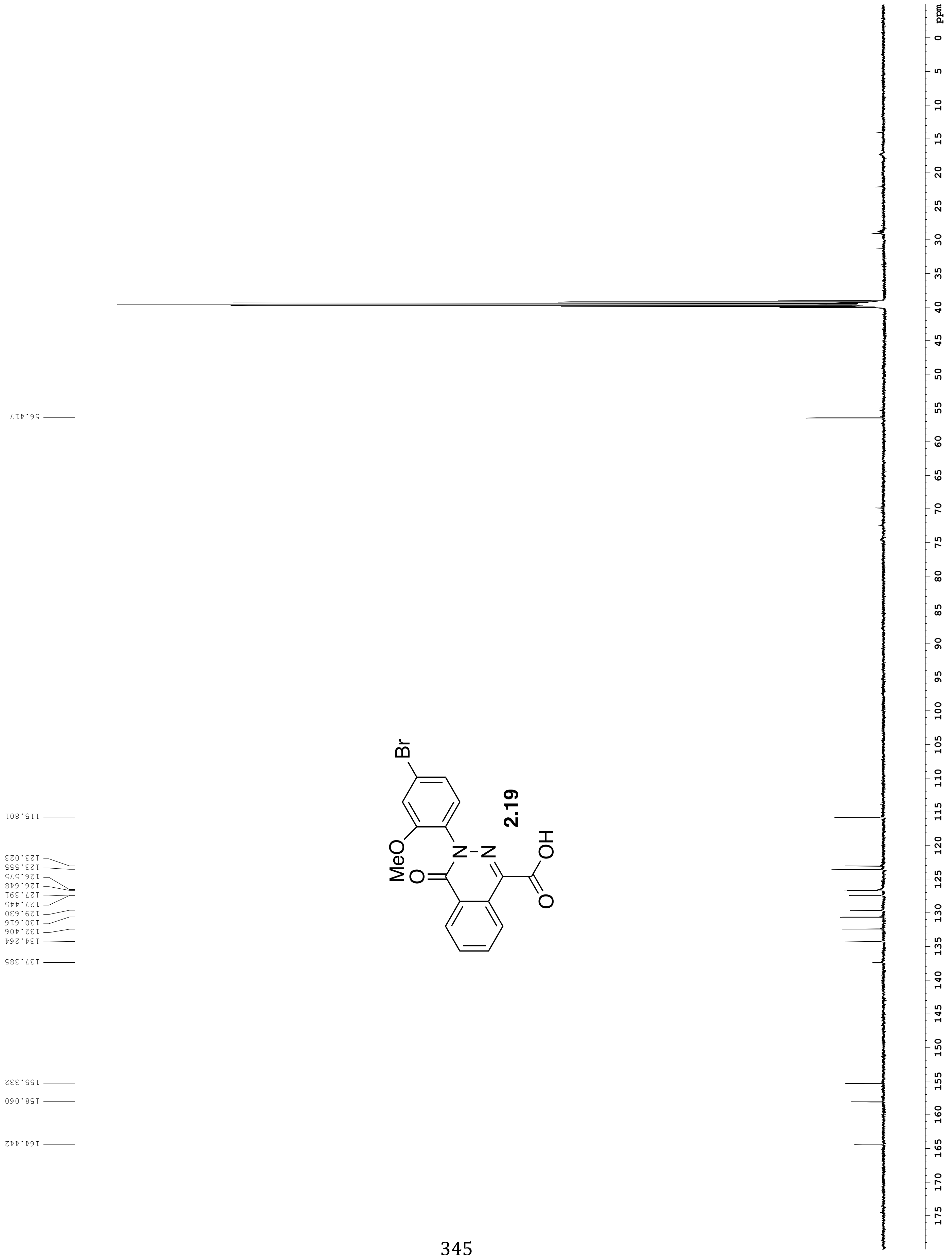

3.800
3.991
7.191
7.195
7.224
7.229
7.240
7.244
7.259
7.263
7.276
7.817
7.832
7.847
7.891
7.905
7.922
8.497
8.512
8.642
8.659
2.997
2.782
1.016
2.401
1.005
0.975
0.984
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Br
MeO
O
N
N
OMe
O

**2.18**

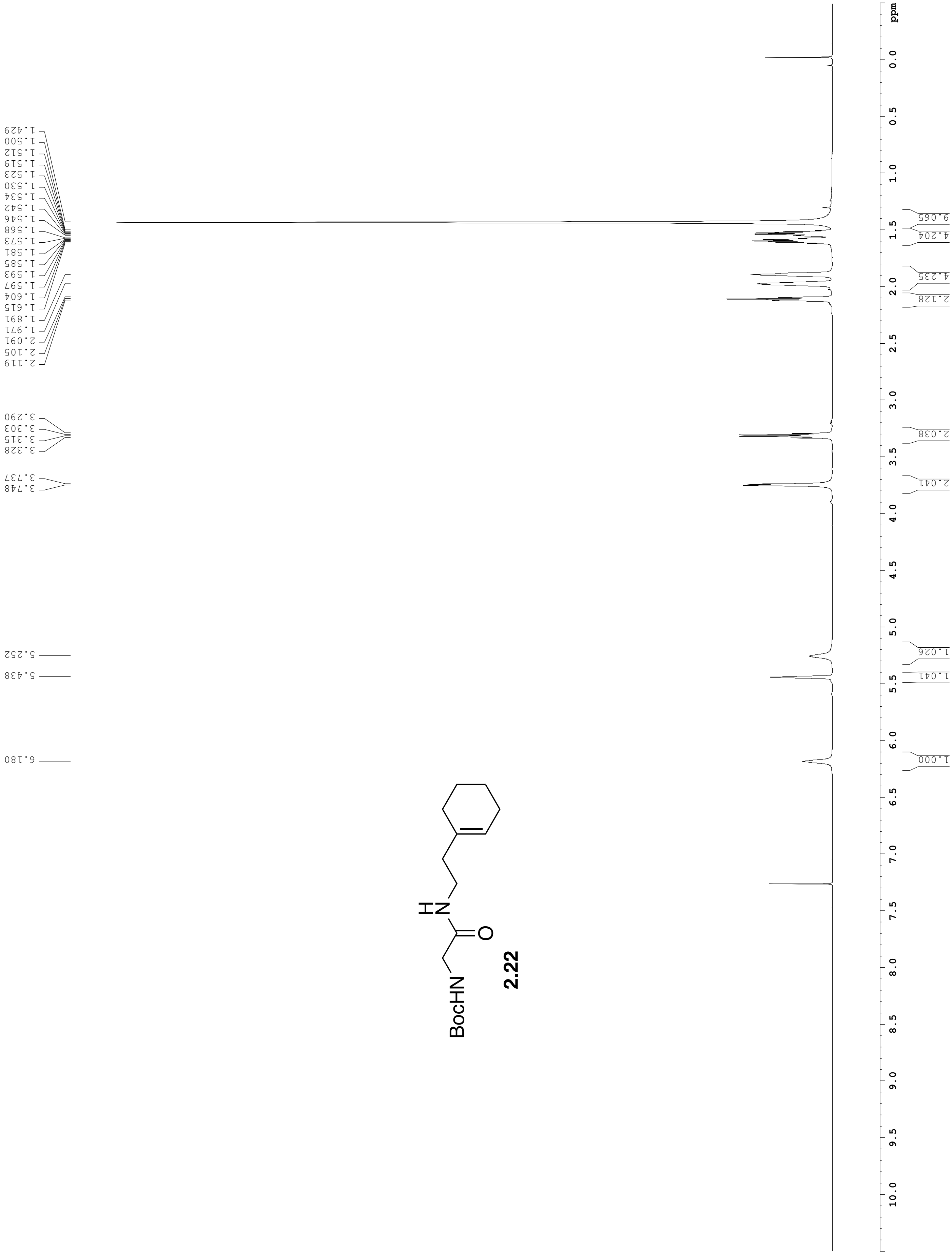
53.216
56.367
116.093
124.133
124.257
126.594
127.565
128.066
128.121
129.583
129.908
132.167
134.103
136.425
155.517
159.059
163.819
Br
MeO
O
N
N
OMe
O
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

**2.18**

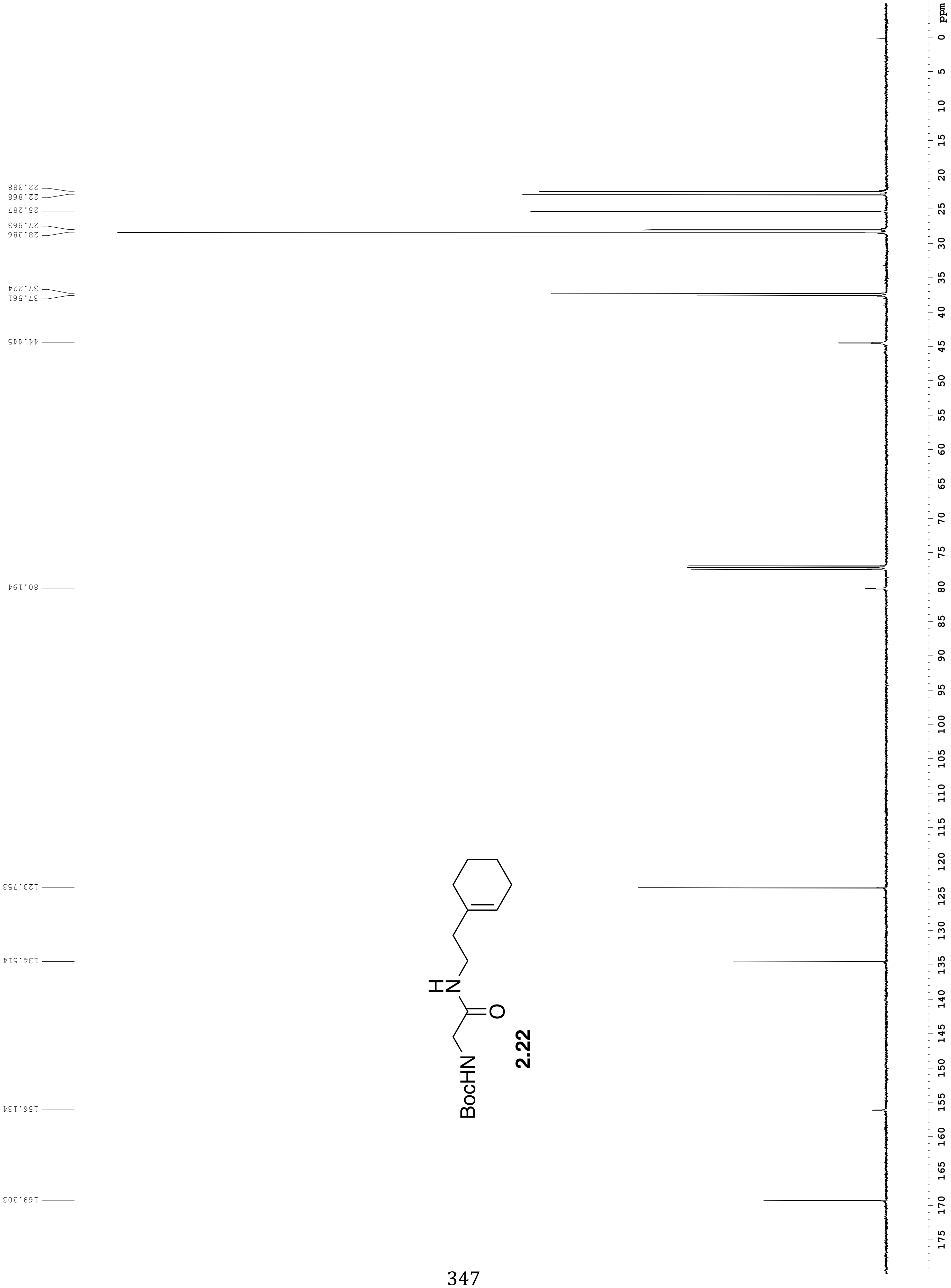

3.778
7.303
7.307
7.320
7.323
7.428
7.445
7.452
7.456
7.927
7.941
7.957
8.017
8.032
8.048
8.323
8.339
8.542
8.558
2.929
0.950
1.917
0.976
1.000
1.030
1.021
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Br
MeO
N
N
O
O
OH
2.19


56.417
115.801
123.023
123.555
126.575
126.648
127.391
127.445
129.630
130.616
132.406
134.264
137.385
155.332
158.060
164.442
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
Br
MeO
O
N
N
OH
O

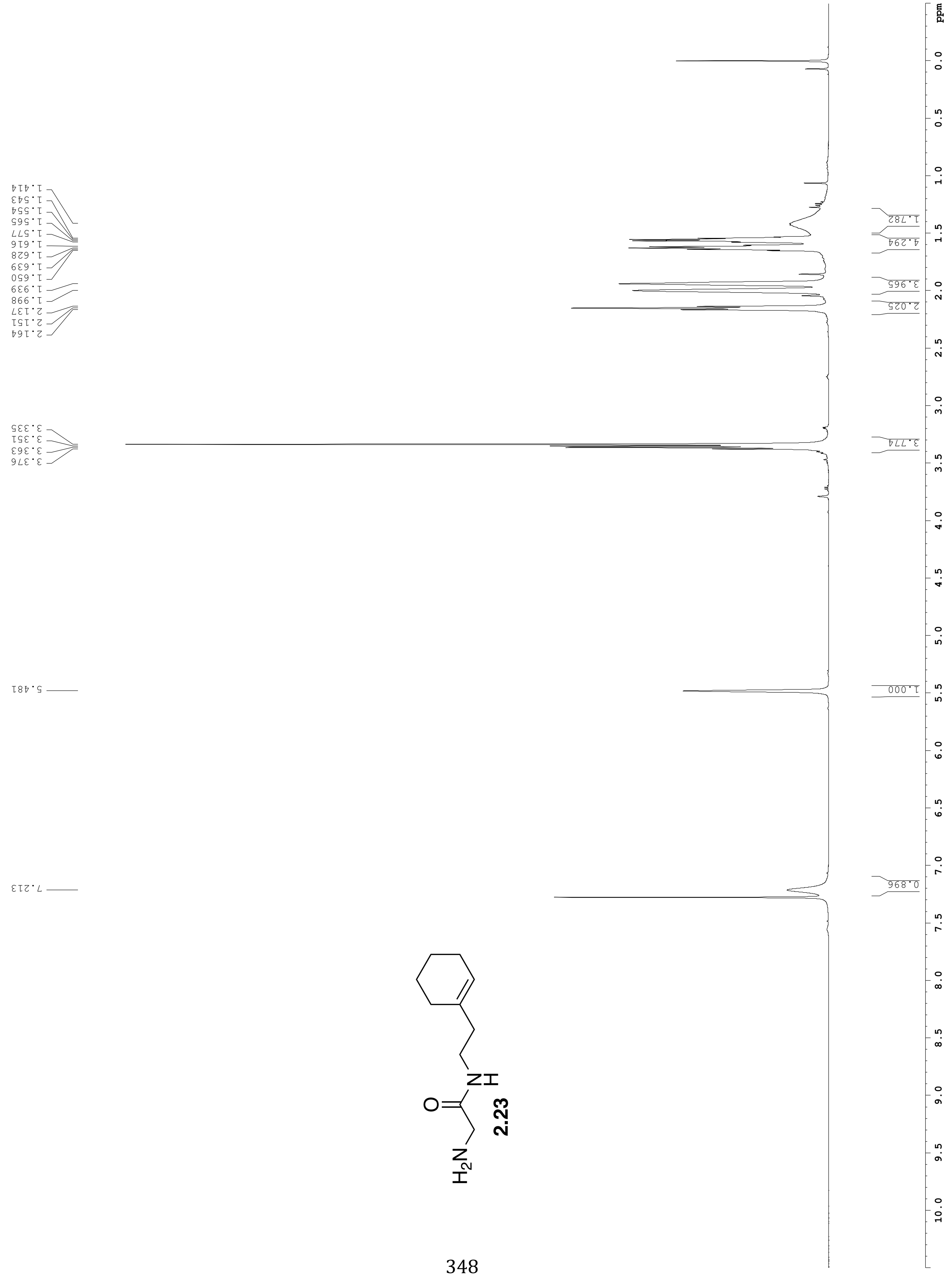
**2.19**


1.429
1.500
1.512
1.519
1.523
1.530
1.534
1.542
1.546
1.568
1.573
1.581
1.585
1.593
1.597
1.604
1.615
1.891
1.971
2.091
2.105
2.119
3.290
3.303
3.315
3.328
3.737
3.748
5.252
5.438
6.180
9.065
4.204
4.235
2.128
2.038
2.041
1.026
1.041
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
H
N
O
BocHN

**2.22**

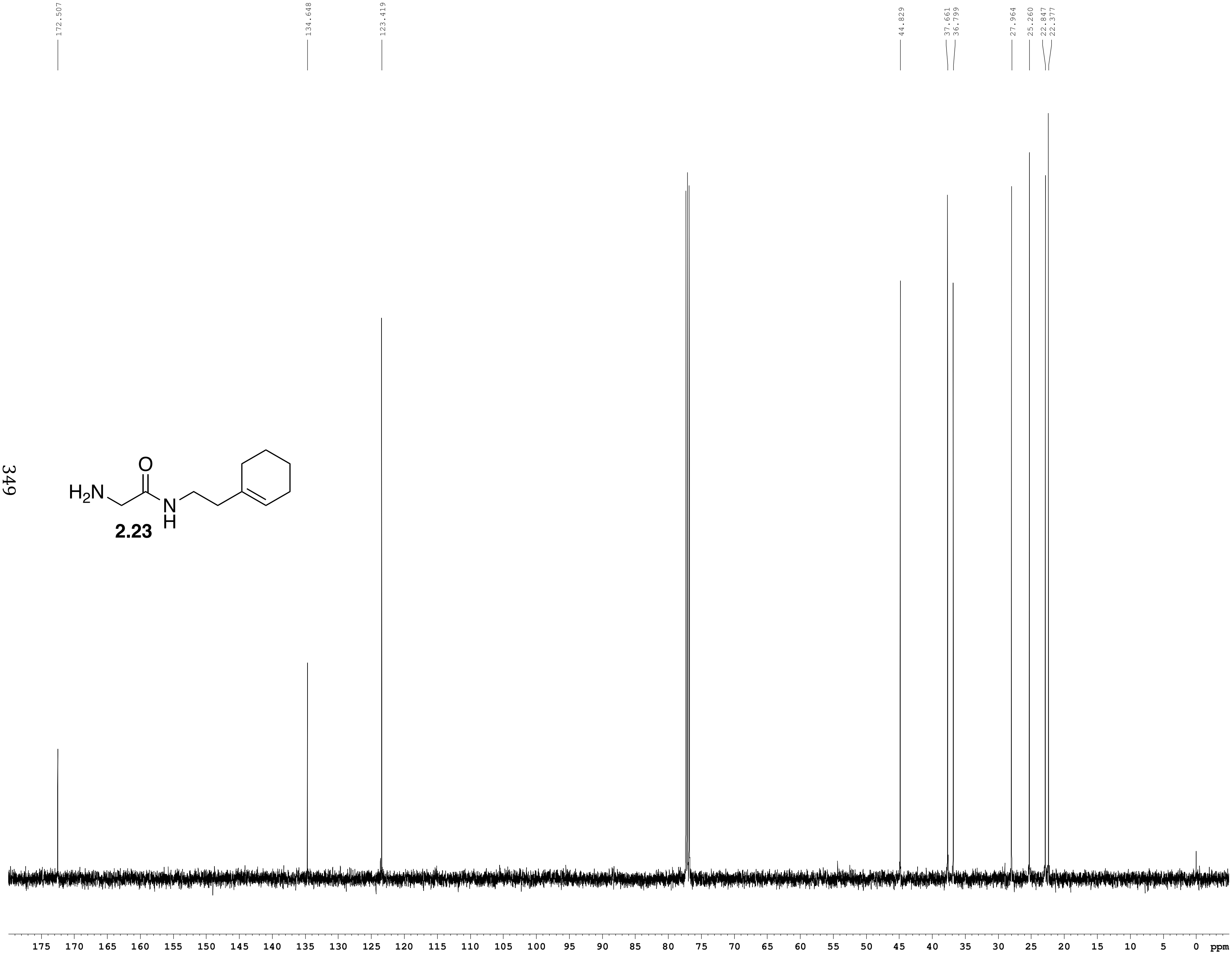

22.388
22.868
25.287
27.963
28.386
37.224
37.561
44.445
80.194
123.753
134.514
156.134
169.303
BocHN
H
N
O
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

**2.22**

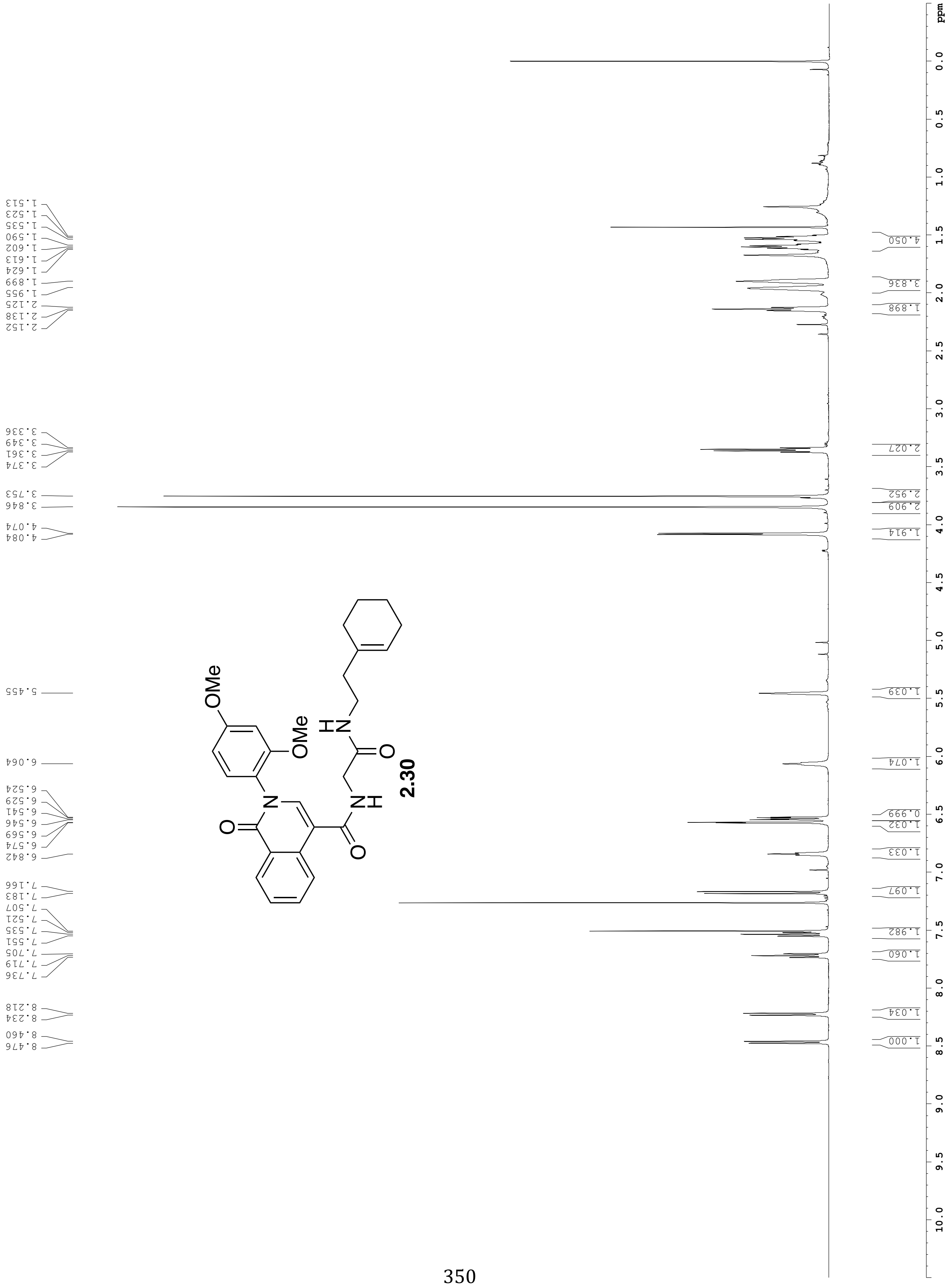


**2.23**

1.414
1.543
1.554
1.565
1.577
1.616
1.628
1.639
1.650
1.939
1.998
2.137
2.151
2.164
3.335
3.351
3.363
3.376
5.481
7.213
1.782
4.294
3.965
2.025
3.774
1.000
0.896
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
$H_2N$
O
N
H

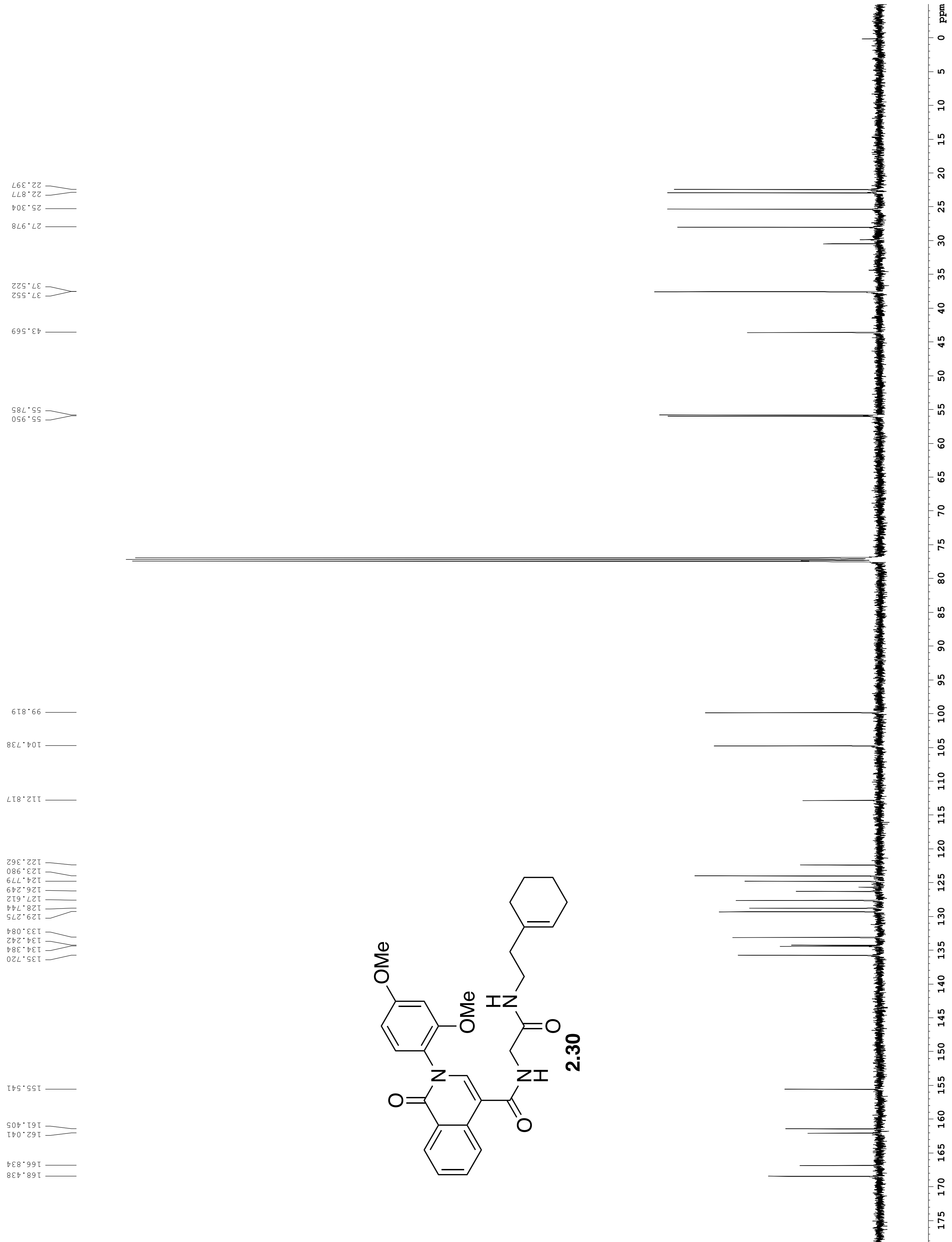

172.507
134.648
123.419
44.829
37.661
36.799
27.964
25.260
22.847
22.377
H2N
O
N
H
175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 ppm

**2.23**

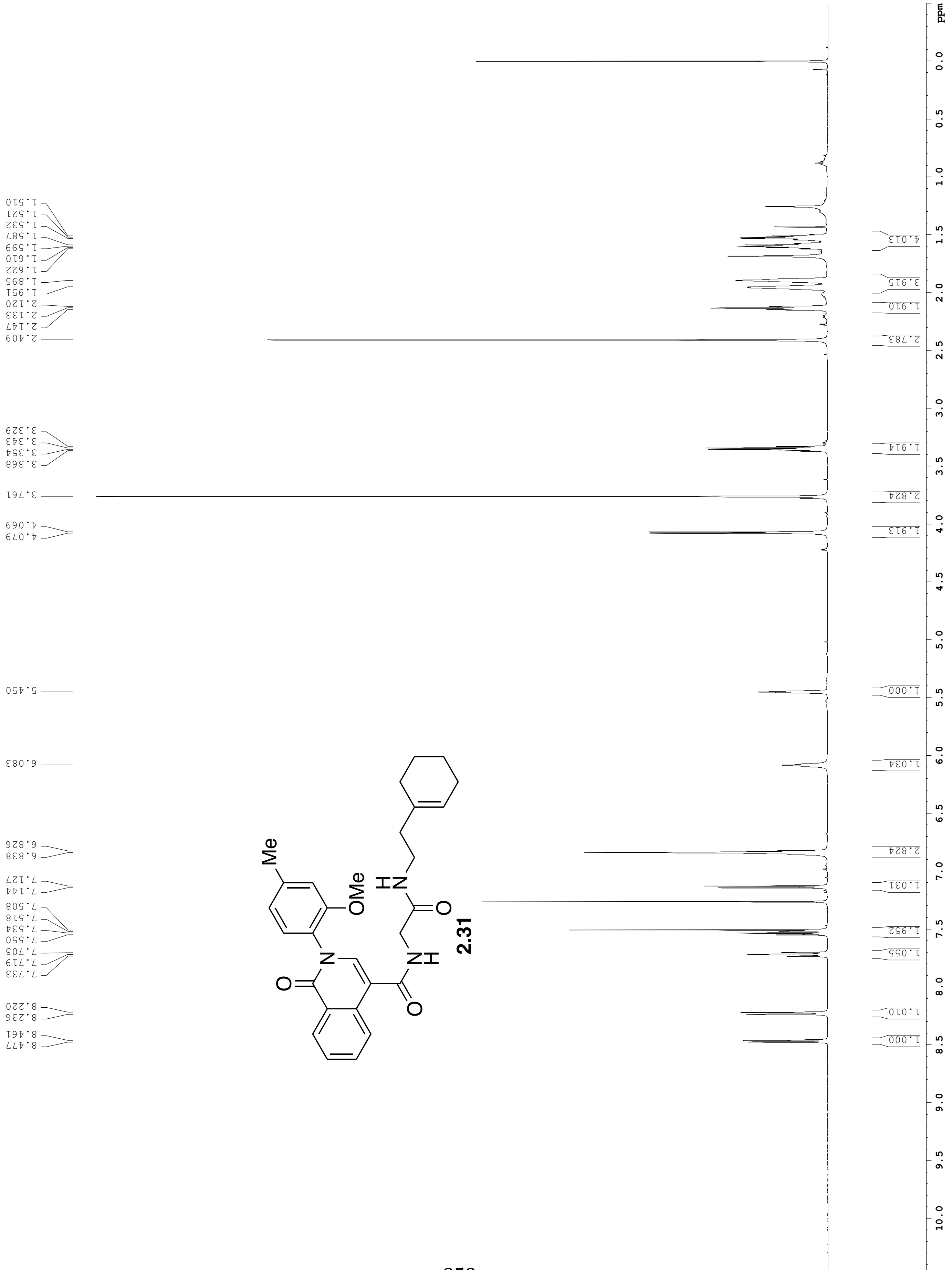


**2.30**

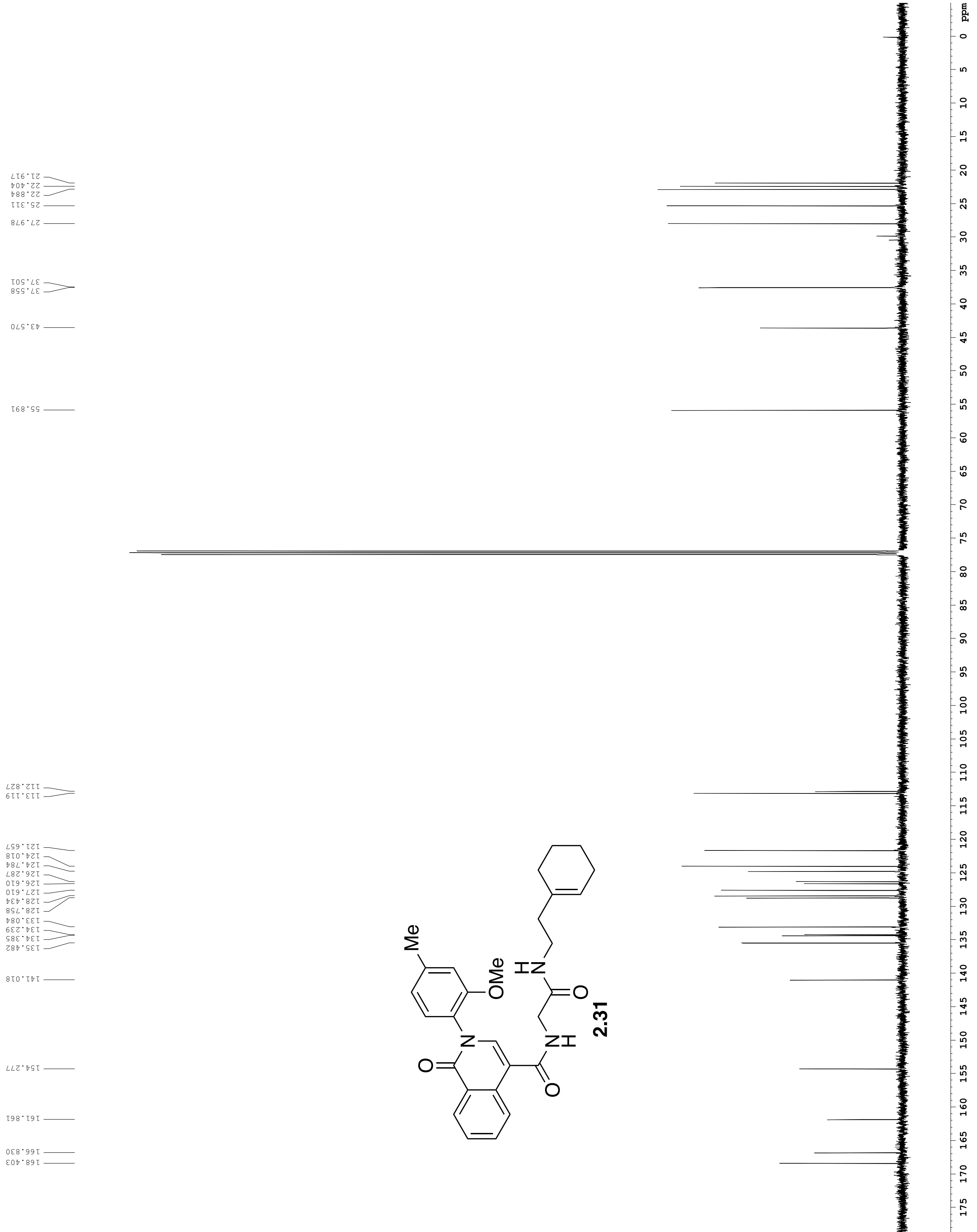
OMe
OMe
N
O
H
N
O
N
H
O
1.513
1.523
1.535
1.590
1.602
1.613
1.624
1.899
1.955
2.125
2.138
2.152
3.336
3.349
3.361
3.374
3.753
3.846
4.074
4.084
5.455
6.064
6.524
6.529
6.541
6.546
6.569
6.574
6.842
7.166
7.183
7.507
7.521
7.535
7.551
7.705
7.719
7.736
8.218
8.234
8.460
8.476
4.050
3.836
1.898
2.027
2.952
2.909
1.914
1.039
1.074
0.999
1.032
1.033
1.097
1.982
1.060
1.034
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0


22.397
22.877
25.304
27.978
37.522
37.552
43.569
55.785
55.950
99.819
104.738
112.817
122.362
123.980
124.779
126.249
127.612
128.744
129.275
133.084
134.242
134.384
135.720
155.541
161.405
162.041
166.834
168.438
OMe
OMe
N
O
O
N
H
O
N
H
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

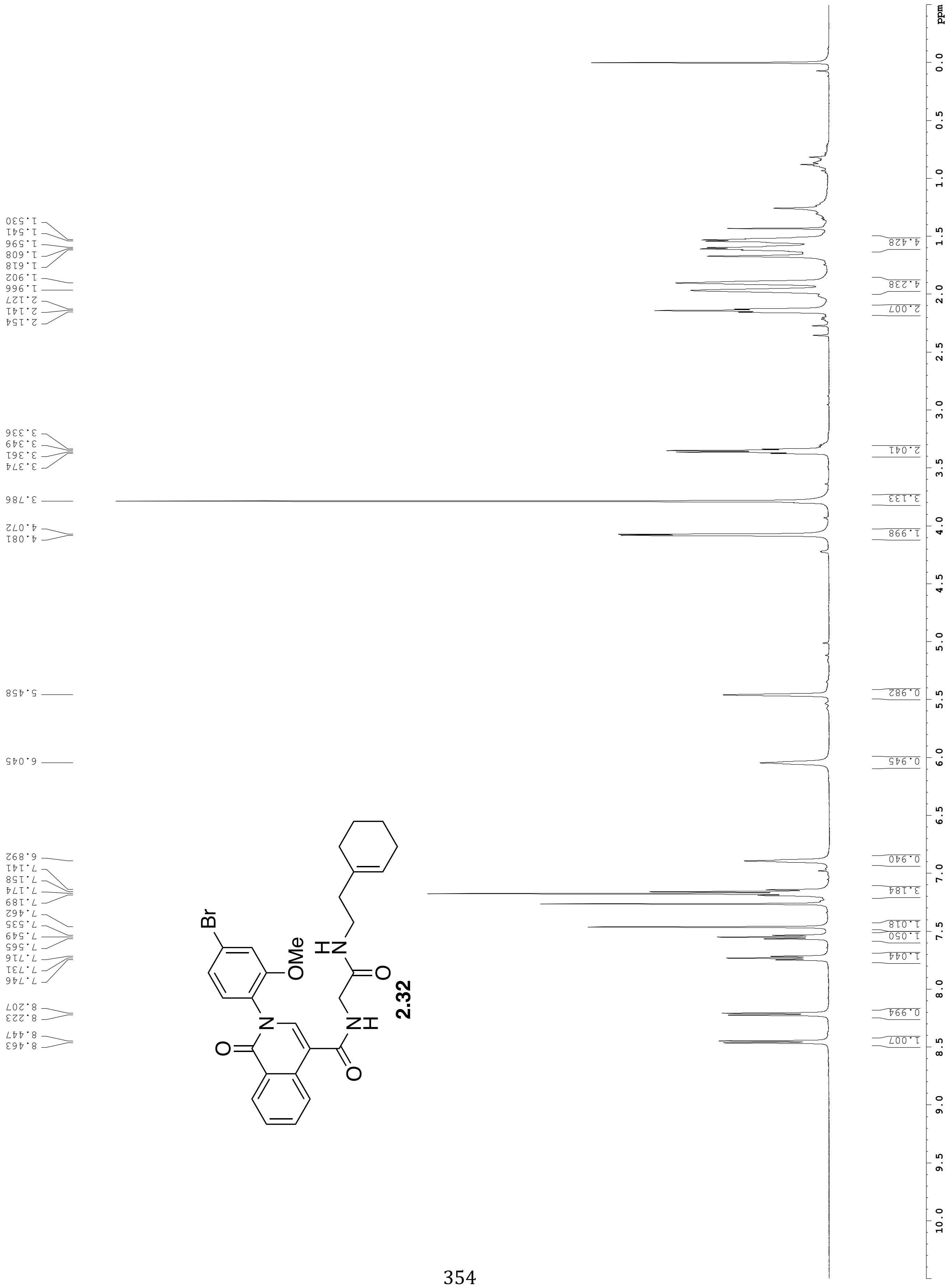
**2.30**


1.510
1.521
1.532
1.587
1.599
1.610
1.622
1.895
1.951
2.120
2.133
2.147
2.409
3.329
3.343
3.354
3.368
3.761
4.069
4.079
5.450
6.083
6.826
6.838
7.127
7.144
7.508
7.518
7.534
7.550
7.705
7.719
7.733
8.220
8.236
8.461
8.477
4.013
3.915
1.910
2.783
1.914
2.824
1.913
1.000
1.034
2.824
1.031
1.952
1.055
1.010
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Me
OMe
N
O
O
N
H
O
N
H

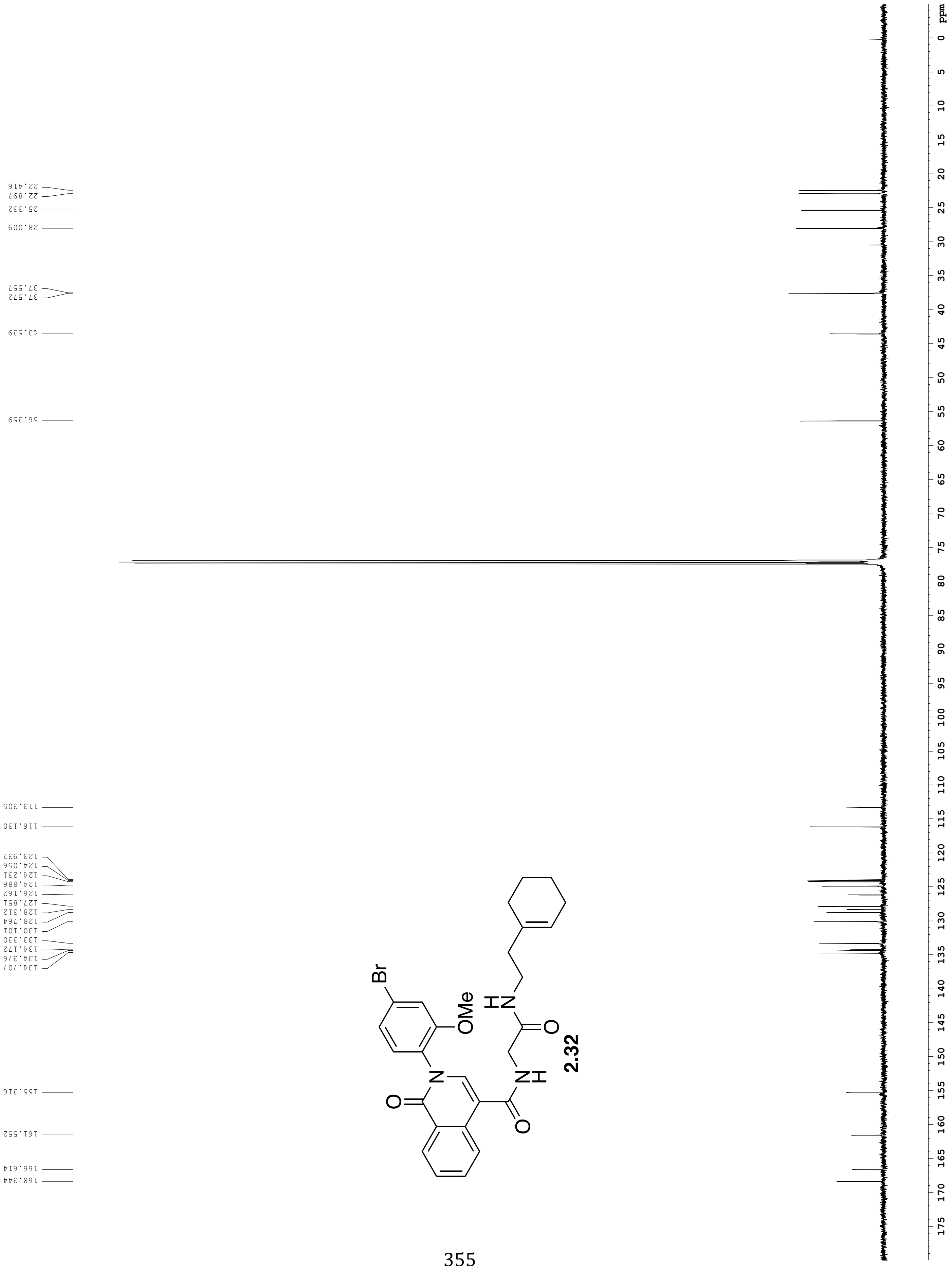
**2.31**


21.917
22.404
22.884
25.311
27.978
37.501
37.558
43.570
55.891
112.827
113.119
121.657
124.018
124.784
126.287
126.610
127.610
128.434
128.758
133.084
134.239
134.385
135.482
141.018
154.277
161.861
166.830
168.403
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
Me
OMe
N
O
O
N
H
O
N
H

**2.31**

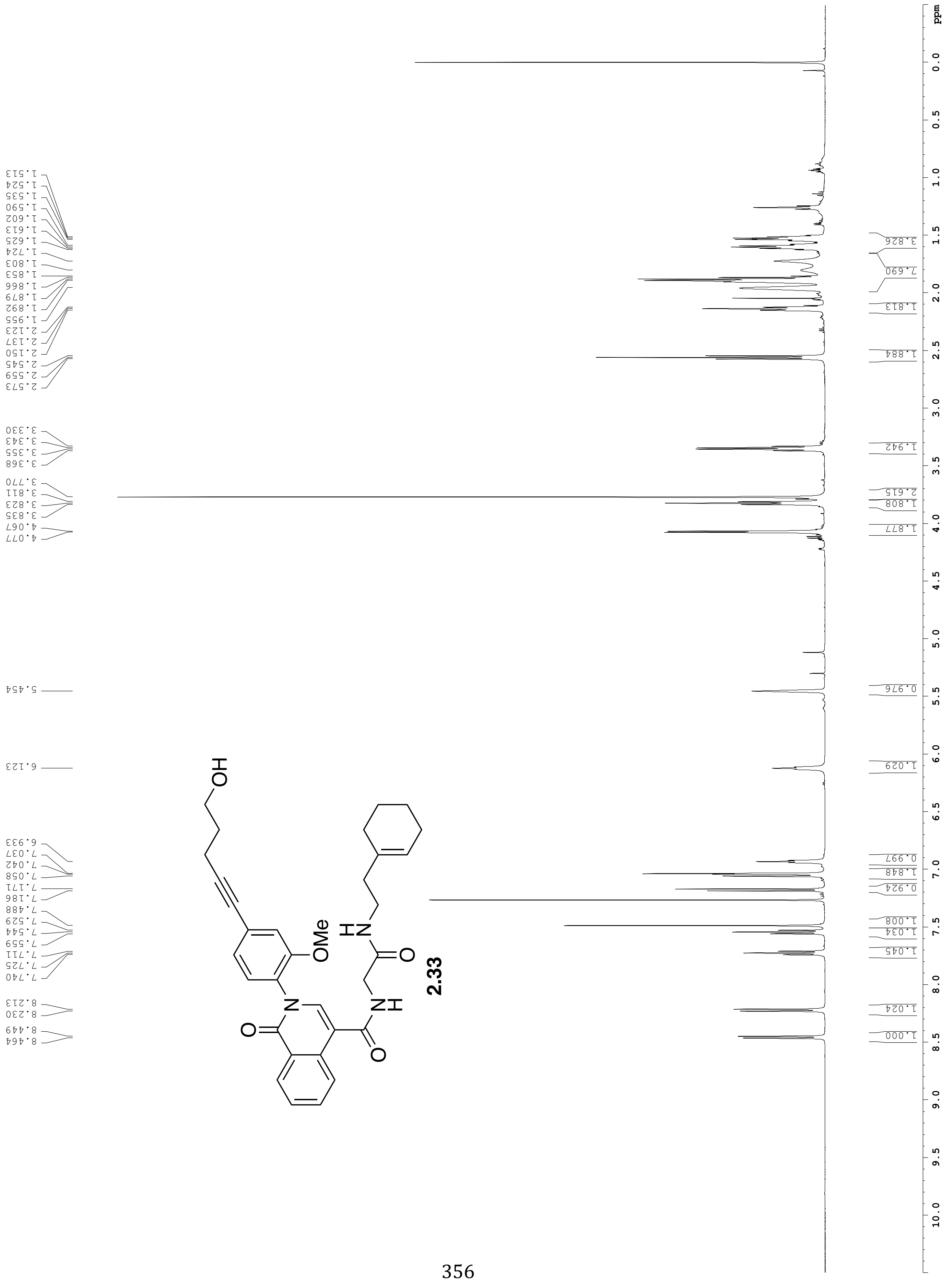

1.530
1.541
1.596
1.608
1.618
1.902
1.966
2.127
2.141
2.154
3.336
3.349
3.361
3.374
3.786
4.072
4.081
5.458
6.045
6.892
7.141
7.158
7.174
7.189
7.462
7.535
7.549
7.565
7.716
7.731
7.746
8.207
8.223
8.447
8.463
4.428
4.238
2.007
2.041
3.133
1.998
0.982
0.945
0.940
3.184
1.018
1.050
1.044
0.994
1.007
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Br
OMe
N
O
O
H
N
O
N
H

**2.32**

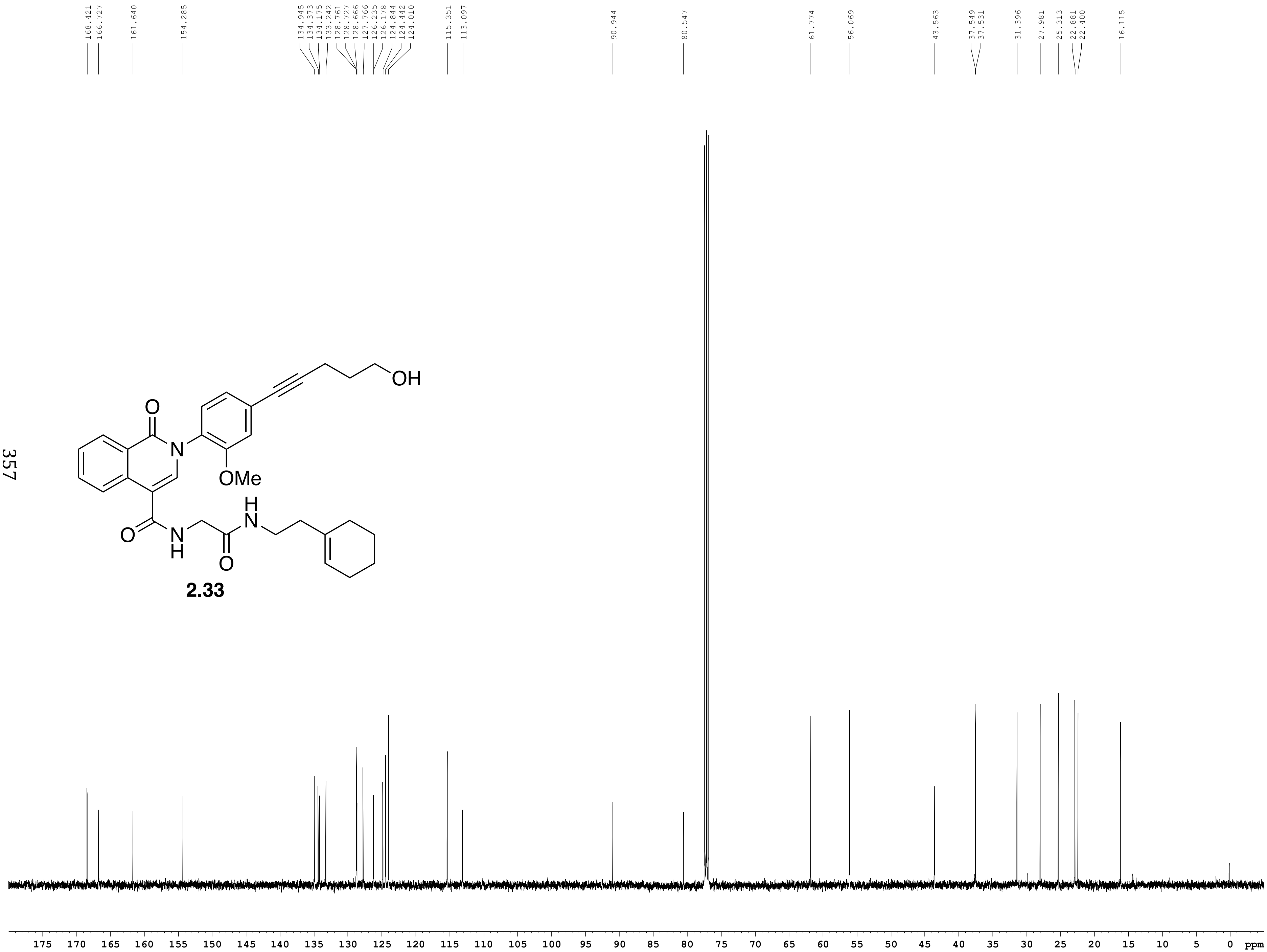


**2.32**

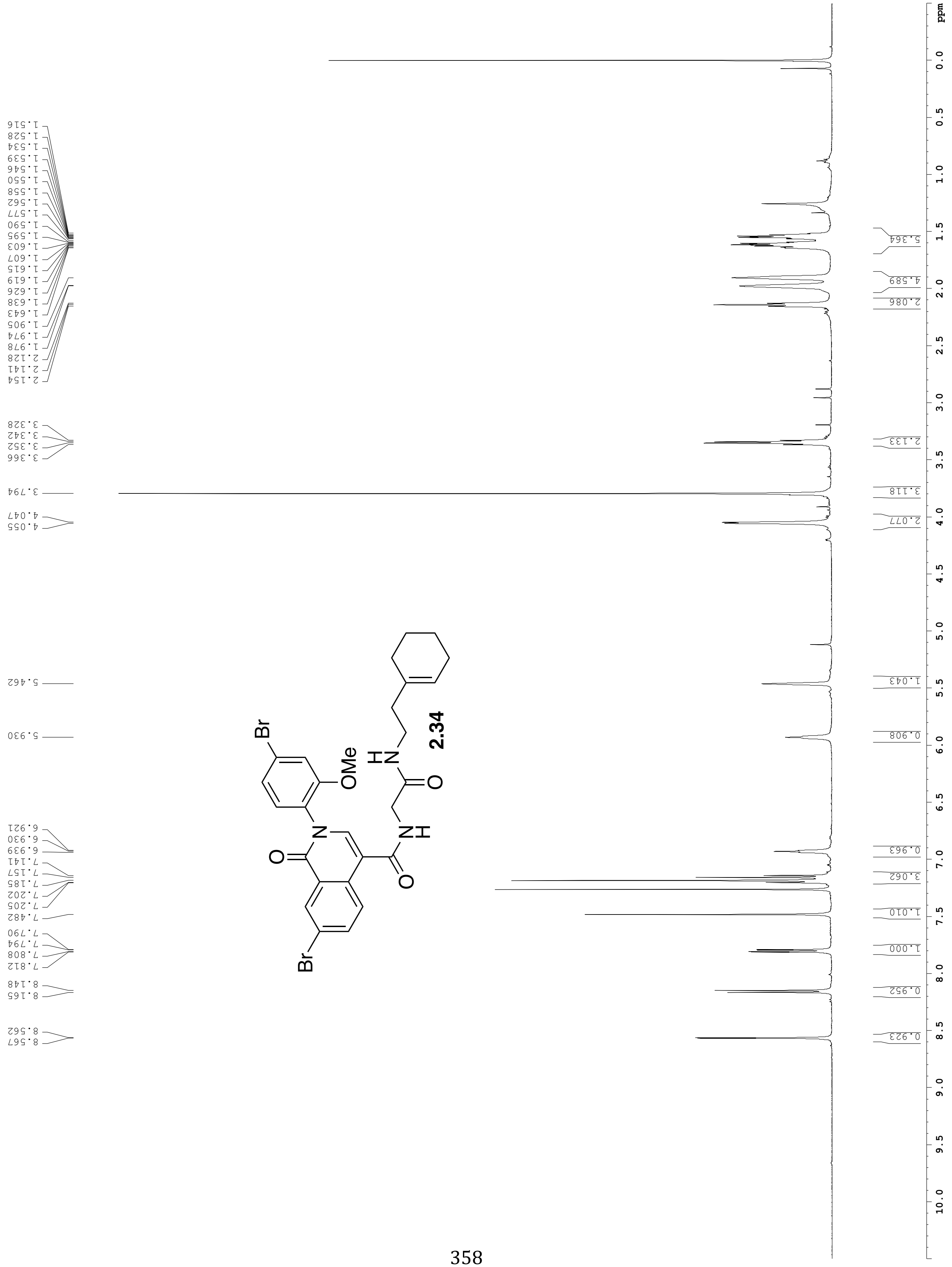
22.416
22.897
25.332
28.009
37.557
37.572
43.539
56.359
113.305
116.130
123.937
124.056
124.231
124.886
126.162
127.851
128.312
128.764
130.101
133.330
134.172
134.376
134.707
155.316
161.552
166.614
168.344
Br
OMe
N
H
O
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

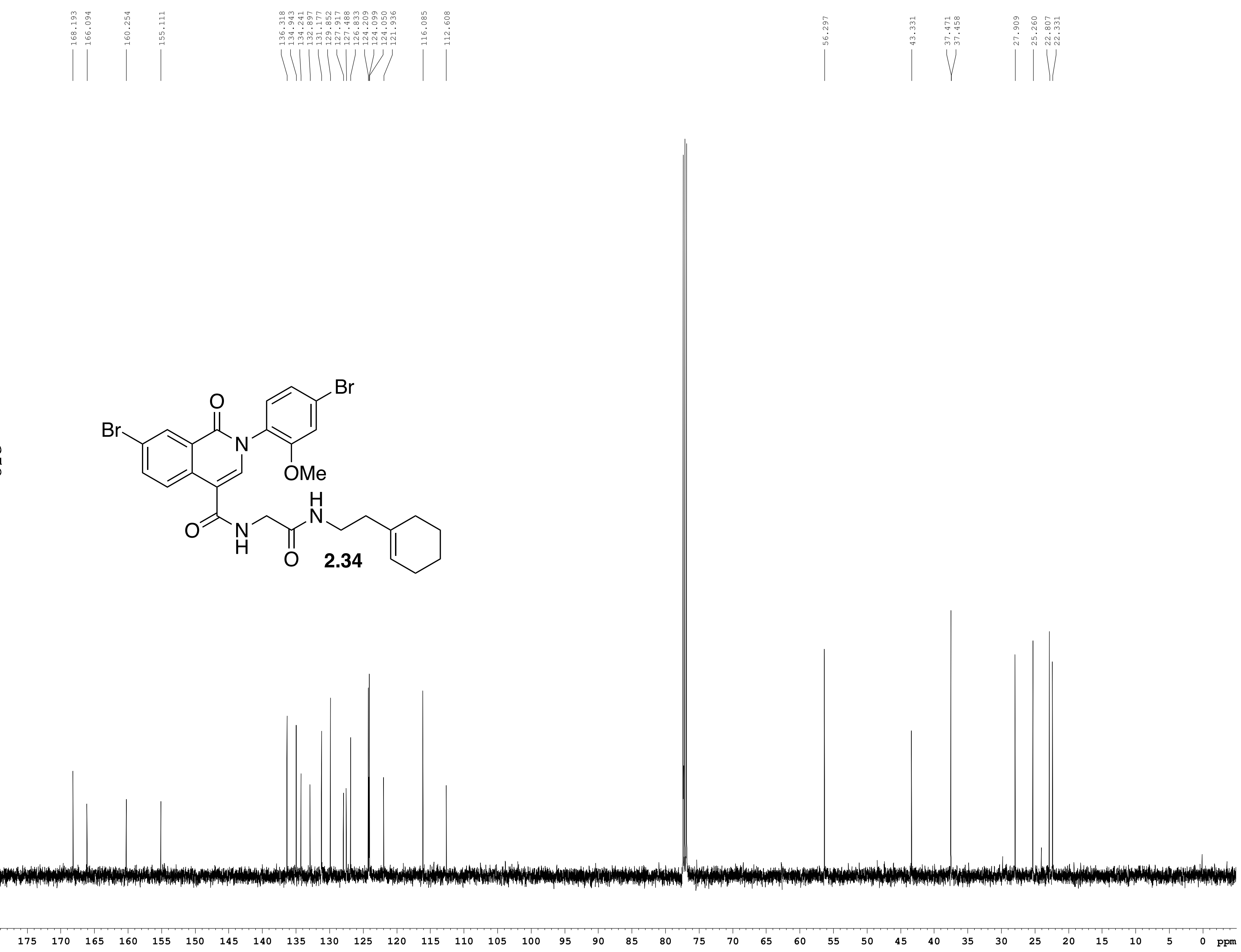

1.513
1.524
1.535
1.590
1.602
1.613
1.625
1.724
1.803
1.853
1.866
1.879
1.892
1.955
2.123
2.137
2.150
2.545
2.559
2.573
3.330
3.343
3.355
3.368
3.770
3.811
3.823
3.835
4.067
4.077
5.454
6.123
6.933
7.037
7.042
7.058
7.171
7.186
7.488
7.529
7.544
7.559
7.711
7.725
7.740
8.213
8.230
8.449
8.464
3.826
7.690
1.813
1.884
1.942
2.615
1.808
1.877
0.976
1.029
0.997
1.848
0.924
1.008
1.034
1.045
1.024
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
OH
OMe
N
O
O
H
N
O
N
H

**2.33**

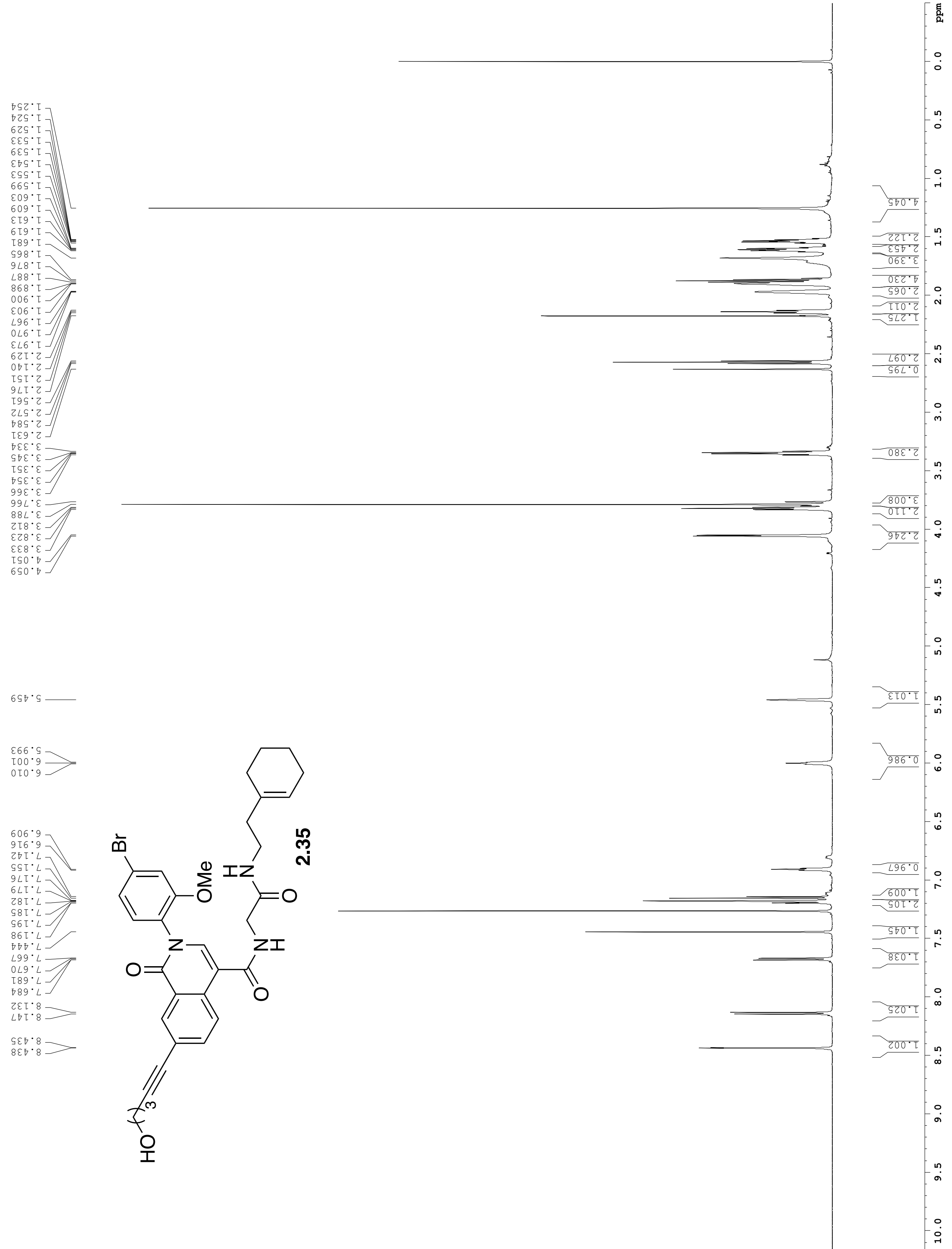

168.421
166.727
161.640
154.285
134.945
134.373
134.175
133.242
128.761
128.727
128.666
127.766
126.235
126.178
124.844
124.442
124.010
115.351
113.097
90.944
80.547
61.774
56.069
43.563
37.549
37.531
31.396
27.981
25.313
22.881
22.400
16.115
O
N
OMe
OH
O
N
H
H
N
O
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
ppm

**2.33**

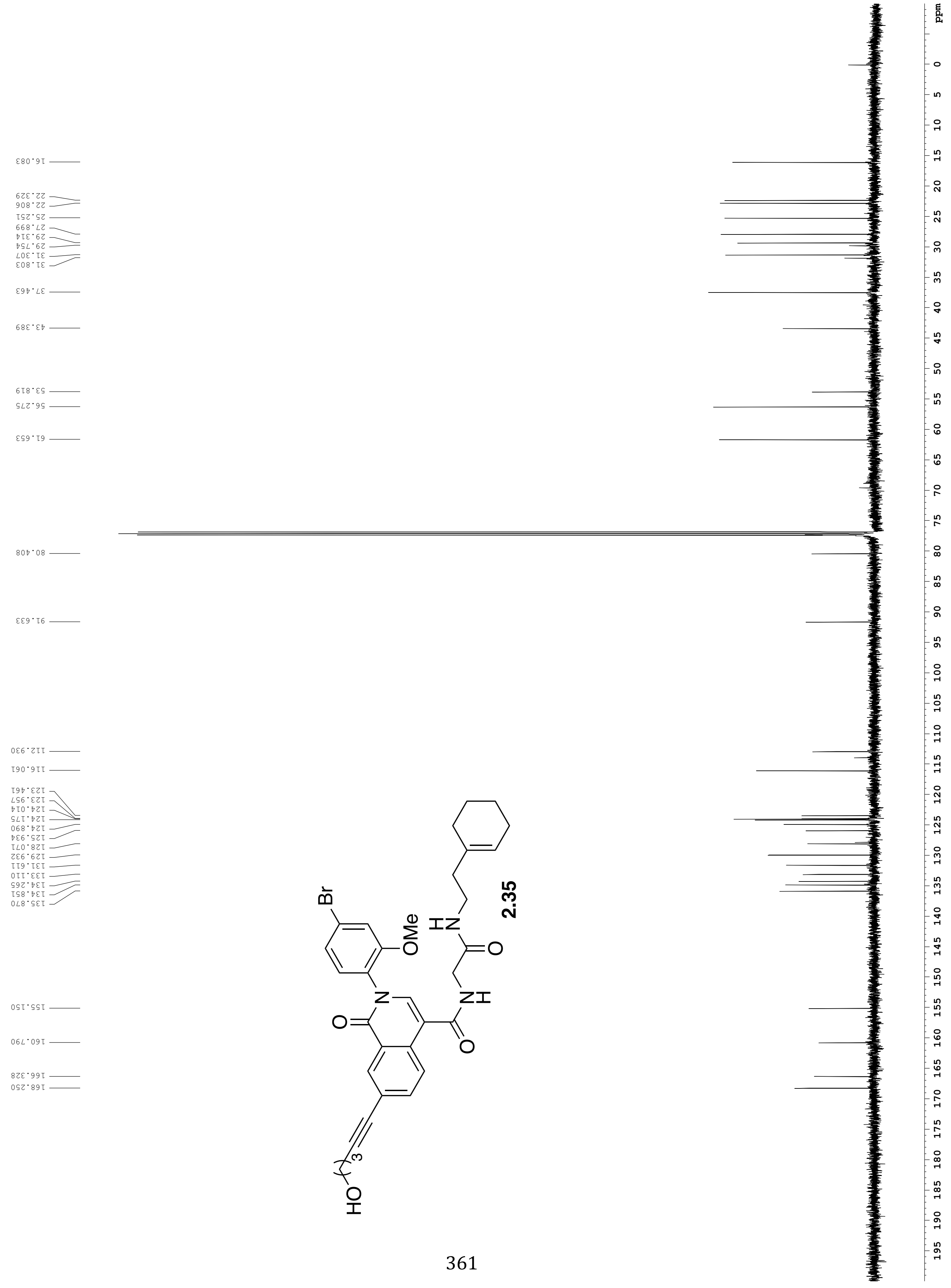

1.516
1.528
1.534
1.539
1.546
1.550
1.558
1.562
1.577
1.590
1.595
1.603
1.607
1.615
1.619
1.626
1.638
1.643
1.905
1.974
1.978
2.128
2.141
2.154
3.328
3.342
3.352
3.366
3.794
4.047
4.055
5.462
5.930
6.921
6.930
6.939
7.141
7.157
7.185
7.202
7.205
7.482
7.790
7.794
7.808
7.812
8.148
8.165
8.562
8.567
5.364
4.589
2.086
2.133
3.118
2.077
1.043
0.908
0.963
3.062
1.010
1.000
0.952
0.923
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Br
OMe
O
N
NH
HN
O
O
Br
2.34


168.193
166.094
160.254
155.111
136.318
134.943
134.241
132.897
131.177
129.852
127.917
127.488
126.833
124.209
124.099
124.050
121.936
116.085
112.608
56.297
43.331
37.471
37.458
27.909
25.260
22.807
22.331
Br
O
N
Br
OMe
O
N
H
H
N
O
175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 ppm

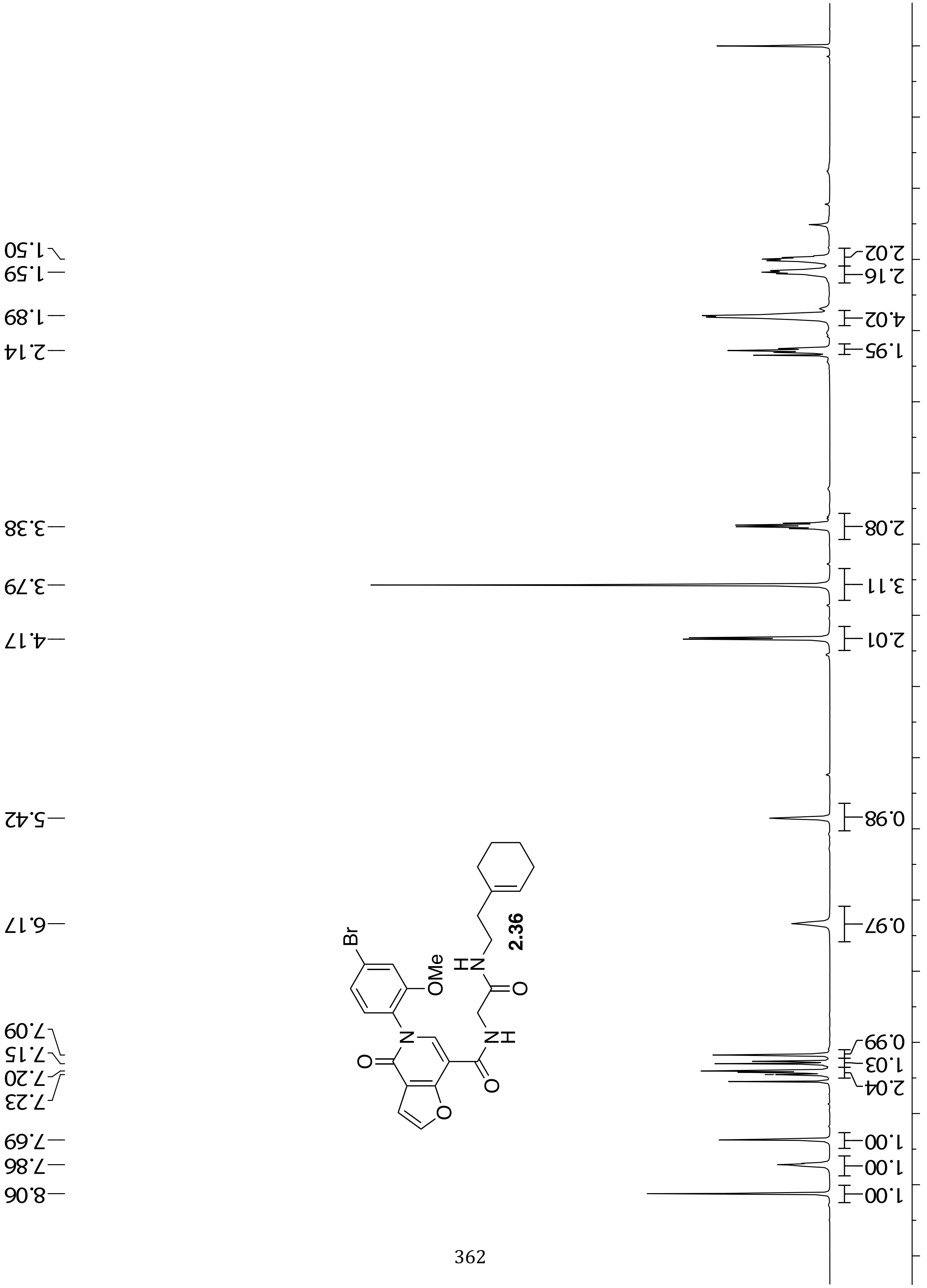
**2.34**


1.254
1.524
1.529
1.533
1.539
1.543
1.553
1.599
1.603
1.609
1.613
1.619
1.681
1.865
1.876
1.887
1.898
1.900
1.903
1.967
1.970
1.973
2.129
2.140
2.151
2.176
2.561
2.572
2.584
2.631
3.334
3.345
3.351
3.354
3.366
3.766
3.788
3.812
3.823
3.833
4.051
4.059
5.459
5.993
6.001
6.010
6.909
6.916
7.142
7.155
7.176
7.179
7.182
7.185
7.195
7.198
7.444
7.667
7.670
7.681
7.684
8.132
8.147
8.435
8.438
4.045
2.122
2.453
3.390
4.230
2.065
2.011
1.275
2.097
0.795
2.380
3.008
2.110
2.246
1.013
0.986
0.967
1.009
2.105
1.045
1.038
1.025
1.002
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Br
OMe
H
N
O
N
O
N
H
O
HO
3

**2.35**

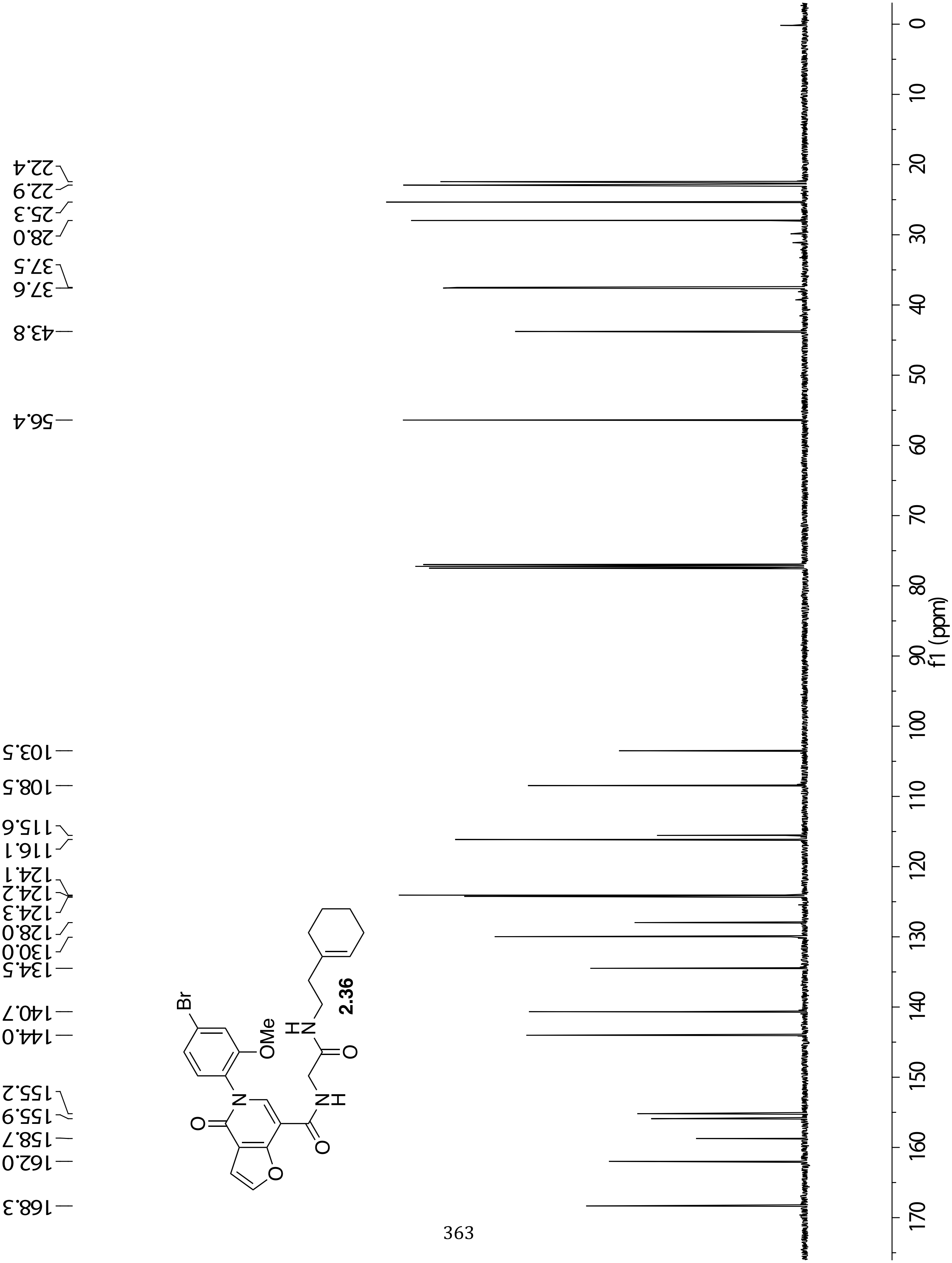

16.083
22.329
22.806
25.251
27.899
29.314
29.754
31.307
31.803
37.463
43.389
53.819
56.275
61.653
80.408
91.633
112.930
116.061
123.461
123.957
124.014
124.175
124.890
125.934
128.071
129.932
131.611
133.110
134.265
134.851
135.870
155.150
160.790
166.328
168.250
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
Br
OMe
N
O
O
N
H
O
N
H
HO
3

**2.35**



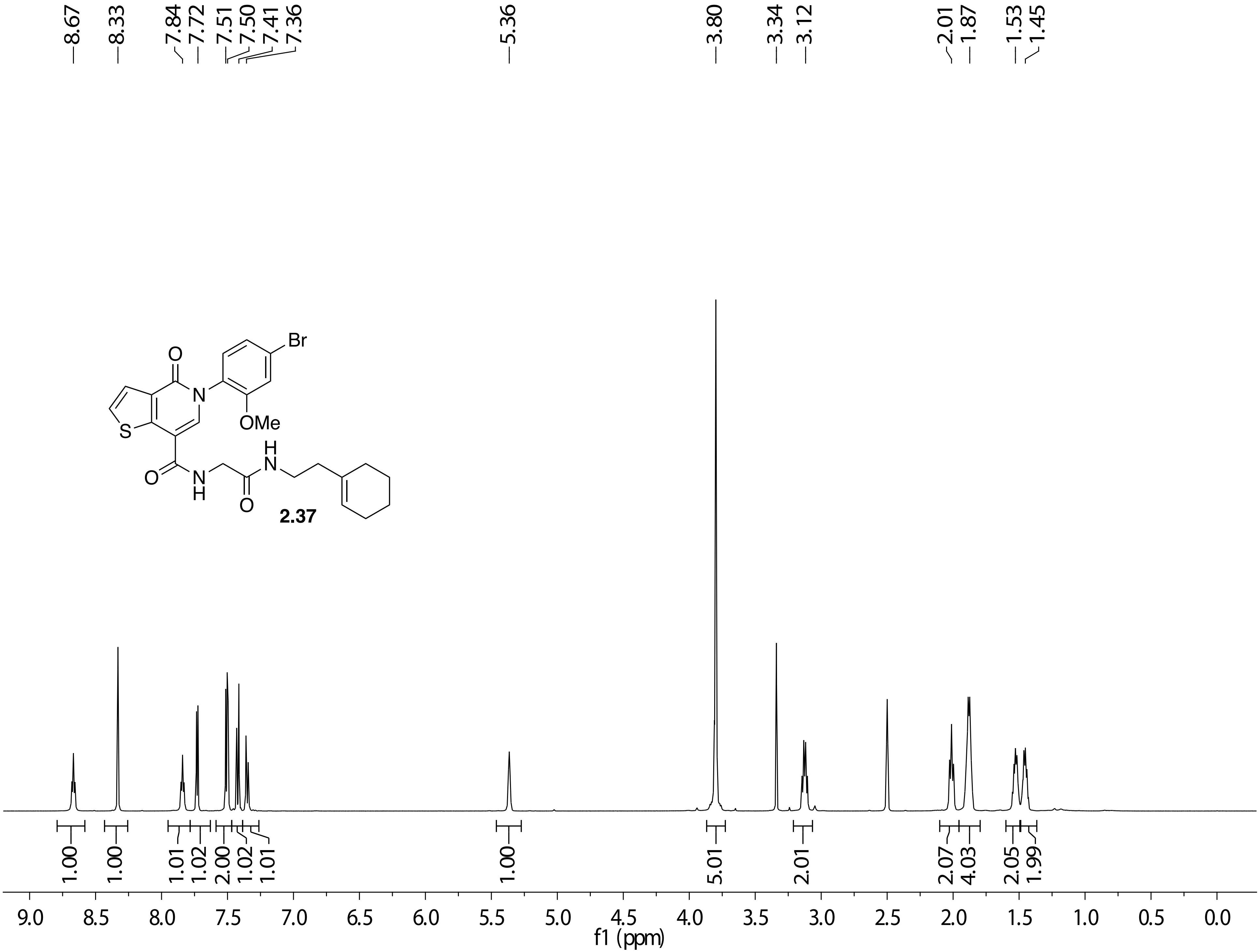
1.50
1.59
1.89
2.14
3.38
3.79
4.17
5.42
6.17
7.09
7.15
7.20
7.23
7.69
7.86
8.06
2.02
2.16
4.02
1.95
2.08
3.11
2.01
0.98
0.97
0.99
1.03
2.04
1.00
1.00
1.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
f1 (ppm)
Br
OMe
N
H
O

**2.36**



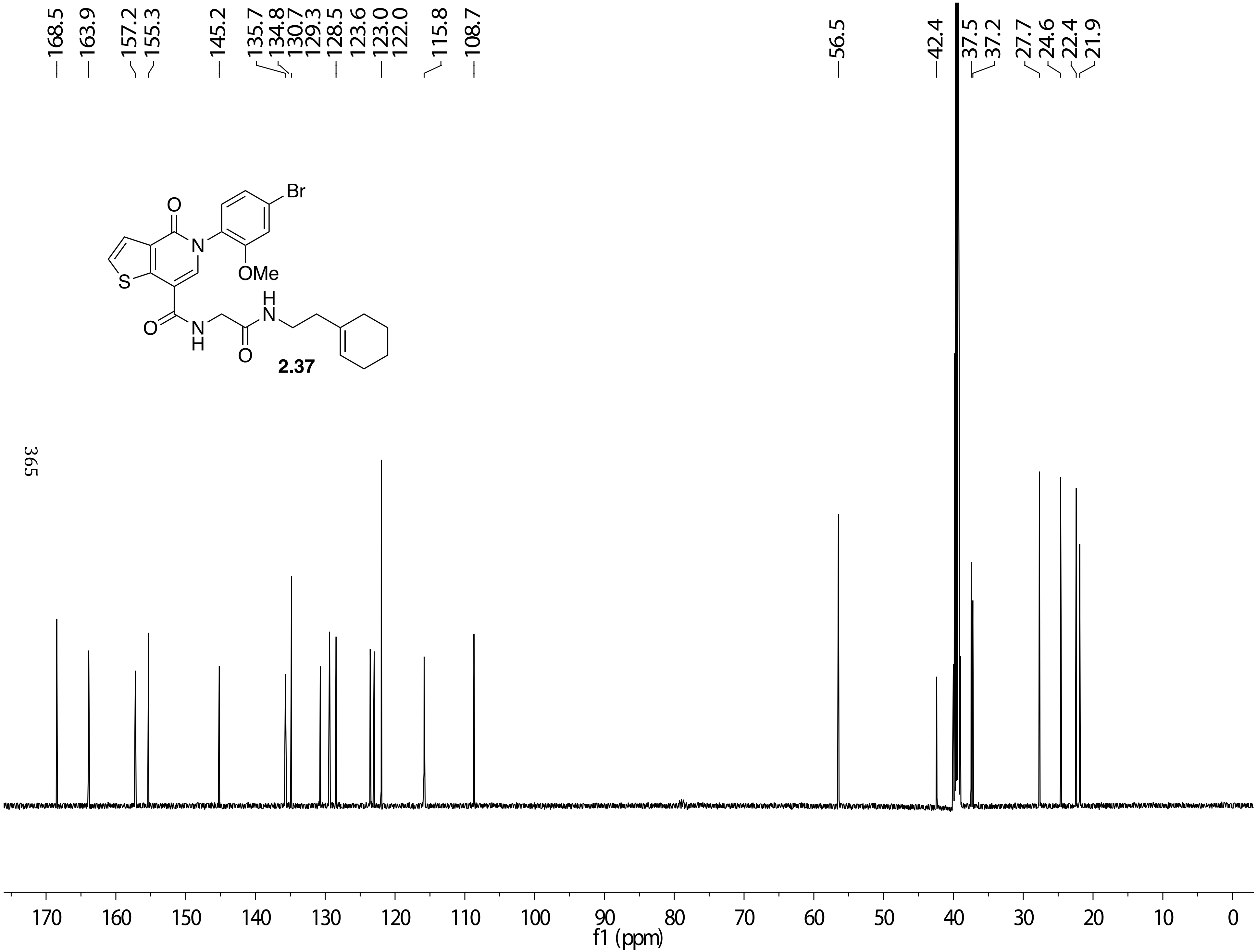
22.4
22.9
25.3
28.0
37.5
37.6
43.8
56.4
103.5
108.5
115.6
116.1
124.1
124.2
124.3
128.0
130.0
134.5
140.7
144.0
155.2
155.9
158.7
162.0
168.3
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
f1 (ppm)
Br
OMe
O
N
H

**2.36**

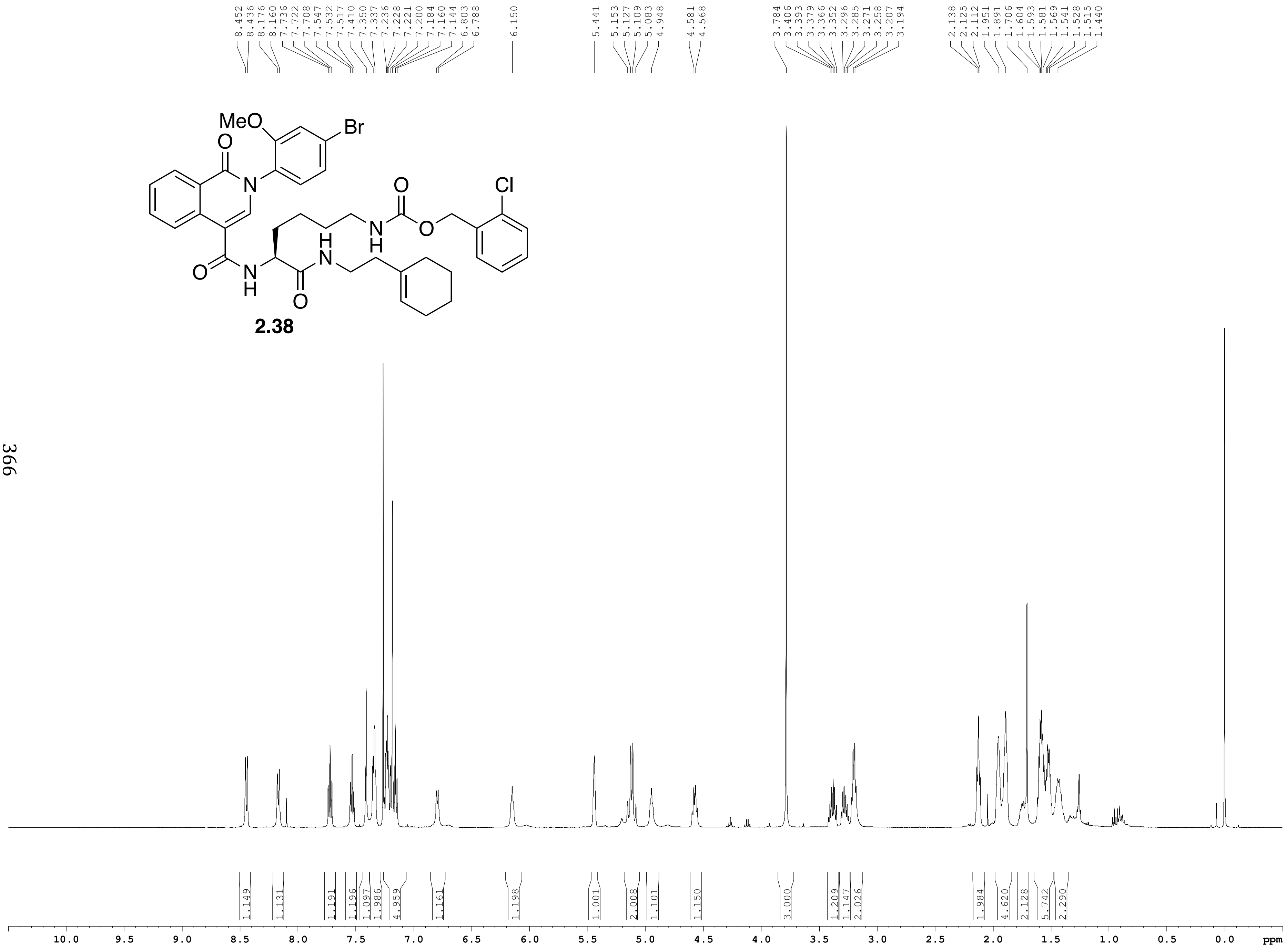


**2.37**

8.67
8.33
7.84
7.72
7.51
7.50
7.41
7.36
5.36
3.80
3.34
3.12
2.01
1.87
1.53
1.45
1.00
1.00
1.01
1.02
2.00
1.02
1.01
1.00
5.01
2.01
2.07
4.03
2.05
1.99
Br
O
N
S
OMe
H
N
O
N
H
O
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

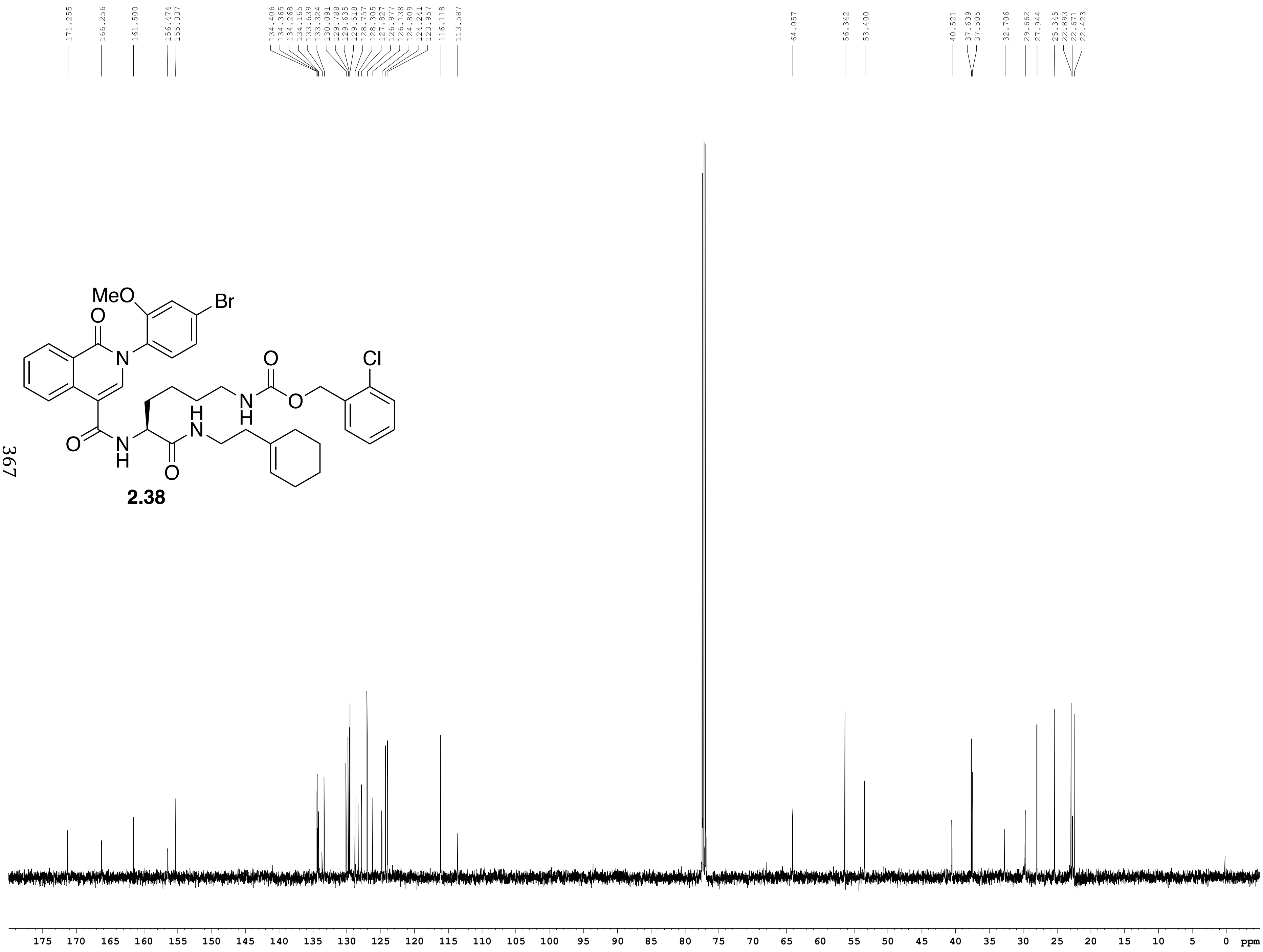


168.5
163.9
157.2
155.3
145.2
135.7
134.8
130.7
129.3
128.5
123.6
123.0
122.0
115.8
108.7
56.5
42.4
37.5
37.2
27.7
24.6
22.4
21.9
O
Br
N
S
OMe
H
N
O
N
H
O
2.37
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

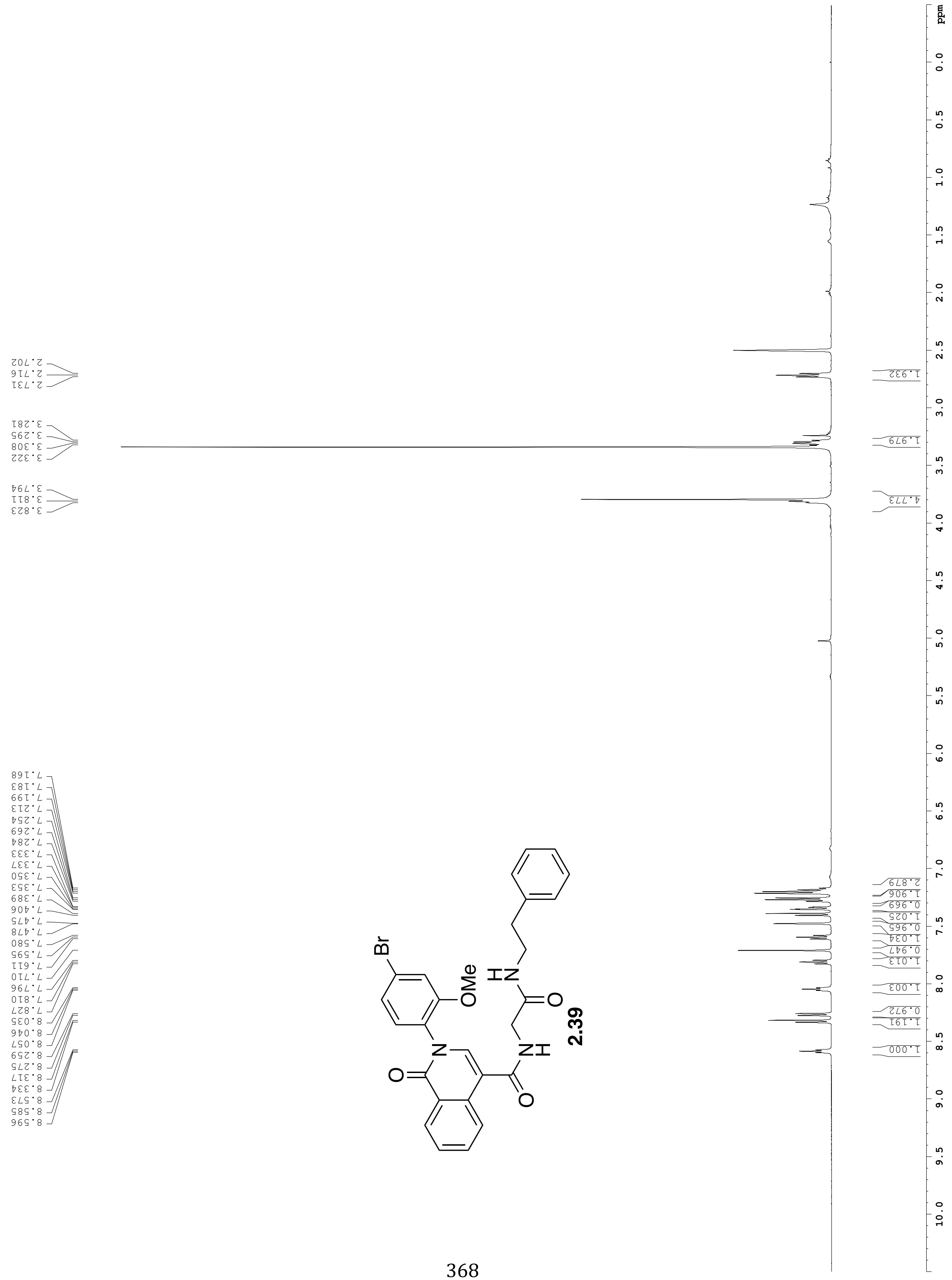


8.452
8.436
8.176
8.160
7.736
7.722
7.708
7.547
7.532
7.517
7.410
7.350
7.337
7.236
7.228
7.221
7.200
7.184
7.160
7.144
6.803
6.788
6.150
5.441
5.153
5.127
5.109
5.083
4.948
4.581
4.568
3.784
3.406
3.393
3.379
3.366
3.352
3.296
3.285
3.271
3.258
3.207
3.194
2.138
2.125
2.112
1.951
1.891
1.706
1.604
1.593
1.581
1.569
1.541
1.528
1.515
1.440
MeO
O
Br
N
O
O
N
H
H
N
H
N
O
O
Cl
O
1.149
1.131
1.191
1.196
1.097
1.986
4.959
1.161
1.198
1.001
2.008
1.101
1.150
3.000
1.209
1.147
2.026
1.984
4.620
2.128
5.742
2.290
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

**2.38**

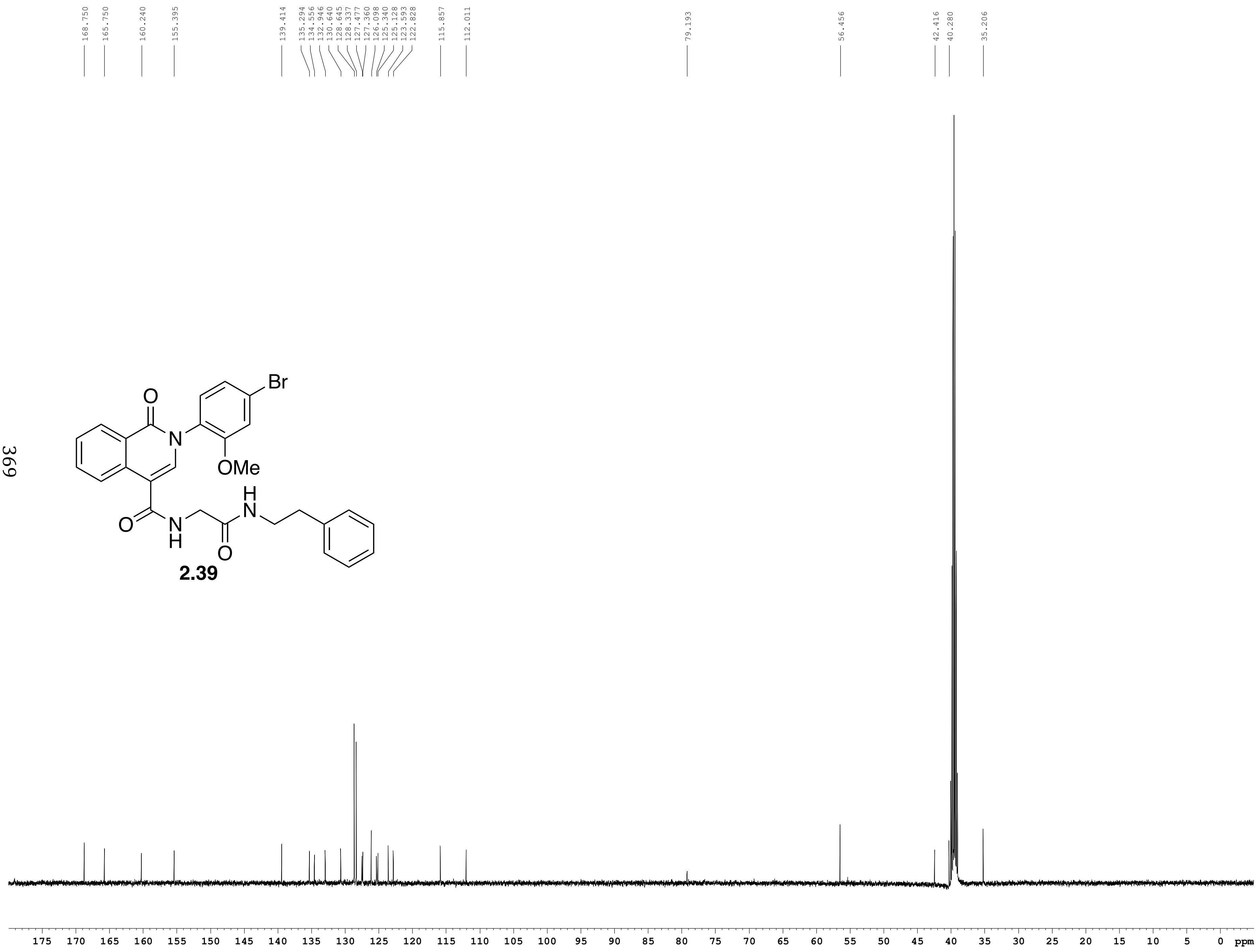
171.255
166.256
161.500
156.474
155.337
134.406
134.365
134.268
134.165
133.639
133.324
130.091
129.788
129.635
129.518
128.757
128.305
127.827
126.977
126.138
124.809
124.241
123.957
116.118
113.587
64.057
56.342
53.400
40.521
37.639
37.505
32.706
29.662
27.944
25.345
22.893
22.671
22.423
MeO
Br
O
N
O
Cl
N
H
O
H
N
O
N
H
O
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
ppm

**2.38**

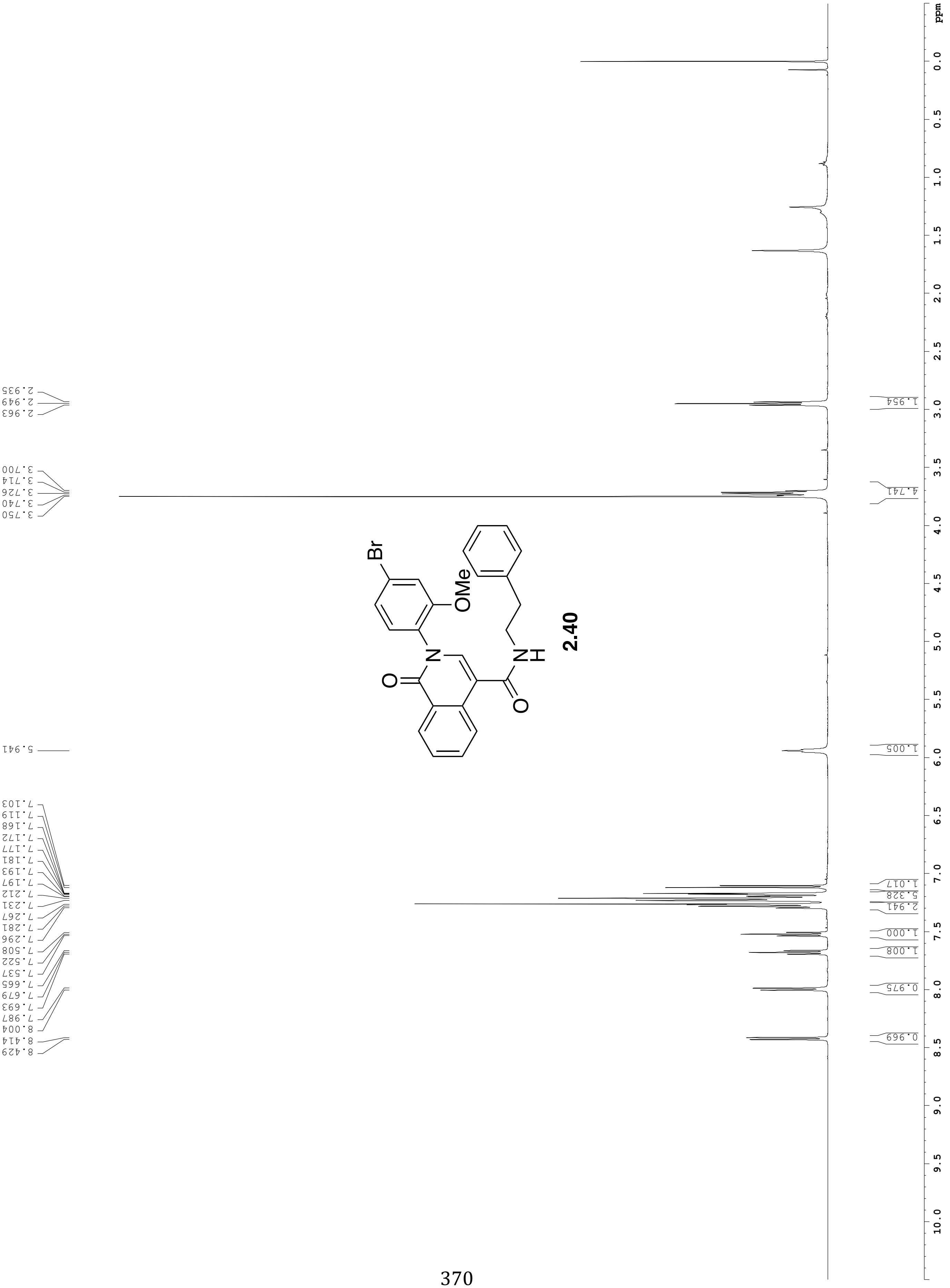


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
2.702
2.716
2.731
3.281
3.295
3.308
3.322
3.794
3.811
3.823
7.168
7.183
7.199
7.213
7.254
7.269
7.284
7.333
7.337
7.350
7.353
7.389
7.406
7.475
7.478
7.580
7.595
7.611
7.710
7.796
7.810
7.827
8.035
8.046
8.057
8.259
8.275
8.317
8.334
8.573
8.585
8.596
1.932
1.979
4.773
2.879
1.906
0.969
1.025
0.965
1.034
0.947
1.013
1.003
0.972
1.191
1.000
Br
OMe
O
N
O
N
H
O
H
N

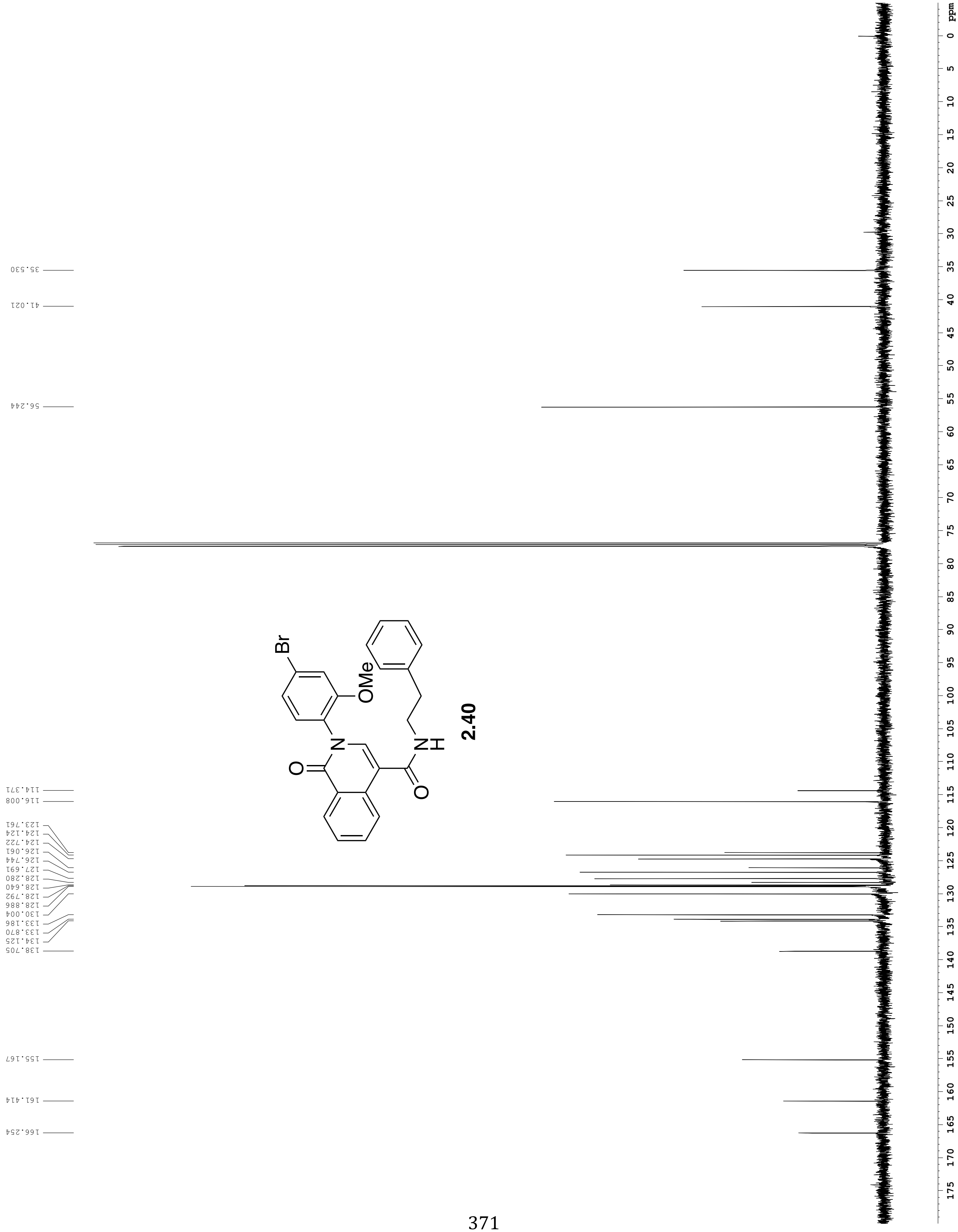
**2.39**


168.750
165.750
160.240
155.395
139.414
135.294
134.556
132.946
130.640
128.645
128.337
127.477
127.360
126.098
125.340
125.128
123.593
122.828
115.857
112.011
79.193
56.456
42.416
40.280
35.206
O
N
Br
OMe
O
N
H
H
N
O
175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 ppm

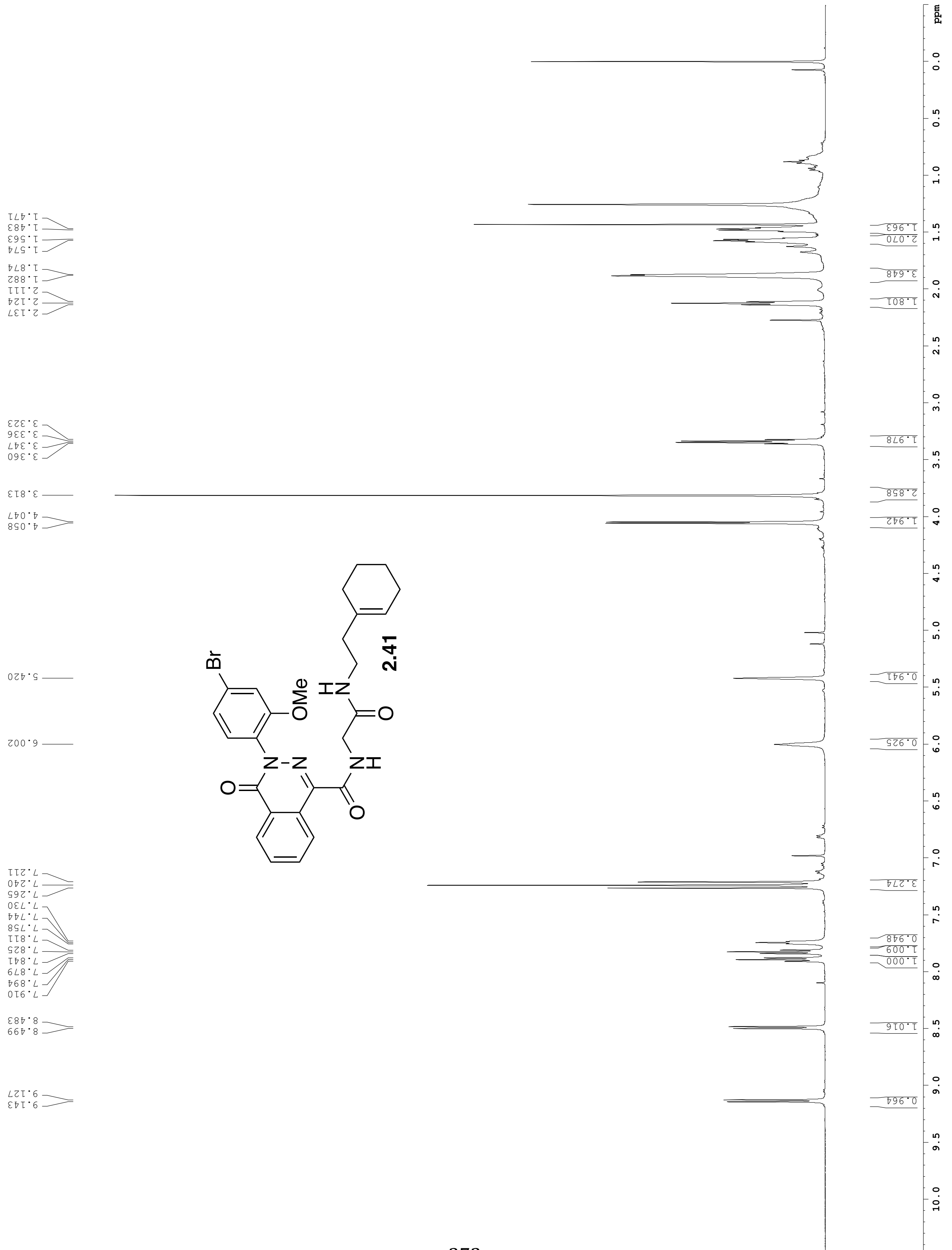
**2.39**


**2.40**

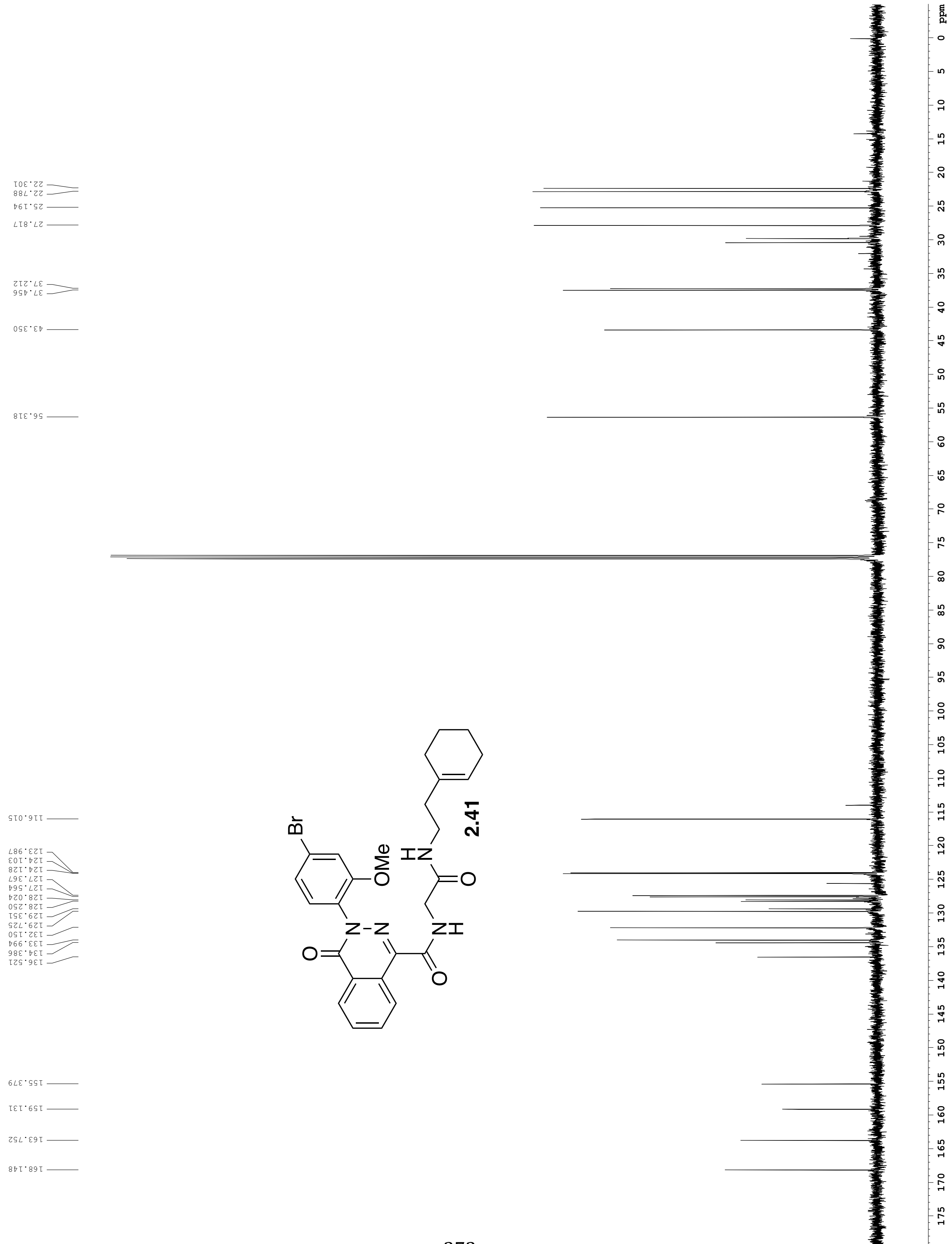
Br
OMe
O
N
N
H
O
2.935
2.949
2.963
3.700
3.714
3.726
3.740
3.750
5.941
7.103
7.119
7.168
7.172
7.177
7.181
7.193
7.197
7.212
7.231
7.267
7.281
7.296
7.508
7.522
7.537
7.665
7.679
7.693
7.987
8.004
8.414
8.429
1.954
4.741
1.005
1.017
5.328
2.941
1.000
1.008
0.975
0.969
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0

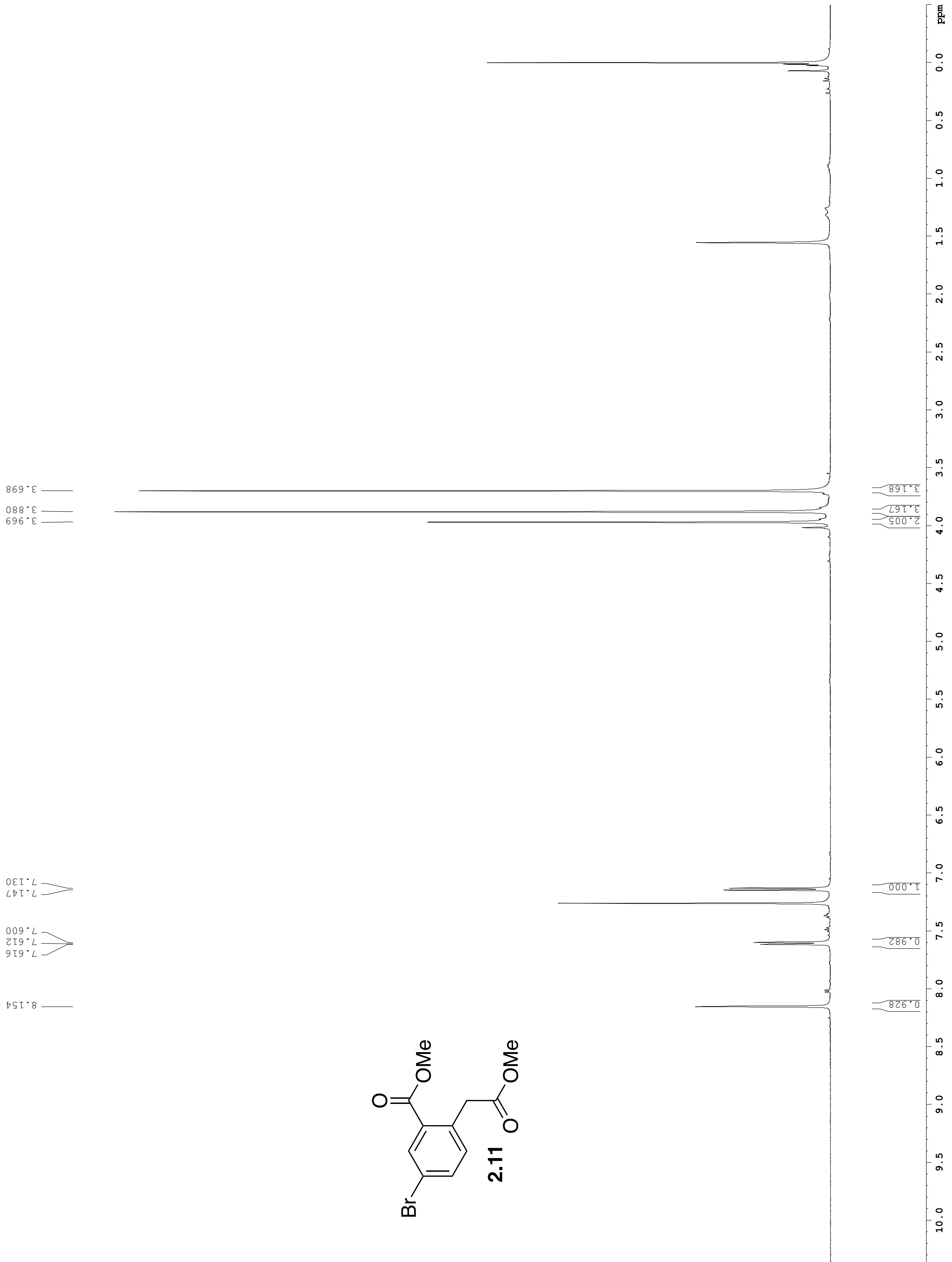

35.530
41.021
56.244
114.371
116.008
123.761
124.124
124.722
126.061
126.744
127.691
128.280
128.640
128.792
128.886
130.004
133.186
133.870
134.125
138.705
155.167
161.414
166.254
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
Br
OMe
N
O
O
N
H

**2.40**

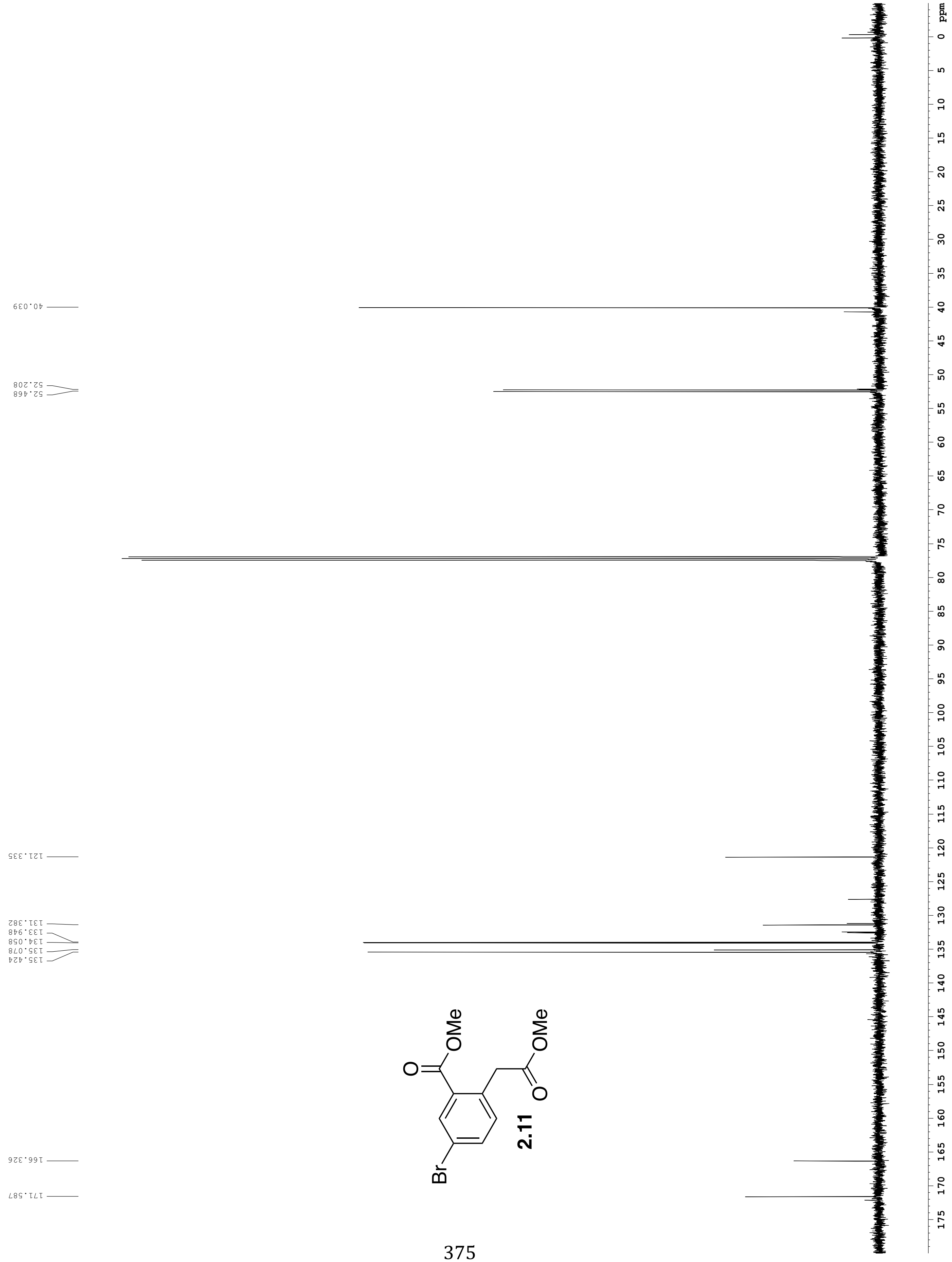

1.471
1.483
1.563
1.574
1.874
1.882
2.111
2.124
2.137
3.323
3.336
3.347
3.360
3.813
4.047
4.058
5.420
6.002
7.211
7.240
7.265
7.730
7.744
7.758
7.811
7.825
7.841
7.879
7.894
7.910
8.483
8.499
9.127
9.143
1.963
2.070
3.648
1.801
1.978
2.858
1.942
0.941
0.925
3.274
0.948
1.009
1.000
1.016
0.964
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Br
OMe
N
N
O
O
O
H
N
H
N

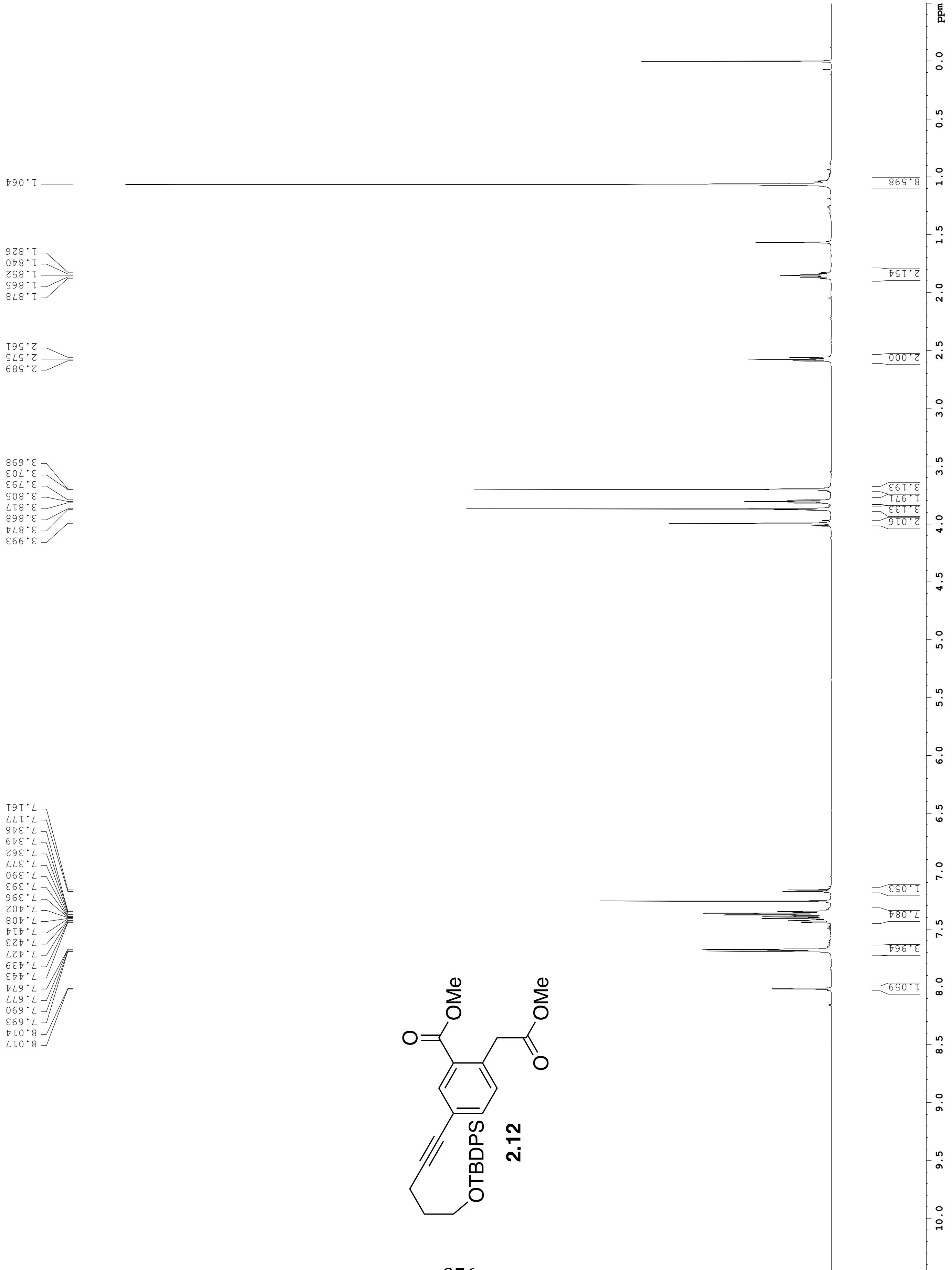
**2.41**


22.301
22.788
25.194
27.817
37.212
37.456
43.350
56.318
116.015
123.987
124.103
124.128
127.367
127.564
128.024
128.250
129.351
129.725
132.150
133.994
134.386
136.521
155.379
159.131
163.752
168.148
Br
OMe
N
N
O
O
H
N
O
N
H
2.41
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

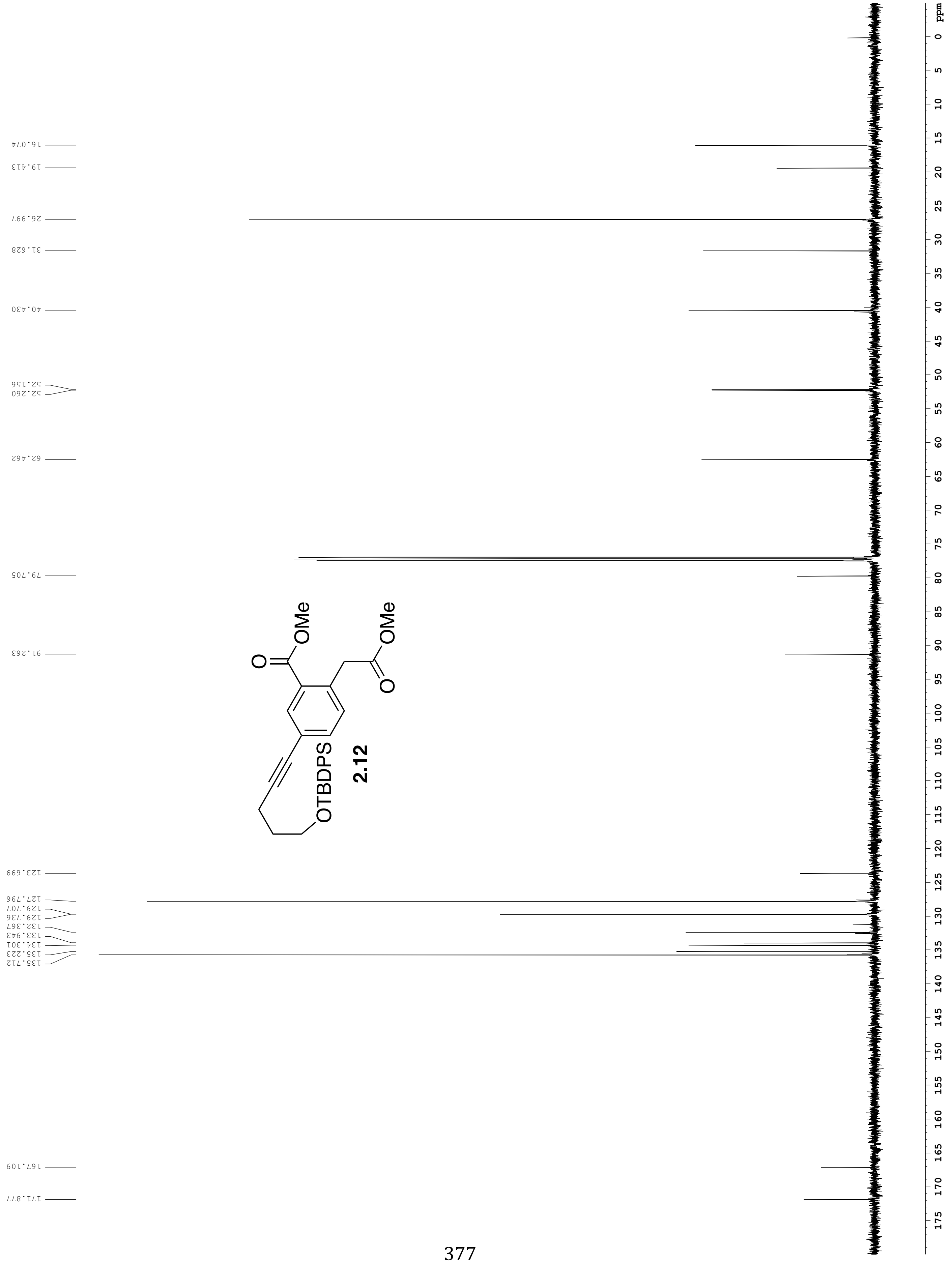

3.698
3.880
3.969
7.130
7.147
7.600
7.612
7.616
8.154
3.168
3.167
2.005
1.000
0.982
0.928
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
OMe
O
OMe
O
Br

**2.11**

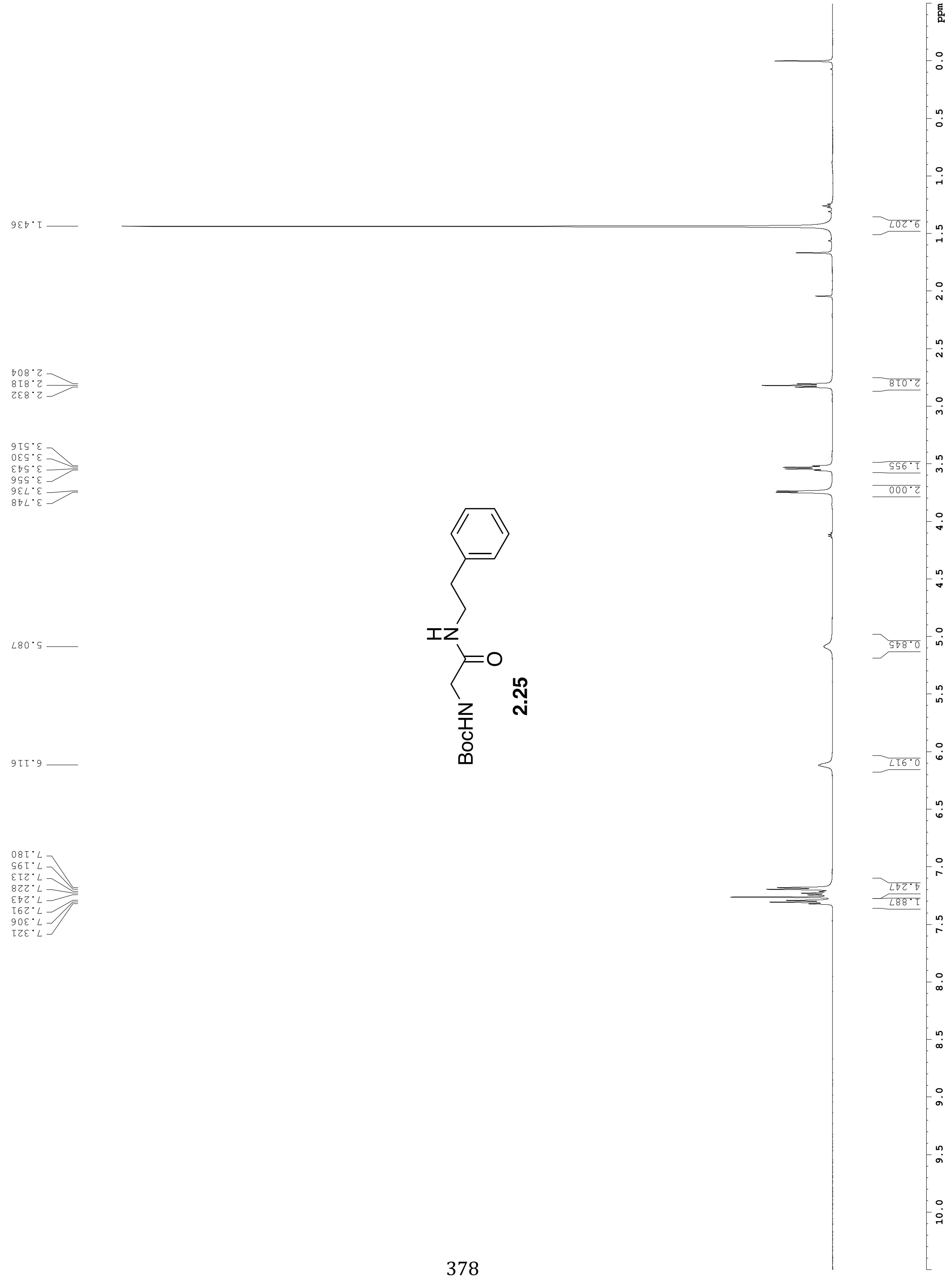

40.039
52.208
52.468
121.335
131.382
133.948
134.058
135.078
135.424
166.326
171.587
Br
O
OMe
O
OMe
2.11
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175


OMe
O
OMe
O
OTBDPS
1.064
1.826
1.840
1.852
1.865
1.878
2.561
2.575
2.589
3.698
3.703
3.793
3.805
3.817
3.868
3.874
3.993
7.161
7.177
7.346
7.349
7.362
7.377
7.390
7.393
7.396
7.402
7.408
7.414
7.423
7.427
7.439
7.443
7.674
7.677
7.690
7.693
8.014
8.017
8.598
2.154
2.000
3.193
1.971
3.133
2.016
1.053
7.084
3.964
1.059
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0

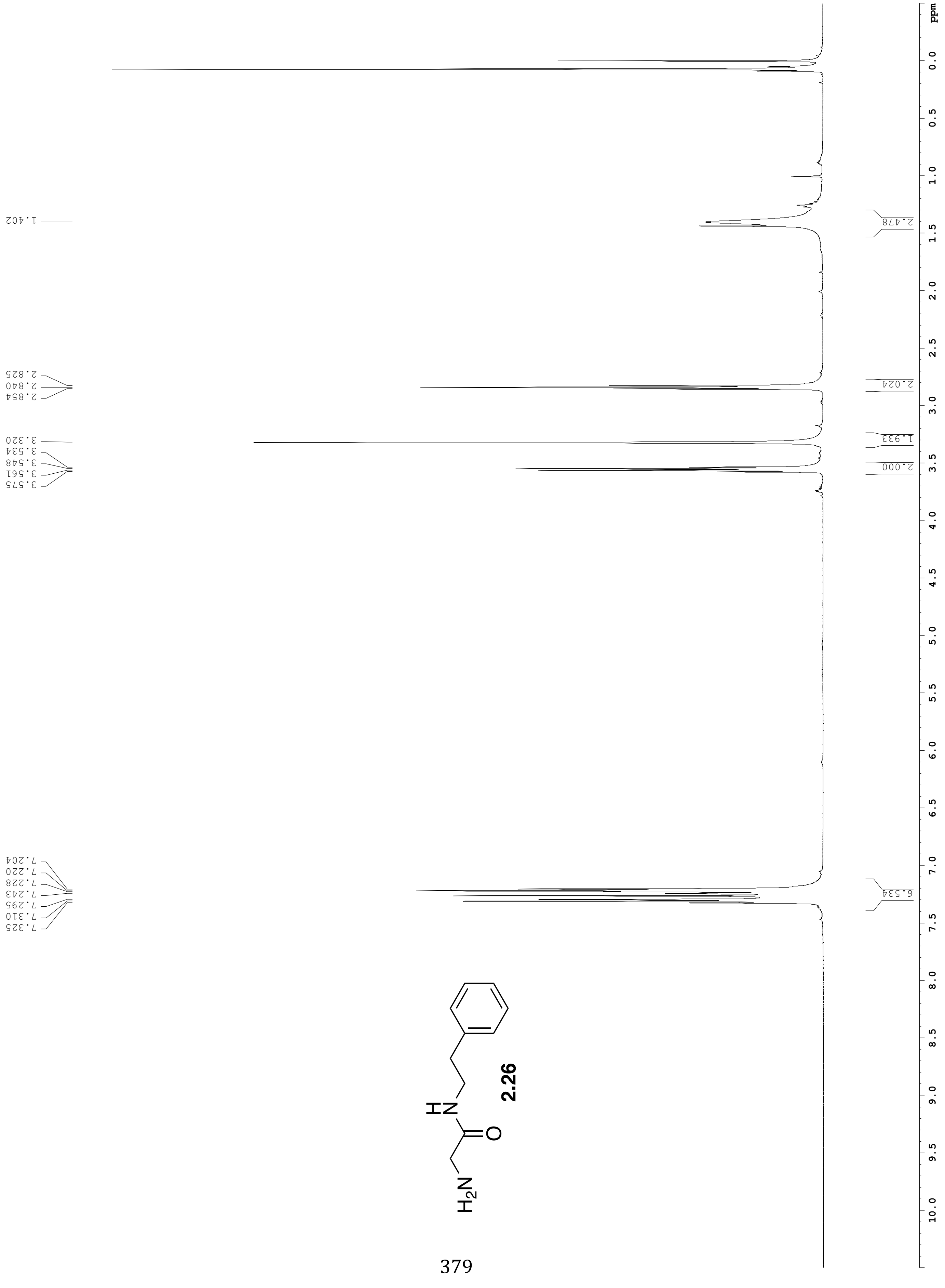
**2.12**


2.12

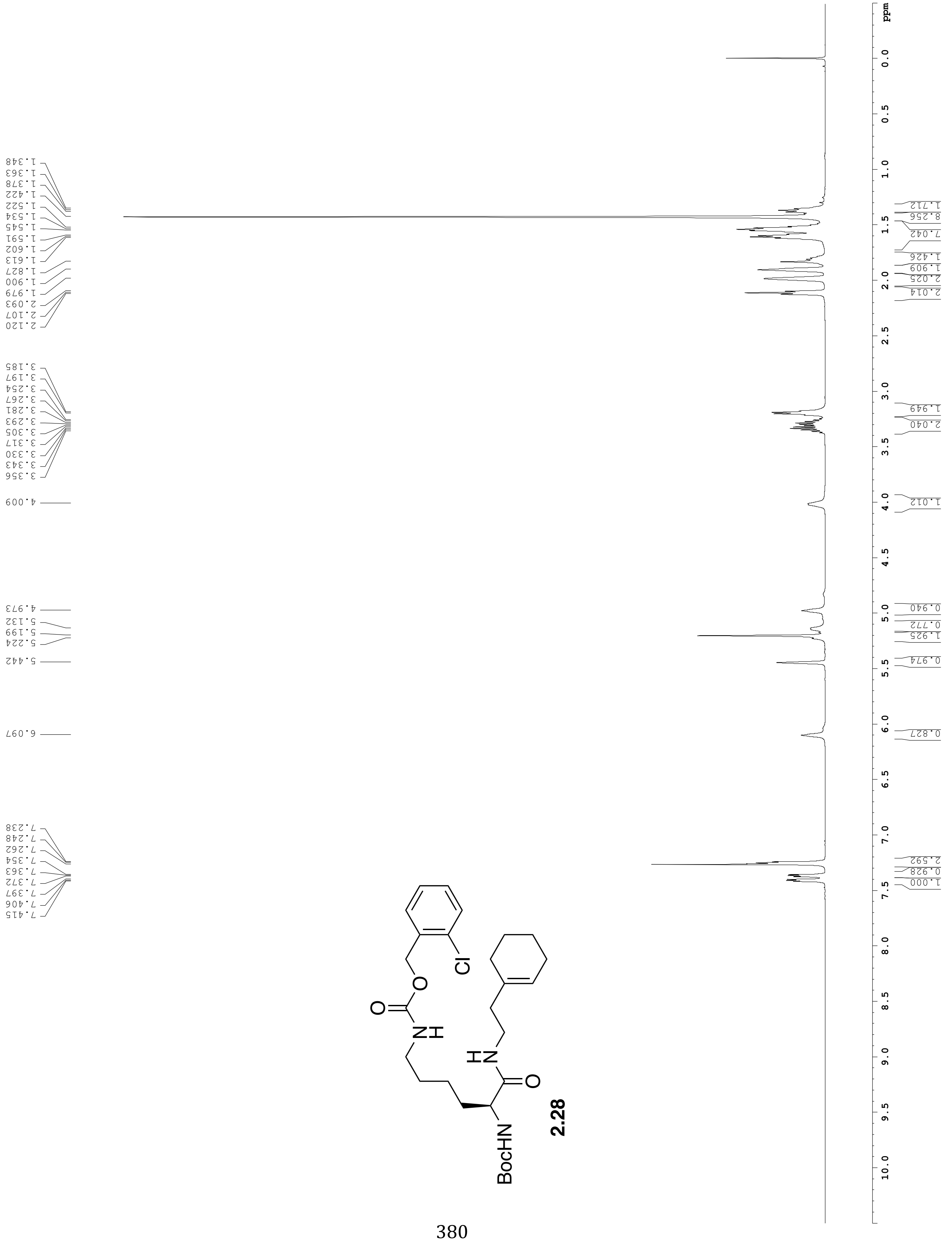
16.074
19.413
26.997
31.628
40.430
52.156
52.260
62.462
79.705
91.263
123.699
127.796
129.707
129.736
132.367
133.943
134.301
135.223
135.712
167.109
171.877
O
OMe
OMe
O
OTBDPS
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
1.436
2.804
2.818
2.832
3.516
3.530
3.543
3.556
3.736
3.748
5.087
6.116
7.180
7.195
7.213
7.228
7.243
7.291
7.306
7.321
9.207
2.018
1.955
2.000
0.845
0.917
4.247
1.887
BocHN
H
N
O

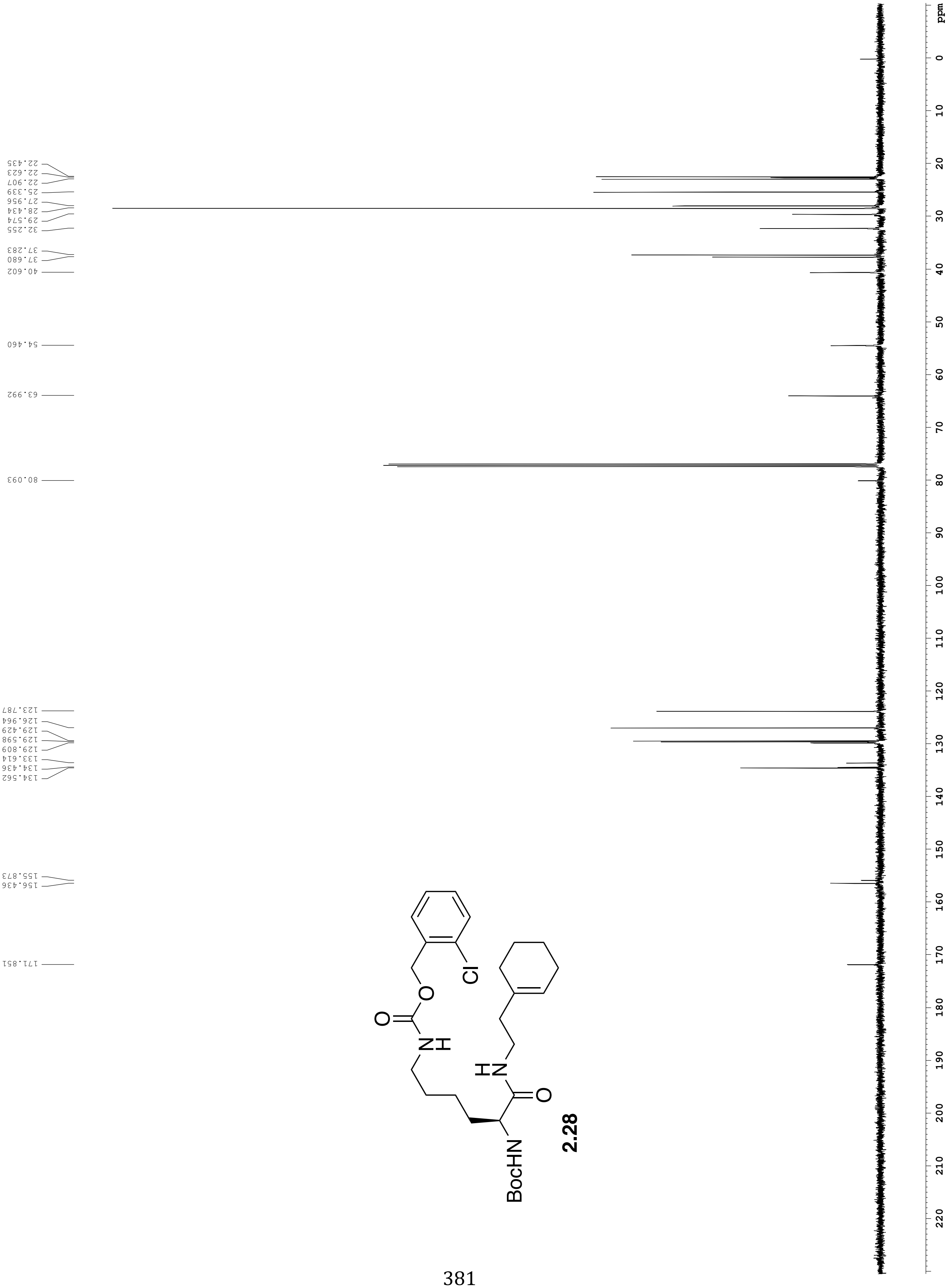
**2.25**


1.402
2.825
2.840
2.854
3.320
3.534
3.548
3.561
3.575
7.204
7.220
7.228
7.243
7.295
7.310
7.325
2.478
2.024
1.933
2.000
6.534
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
H
N
O
$H_2N$

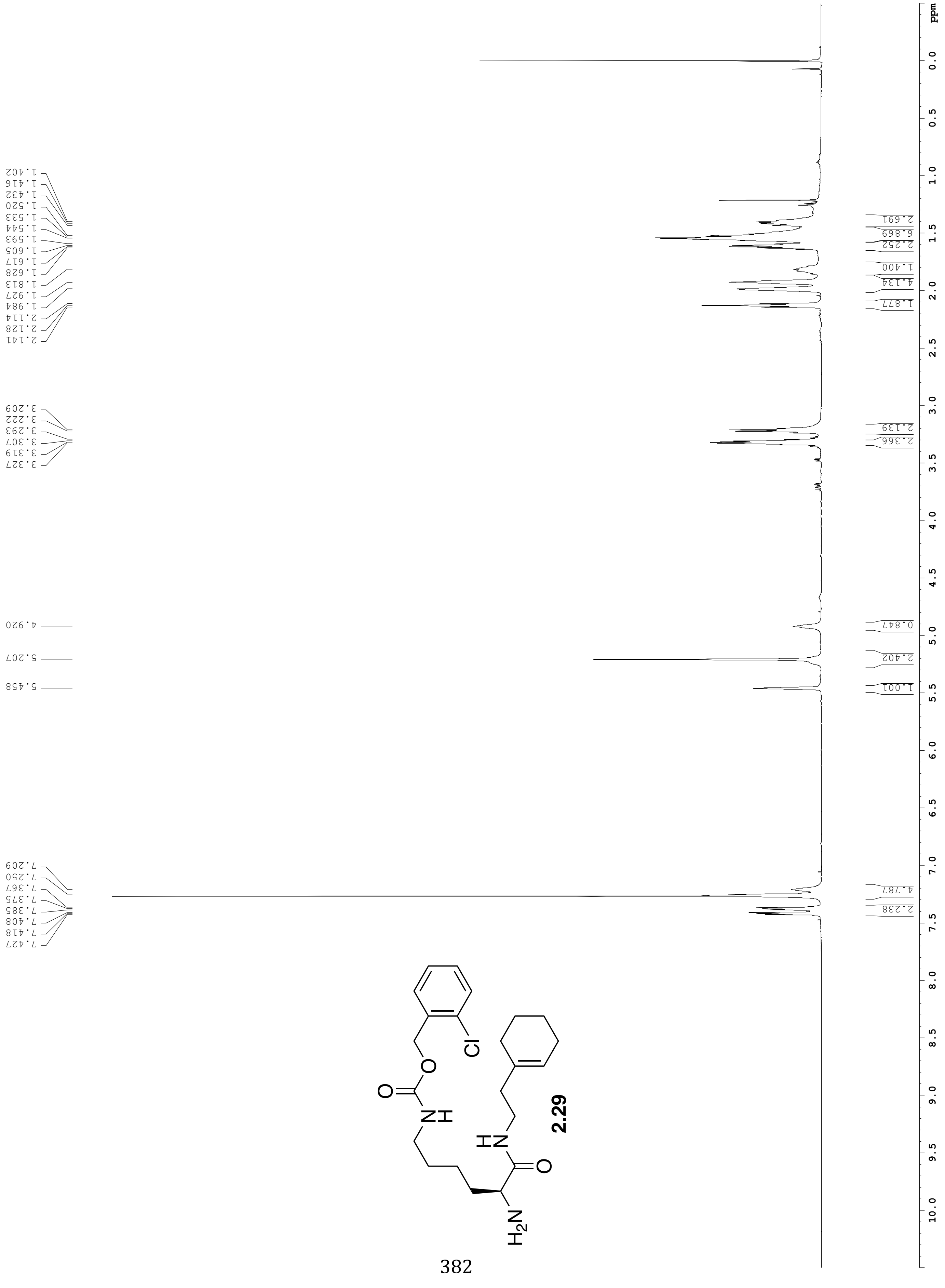
**2.26**


1.348
1.363
1.378
1.422
1.522
1.534
1.545
1.591
1.602
1.613
1.827
1.900
1.979
2.093
2.107
2.120
3.185
3.197
3.254
3.267
3.281
3.293
3.305
3.317
3.330
3.343
3.356
4.009
4.973
5.132
5.199
5.224
5.442
6.097
7.238
7.248
7.262
7.354
7.363
7.372
7.397
7.406
7.415
1.712
8.256
7.042
1.426
1.909
2.025
2.014
1.949
2.040
1.012
0.940
0.772
1.925
0.974
0.827
2.592
0.928
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Cl
O
O
NH
HN
O
BocHN

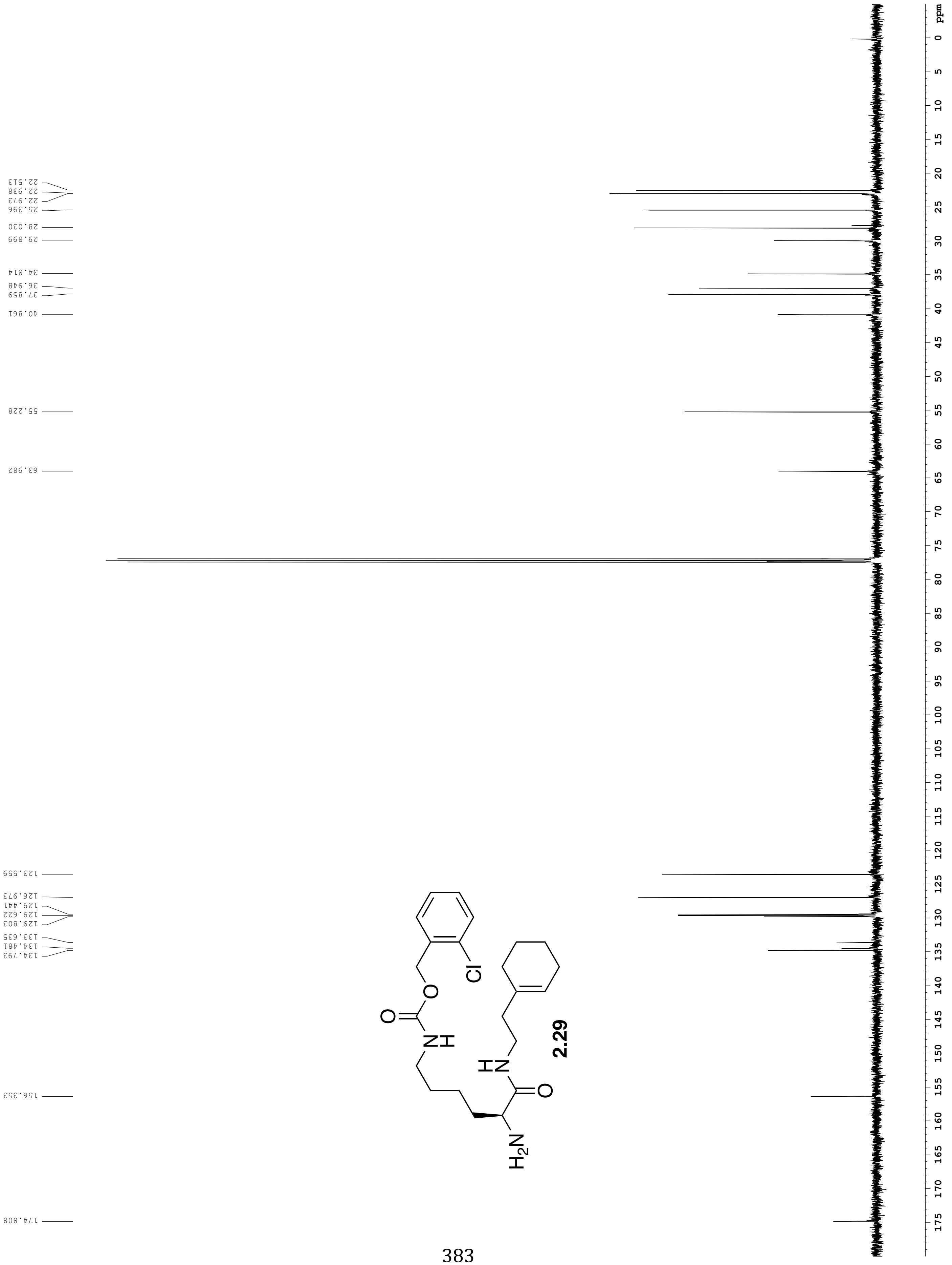
**2.28**


22.435
22.623
22.907
25.339
27.956
28.434
29.574
32.255
37.283
37.680
40.602
54.460
63.992
80.093
123.787
126.964
129.429
129.598
129.809
133.614
134.436
134.562
155.873
156.436
171.851
ppm
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
O
O
N
H
Cl
HN
O
BocHN

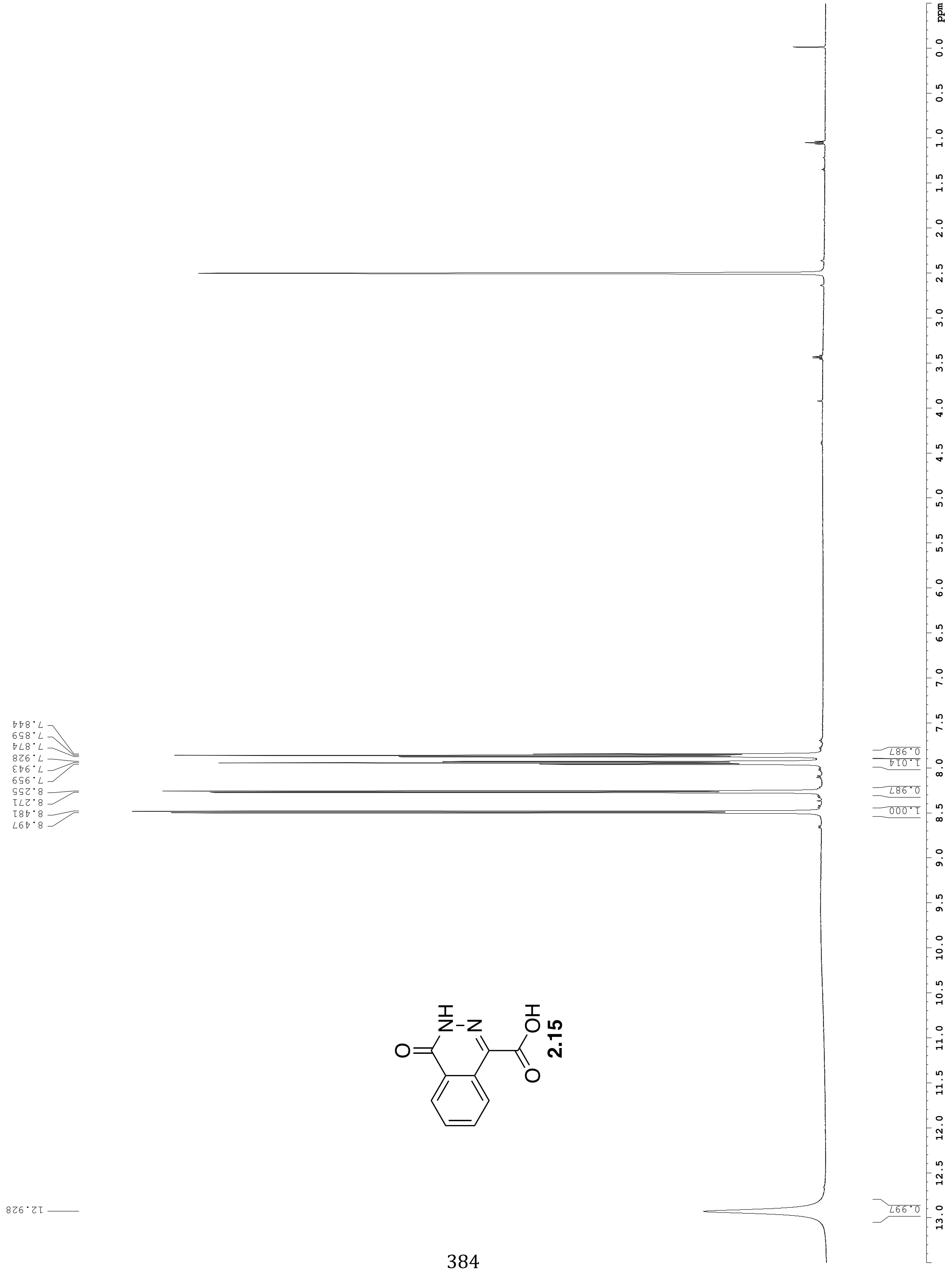
**2.28**


1.402
1.416
1.432
1.520
1.533
1.544
1.593
1.605
1.617
1.628
1.813
1.927
1.984
2.114
2.128
2.141
3.209
3.222
3.293
3.307
3.319
3.327
4.920
5.207
5.458
7.209
7.250
7.367
7.375
7.385
7.408
7.418
7.427
2.691
6.869
2.252
1.400
4.134
1.877
2.139
2.366
0.847
2.402
1.001
4.787
2.238
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
O
NH
Cl
HN
O
H2N

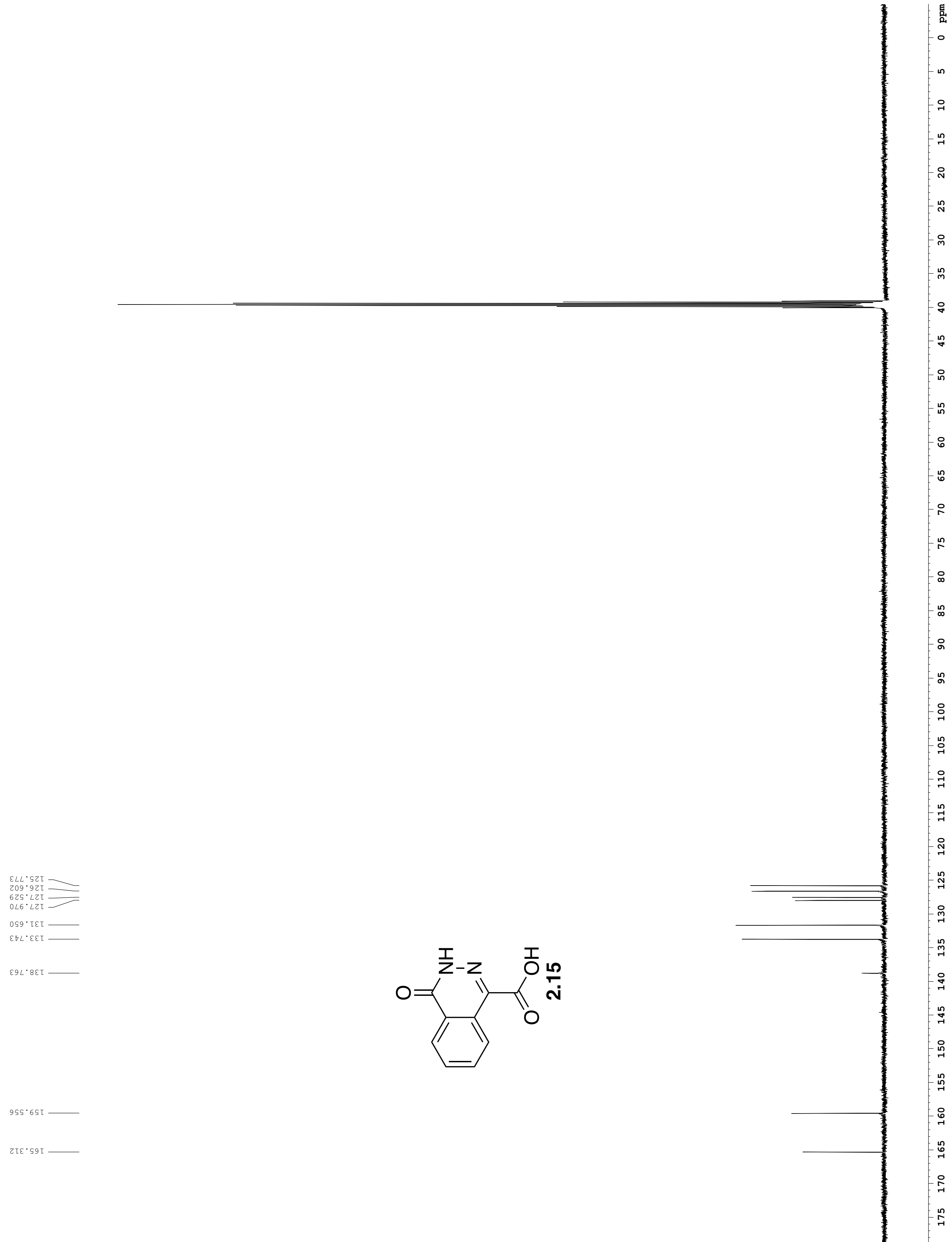
**2.29**

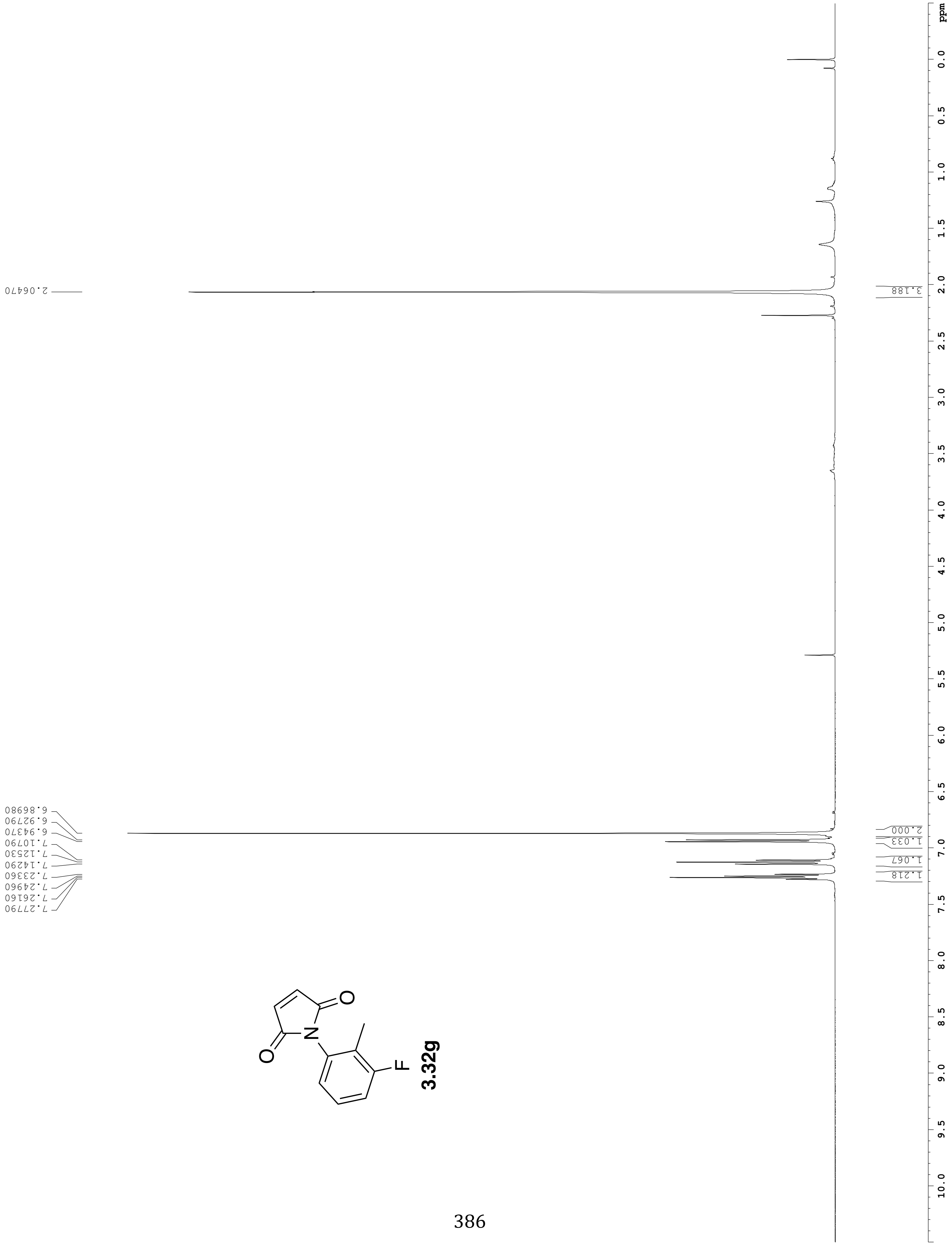

22.513
22.938
22.973
25.396
28.030
29.899
34.814
36.948
37.859
40.861
55.228
63.982
123.559
126.973
129.441
129.622
129.803
133.635
134.481
134.793
156.353
174.808
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
O
O
NH
Cl
HN
O
$H_2N$

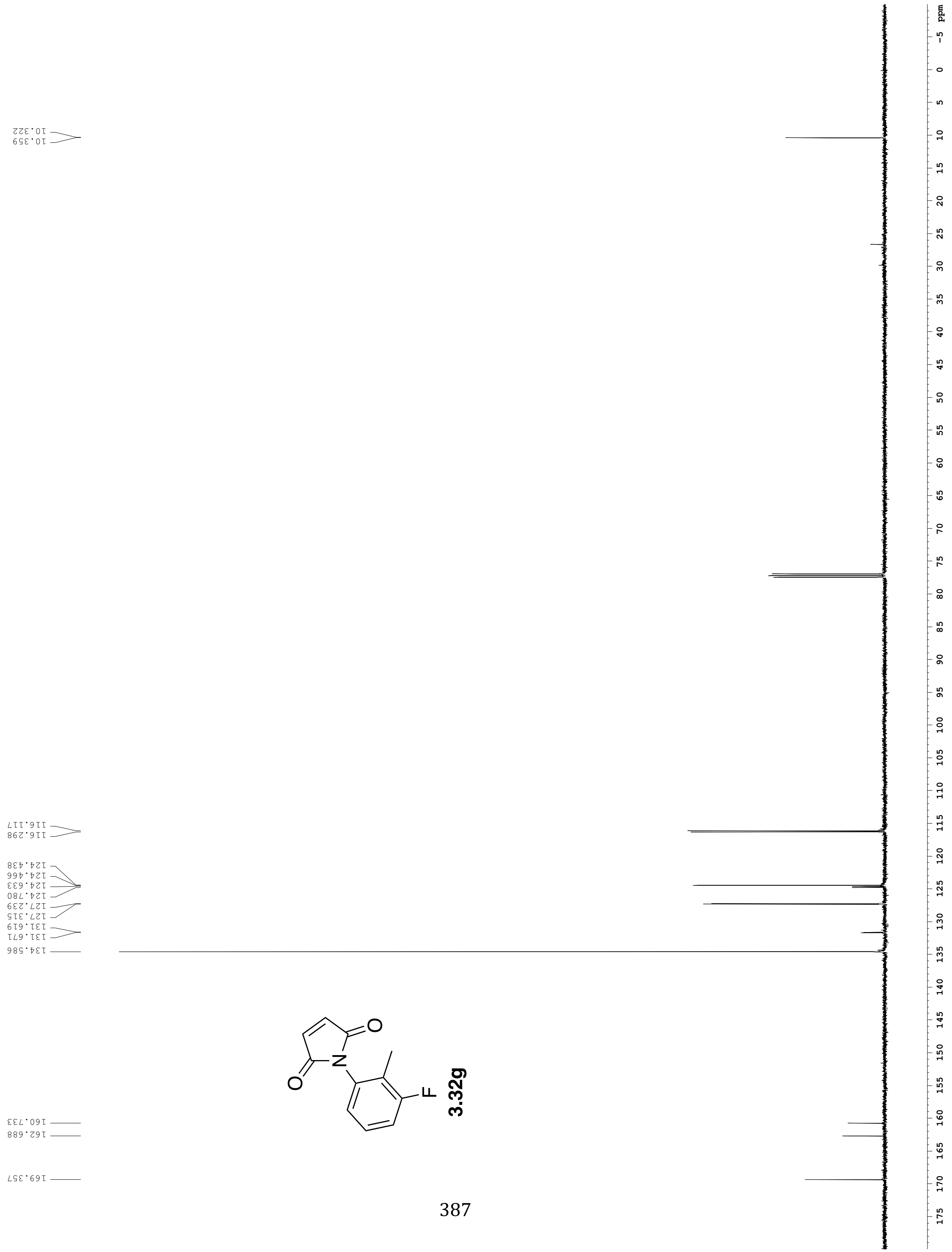
**2.29**



7.844
7.859
7.874
7.928
7.943
7.959
8.255
8.271
8.481
8.497
12.928
0.987
1.014
0.987
1.000
0.997
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
O
NH
N
OH
O
2.15

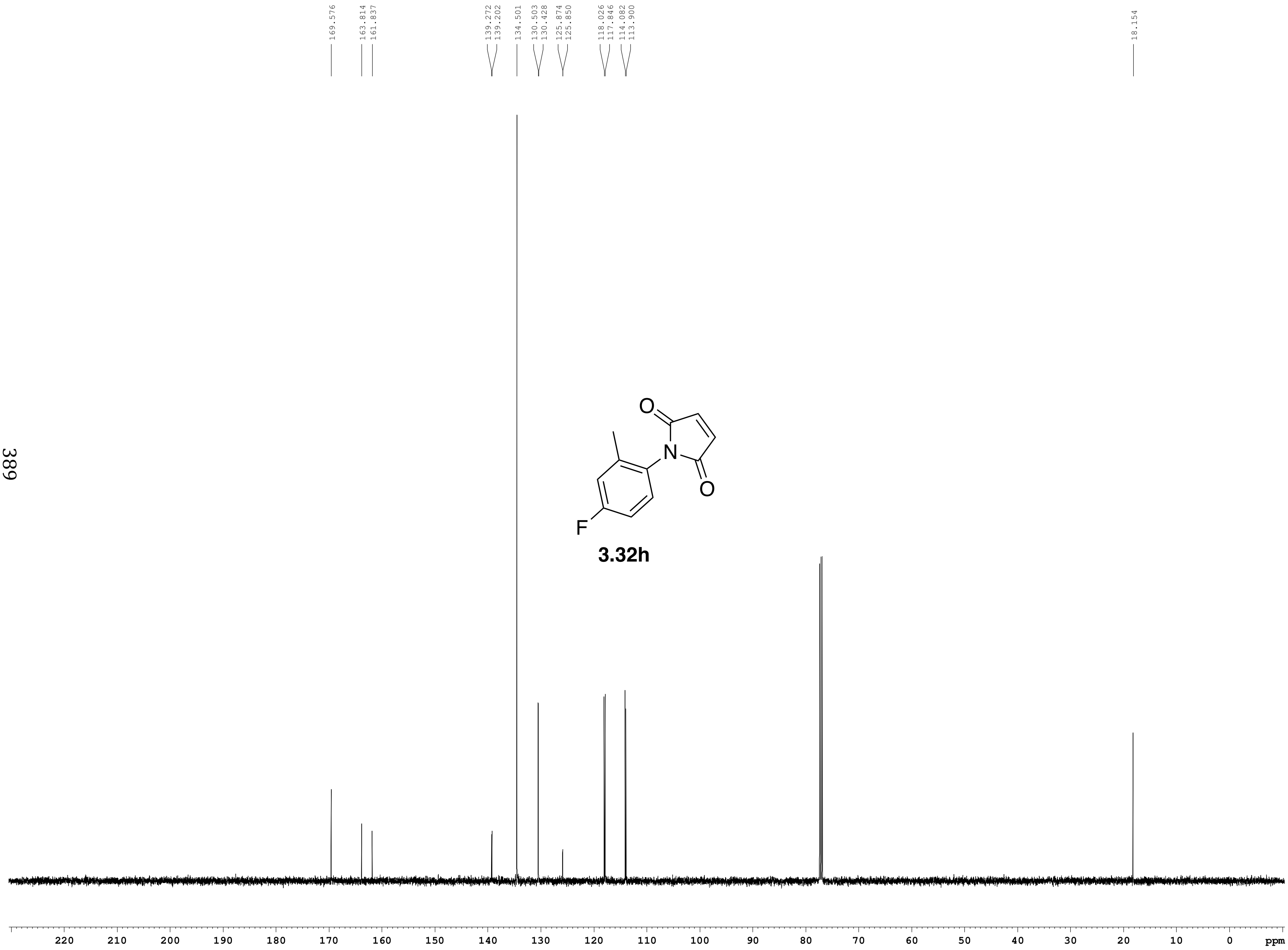

2.15
125.773
126.602
127.529
127.970
131.650
133.743
138.763
159.556
165.312
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
O
NH
N
OH
O


2.06470
6.86980
6.92790
6.94370
7.10790
7.12530
7.14290
7.23360
7.24960
7.26160
7.27790
3.188
2.000
1.033
1.067
1.218
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
N
O
F
3.32g


10.322
10.359
116.117
116.298
124.438
124.466
124.633
124.780
127.239
127.315
131.619
131.671
134.586
160.733
162.688
169.357
O
N
O
F
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

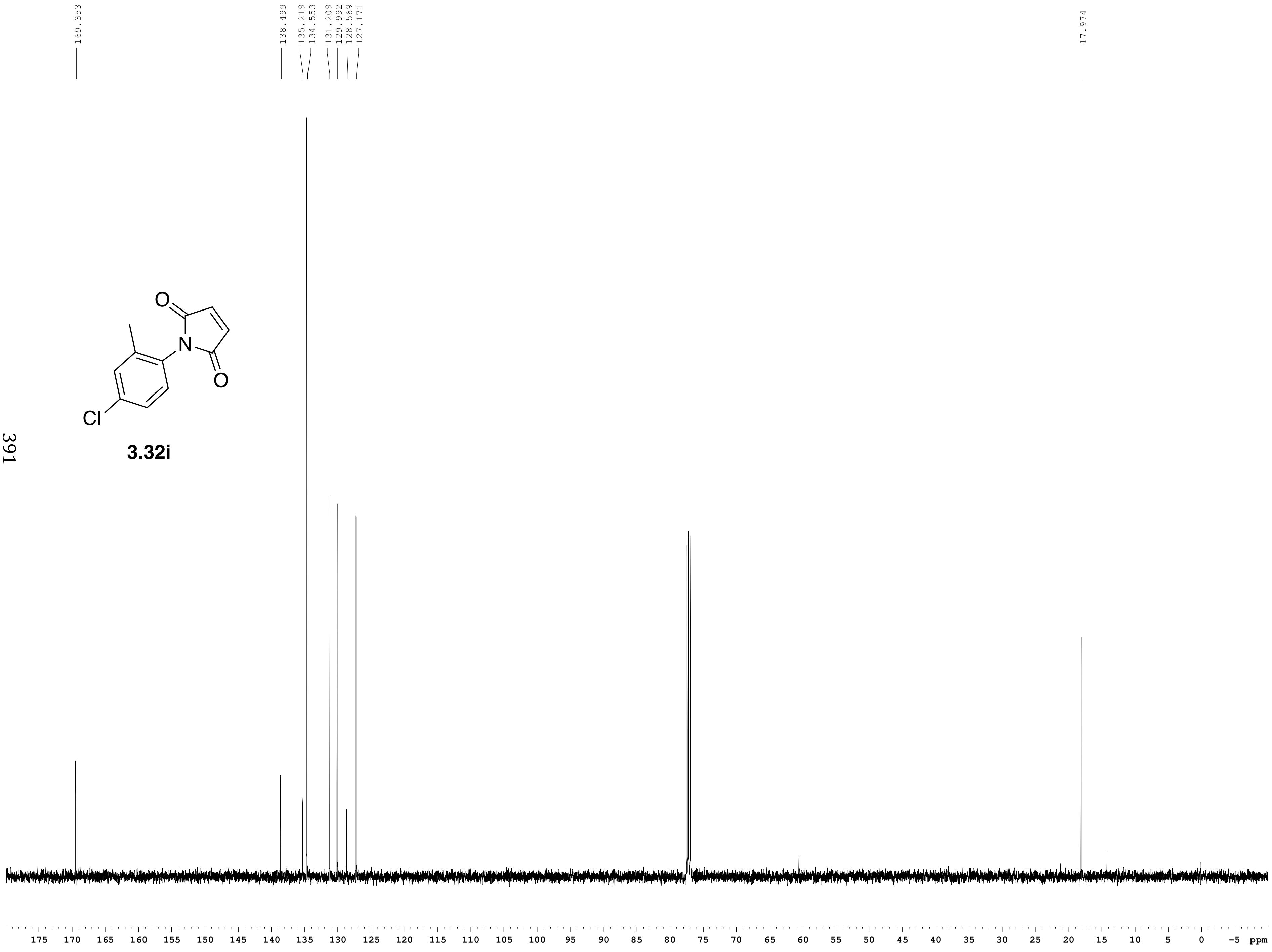
**3.32g**


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
2.204
6.934
7.029
7.035
7.046
7.052
7.062
7.068
7.089
7.095
7.107
7.113
7.132
7.142
7.149
7.160
3.004
2.000
1.029
1.024
1.021
O
N
O
F
3.32h

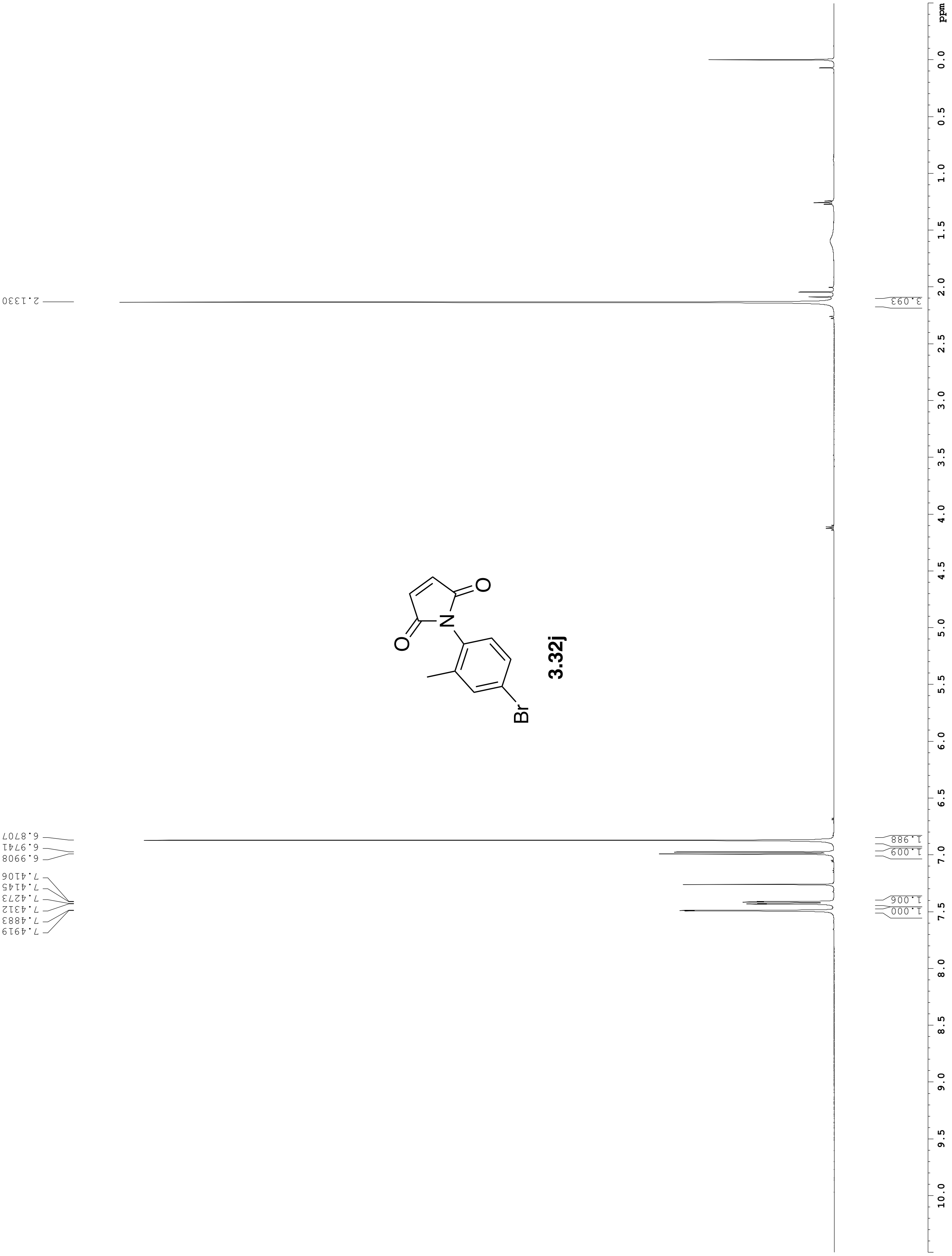

169.576
163.814
161.837
139.272
139.202
134.501
130.503
130.428
125.874
125.850
118.026
117.846
114.082
113.900
18.154
O
N
O
F
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

**3.32h**

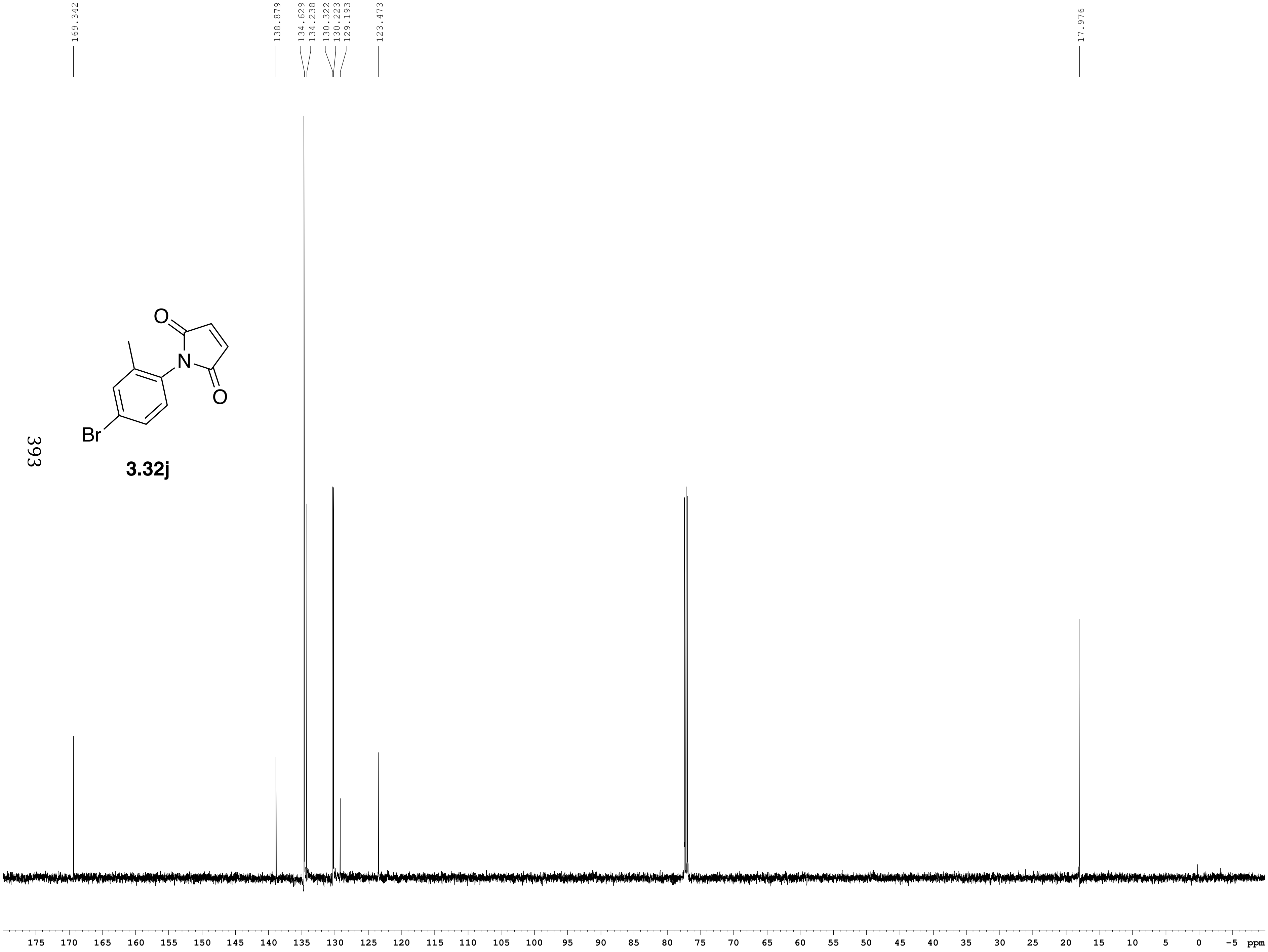

2.1329
6.8717
7.0372
7.0540
7.2779
7.3257
2.970
1.959
1.026
1.472
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
N
O
Cl
3.32i


169.353
138.499
135.219
134.553
131.209
129.992
128.569
127.171
17.974
O
N
O
Cl
175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 −5 ppm

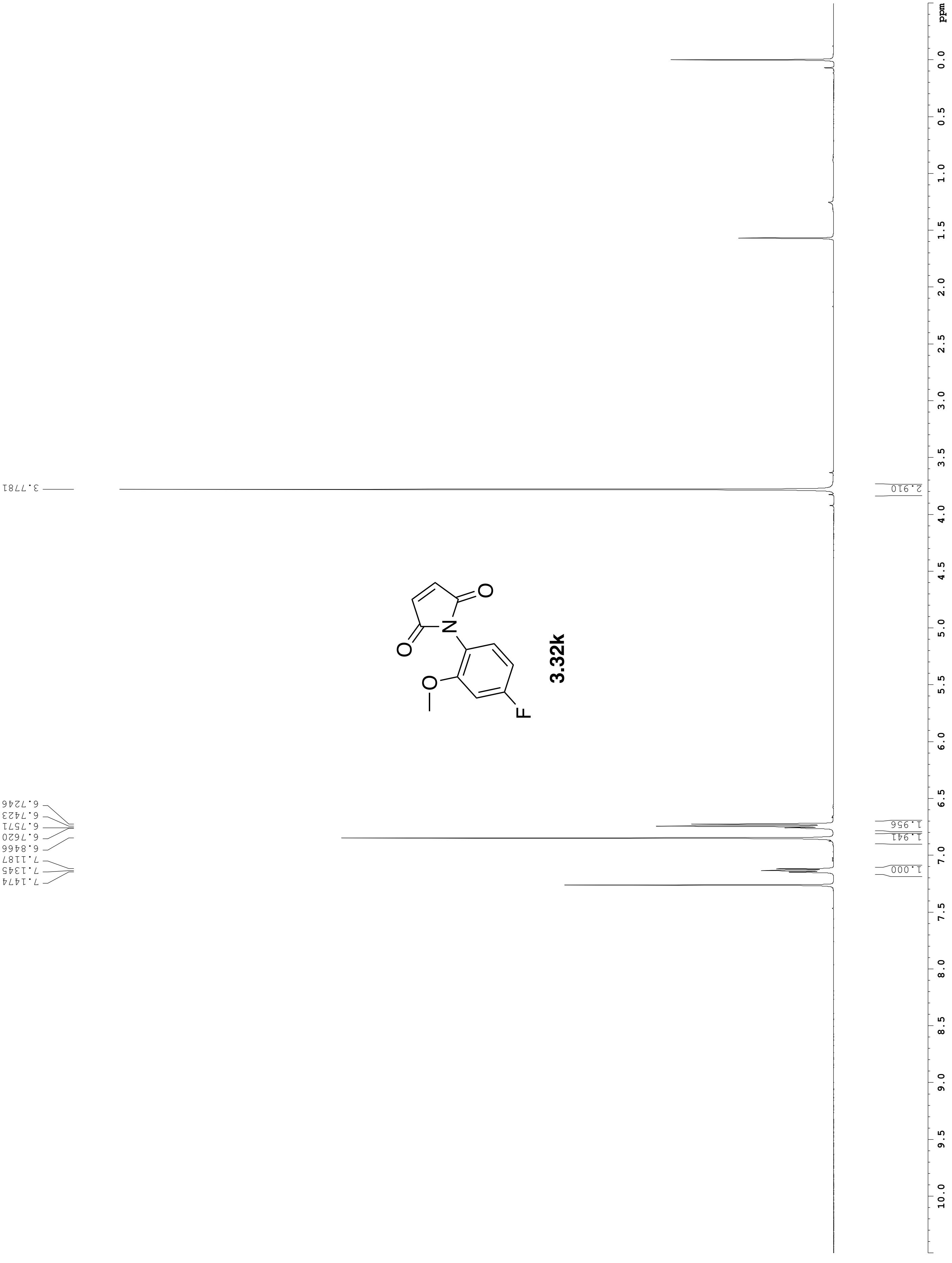
**3.32i**


2.1330
6.8707
6.9741
6.9908
7.4106
7.4145
7.4273
7.4312
7.4883
7.4919
3.093
1.988
1.009
1.006
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
N
O
Br

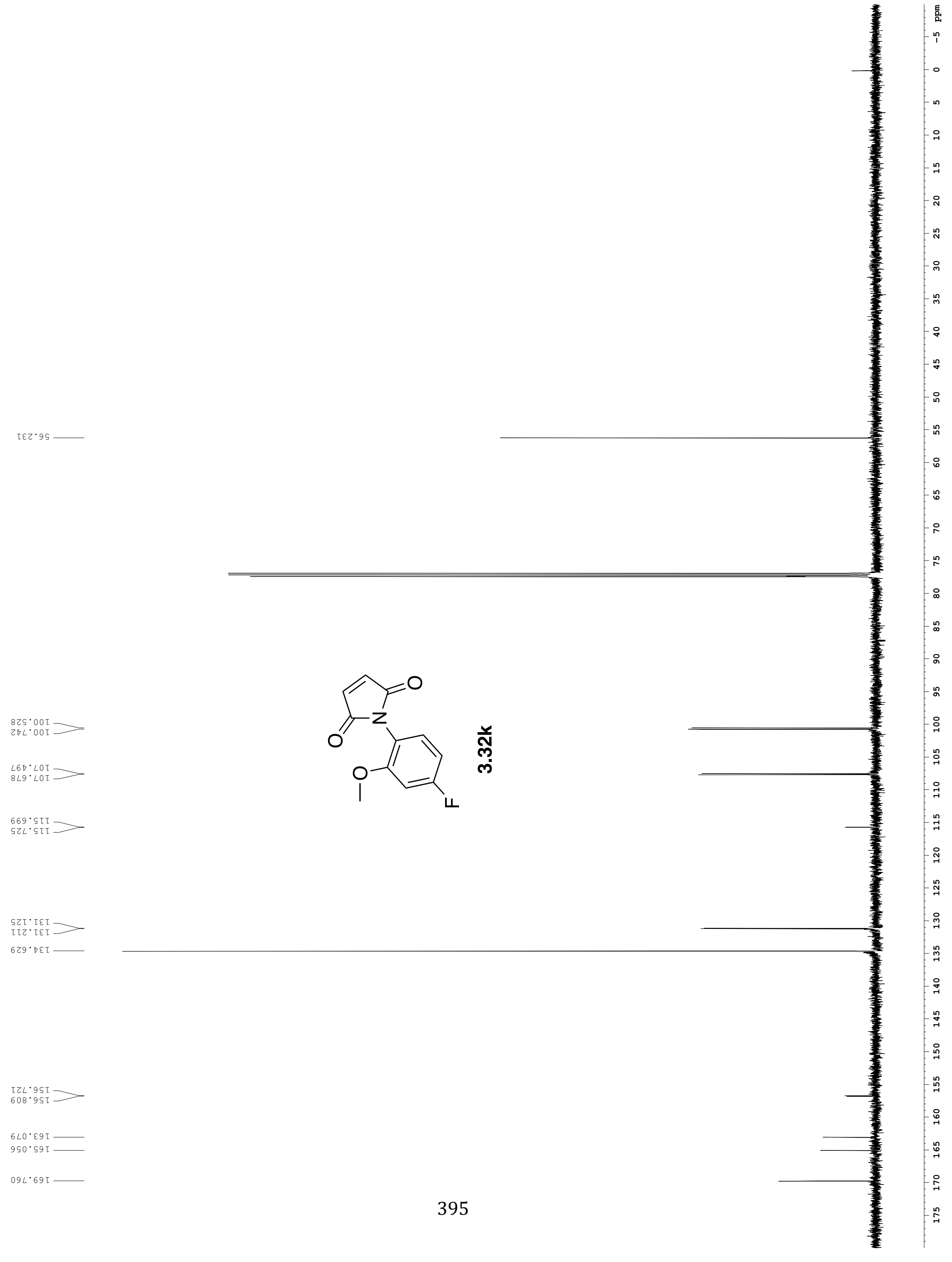
**3.32j**


169.342
138.879
134.629
134.238
130.322
130.223
129.193
123.473
17.976
O
N
O
Br
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
ppm

**3.32j**

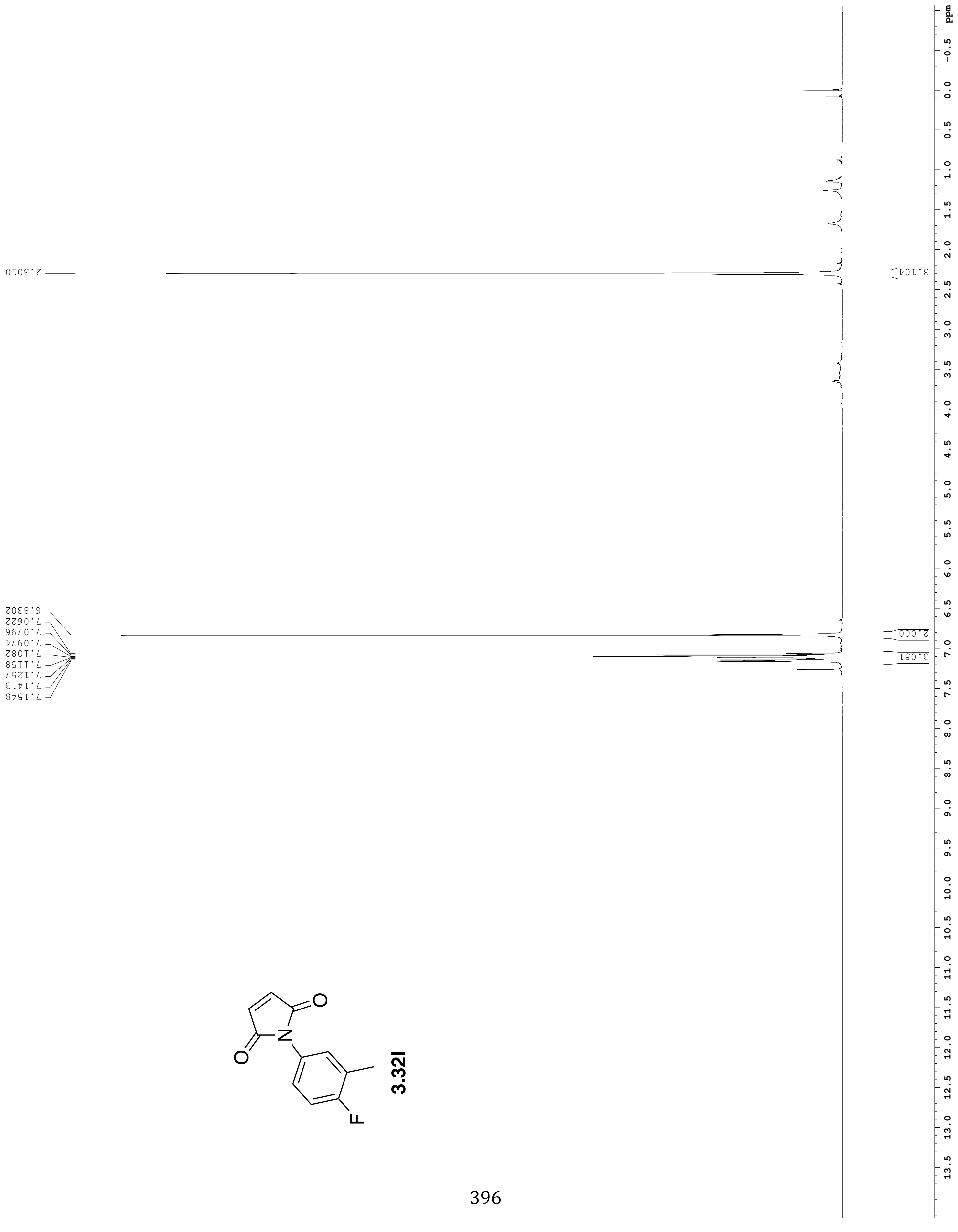

3.7781
6.7246
6.7423
6.7571
6.7620
6.8466
7.1187
7.1345
7.1474
2.910
1.956
1.941
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
N
O
O
F

**3.32k**

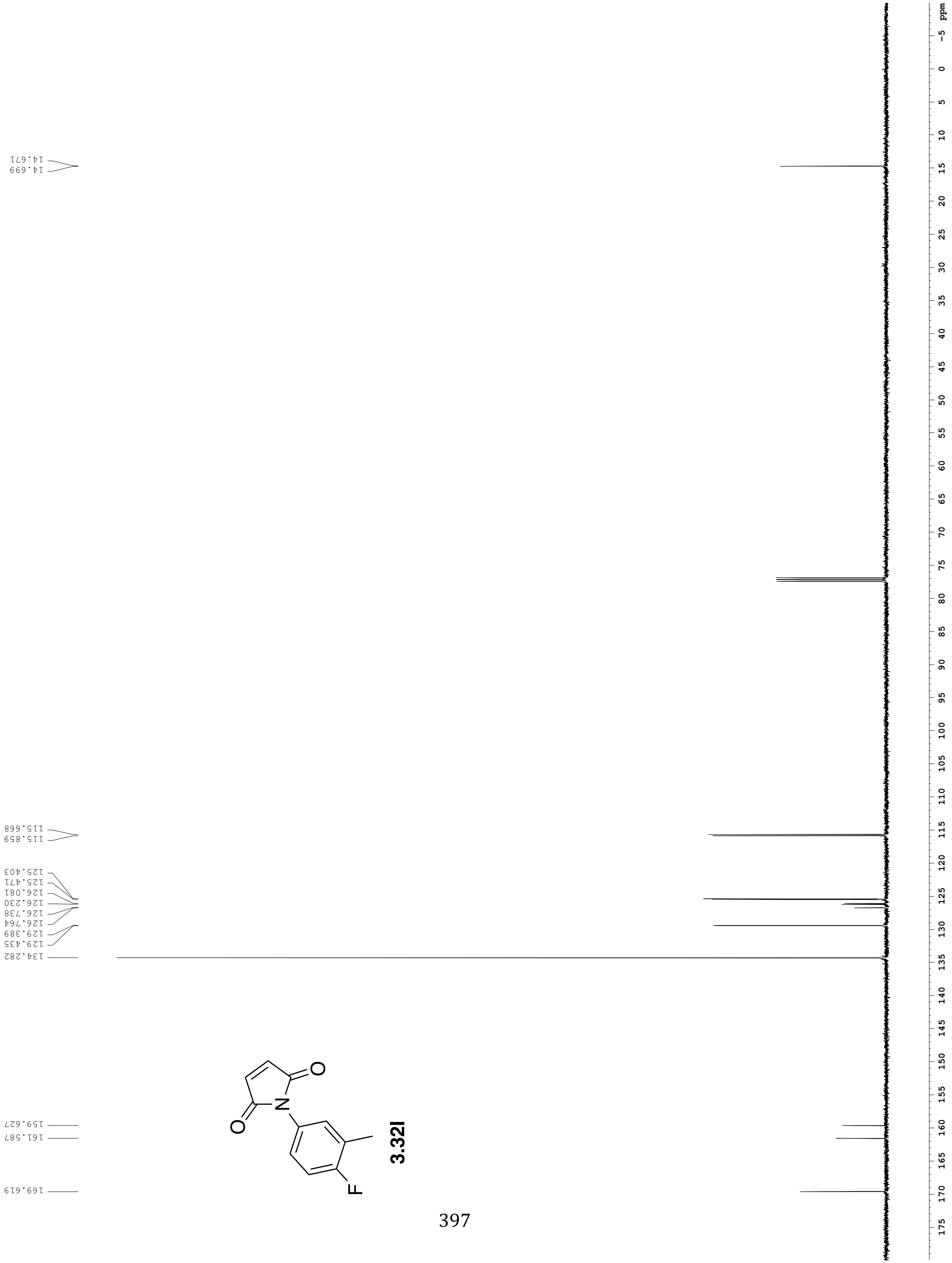


56.231
100.528
100.742
107.497
107.678
115.699
115.725
131.125
131.211
134.629
156.721
156.809
163.079
165.056
169.760
O
N
O
O
F
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

**3.32k**

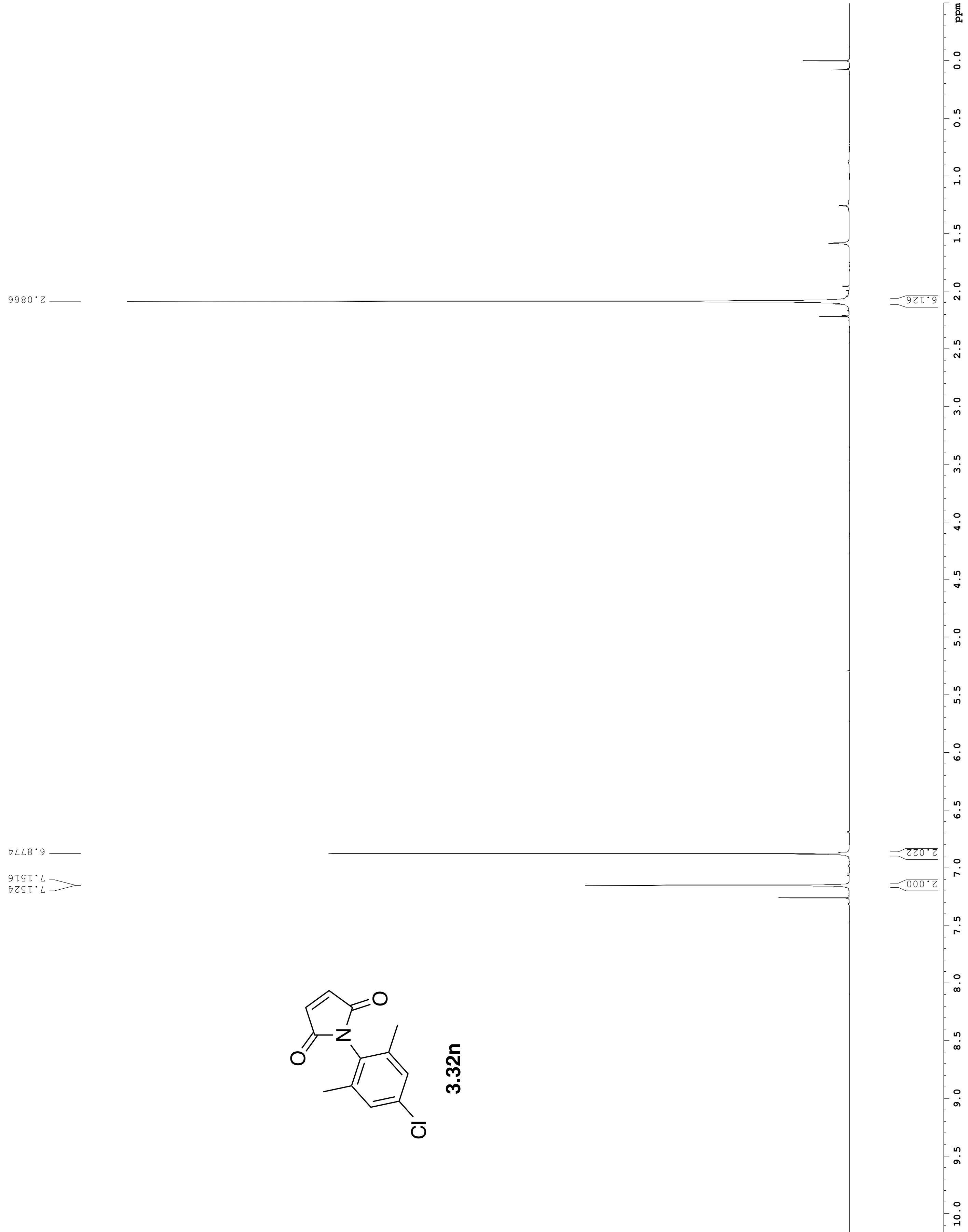

2.3010
6.8302
7.0622
7.0796
7.0974
7.1082
7.1158
7.1257
7.1413
7.1548
3.104
2.000
3.051
ppm
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
O
N
O
F

**3.32l**



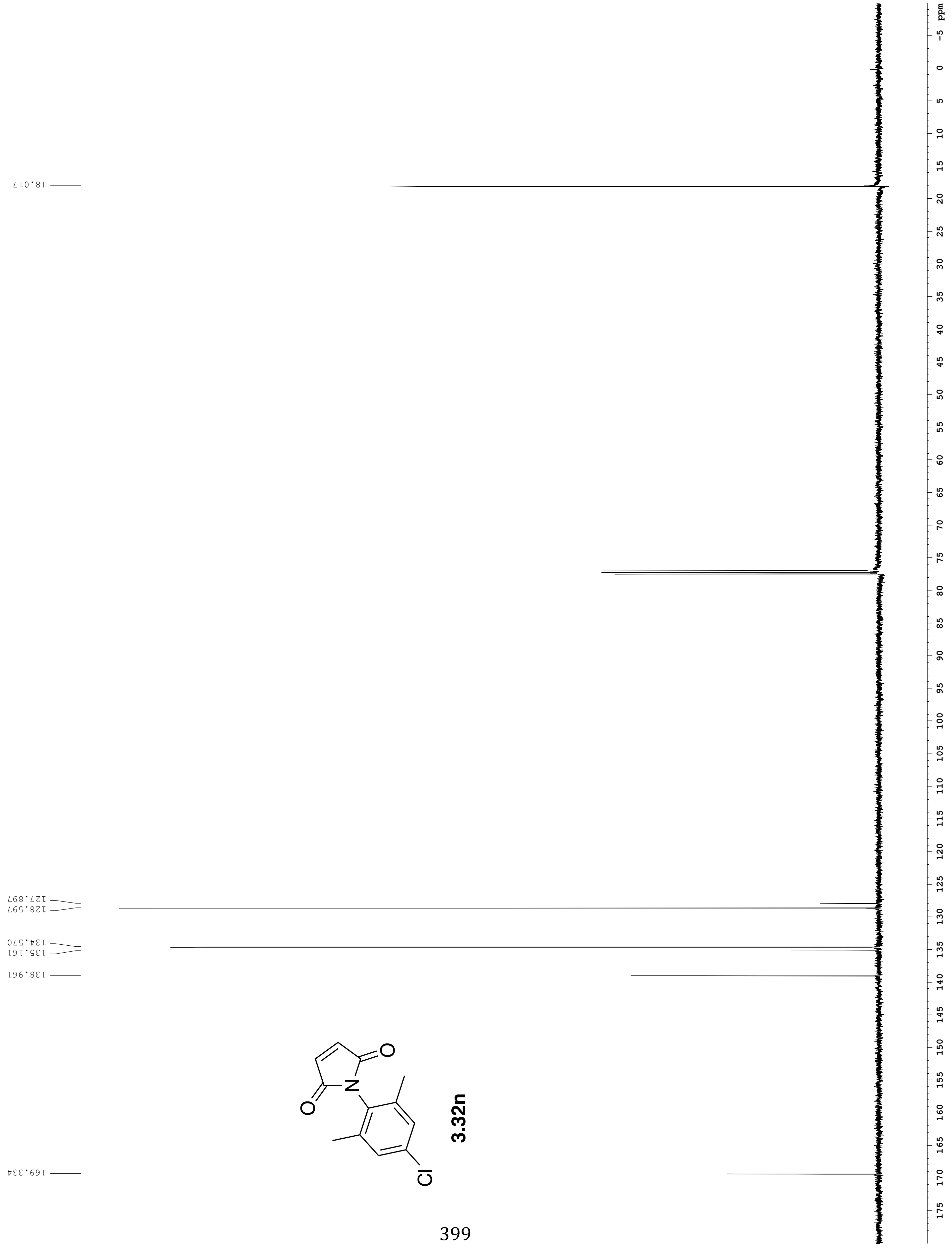
**3.32l**

14.671
14.699
115.668
115.859
125.403
125.471
126.081
126.230
126.738
126.764
129.389
129.435
134.282
159.627
161.587
169.619
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
O
N
O
F

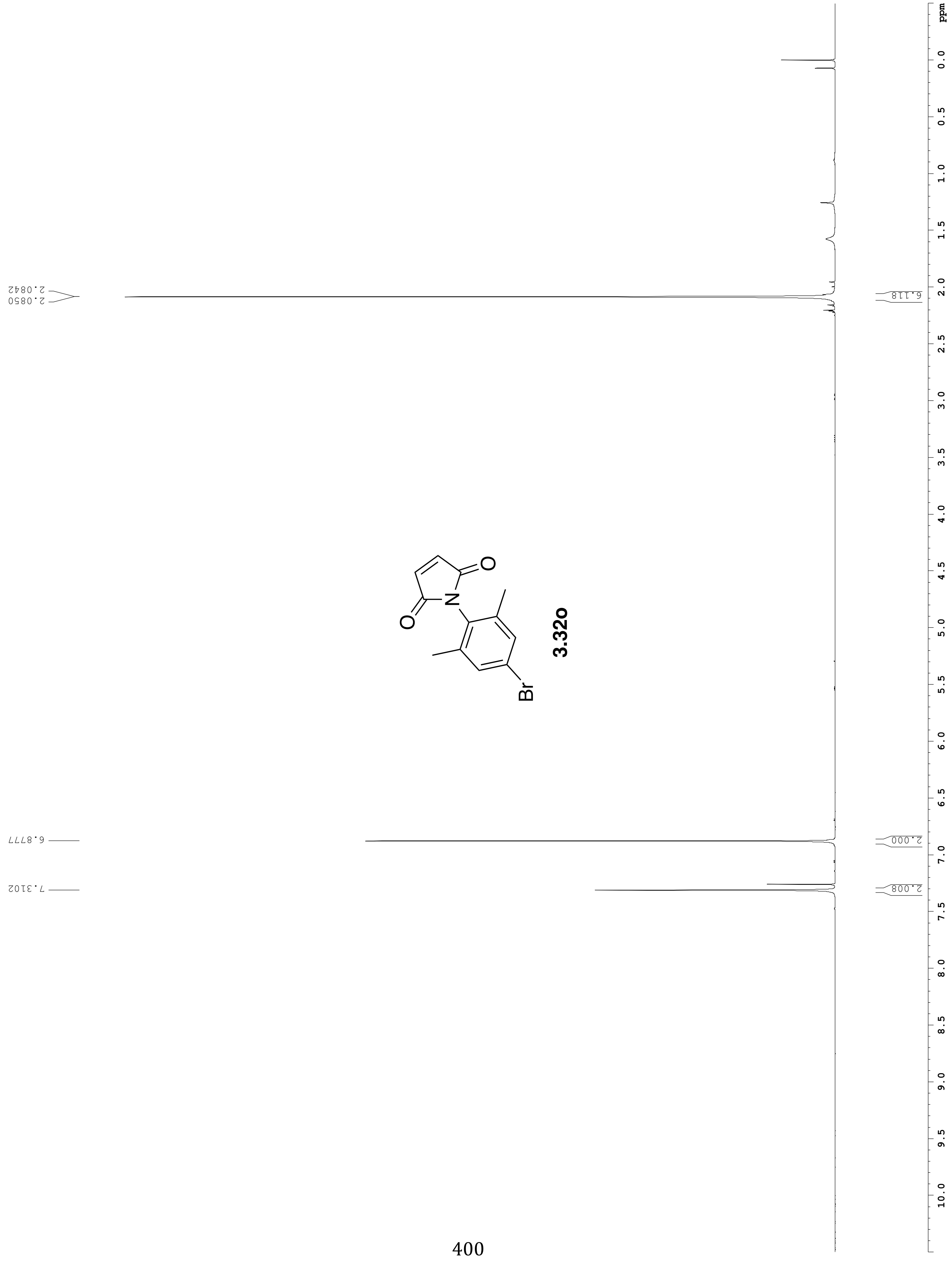


**3.32n**

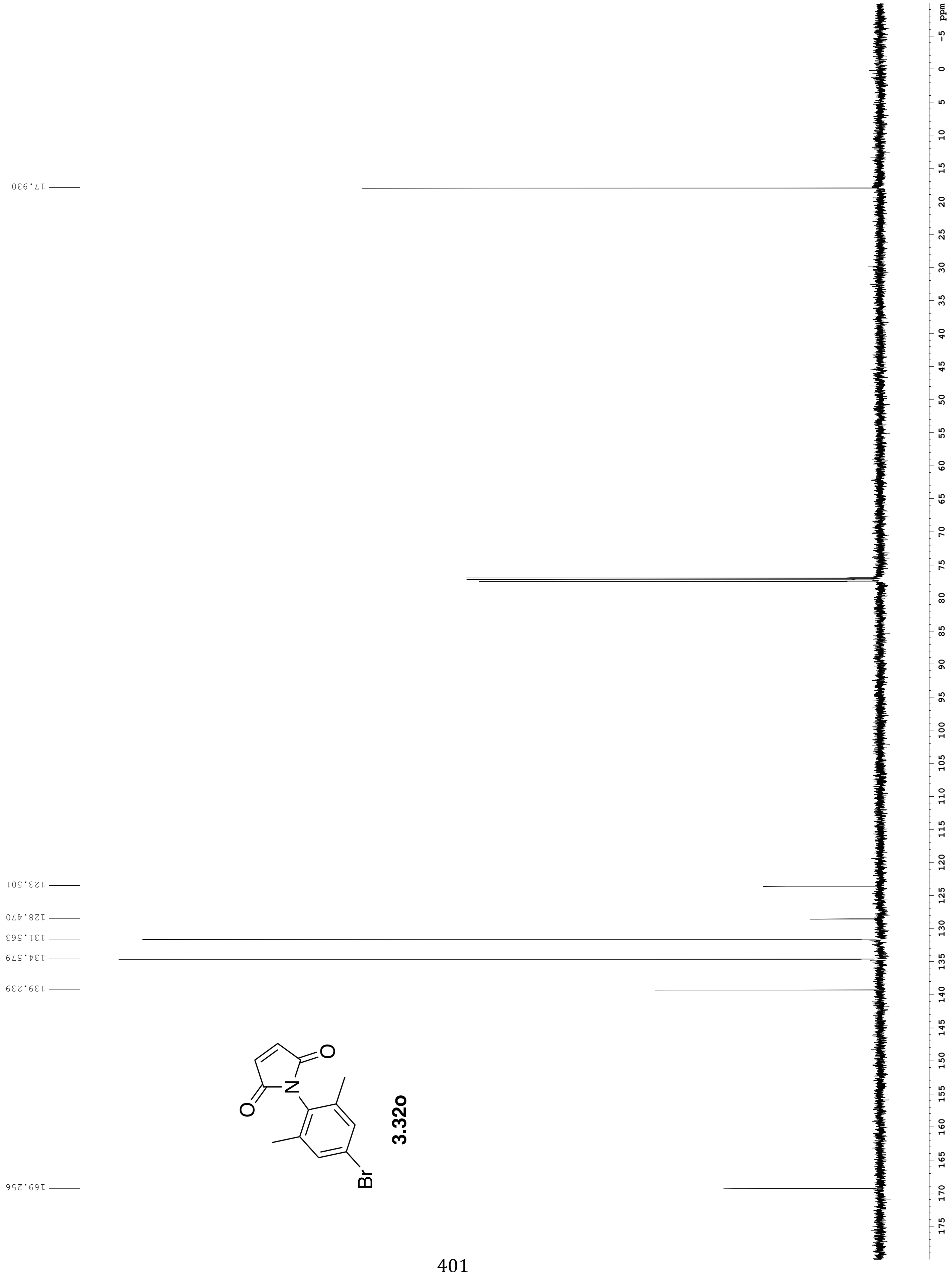
2.0866
6.8774
7.1516
7.1524
6.126
2.022
2.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
N
O
Cl

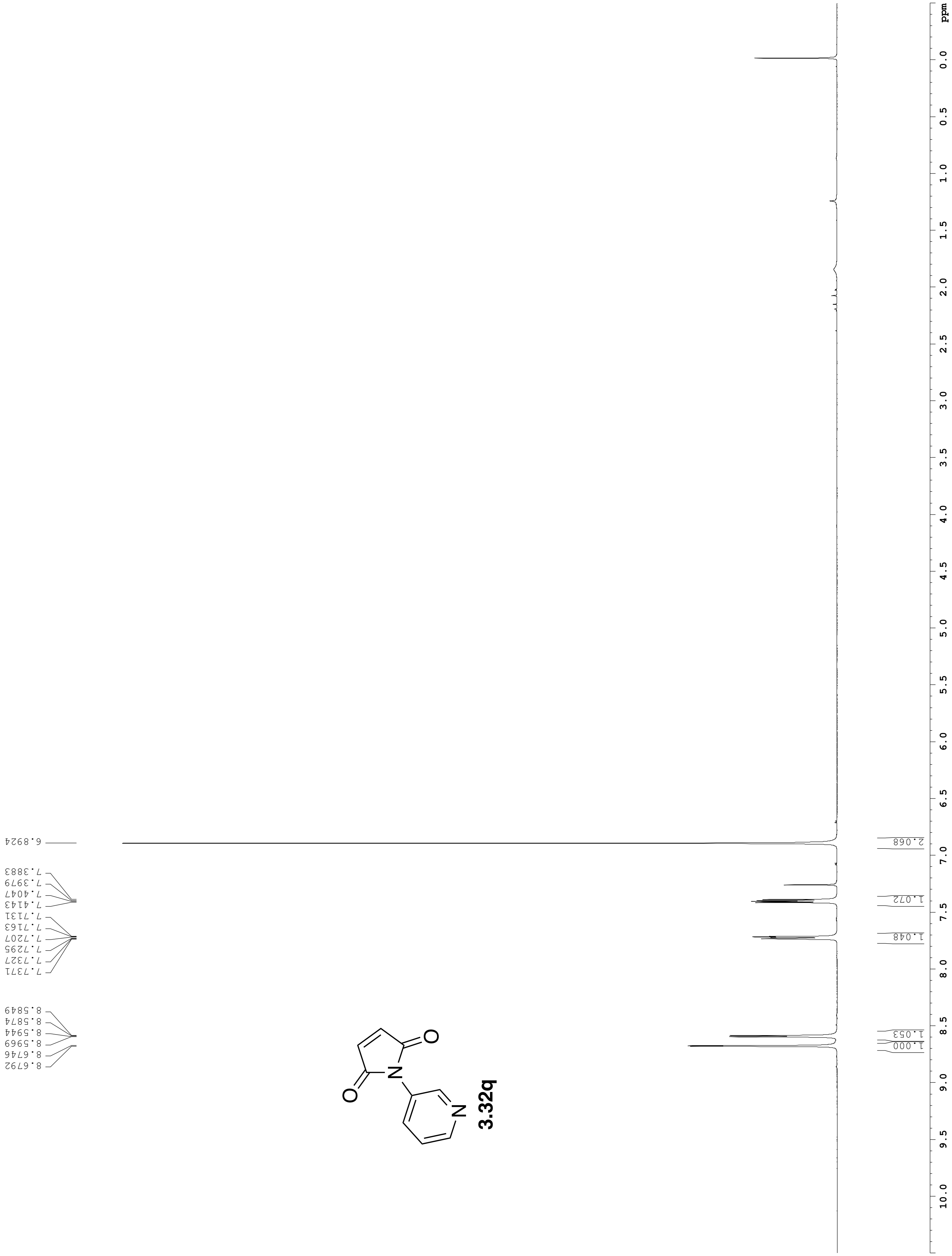

18.017
127.897
128.597
134.570
135.161
138.961
169.334
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
O
N
O
Cl

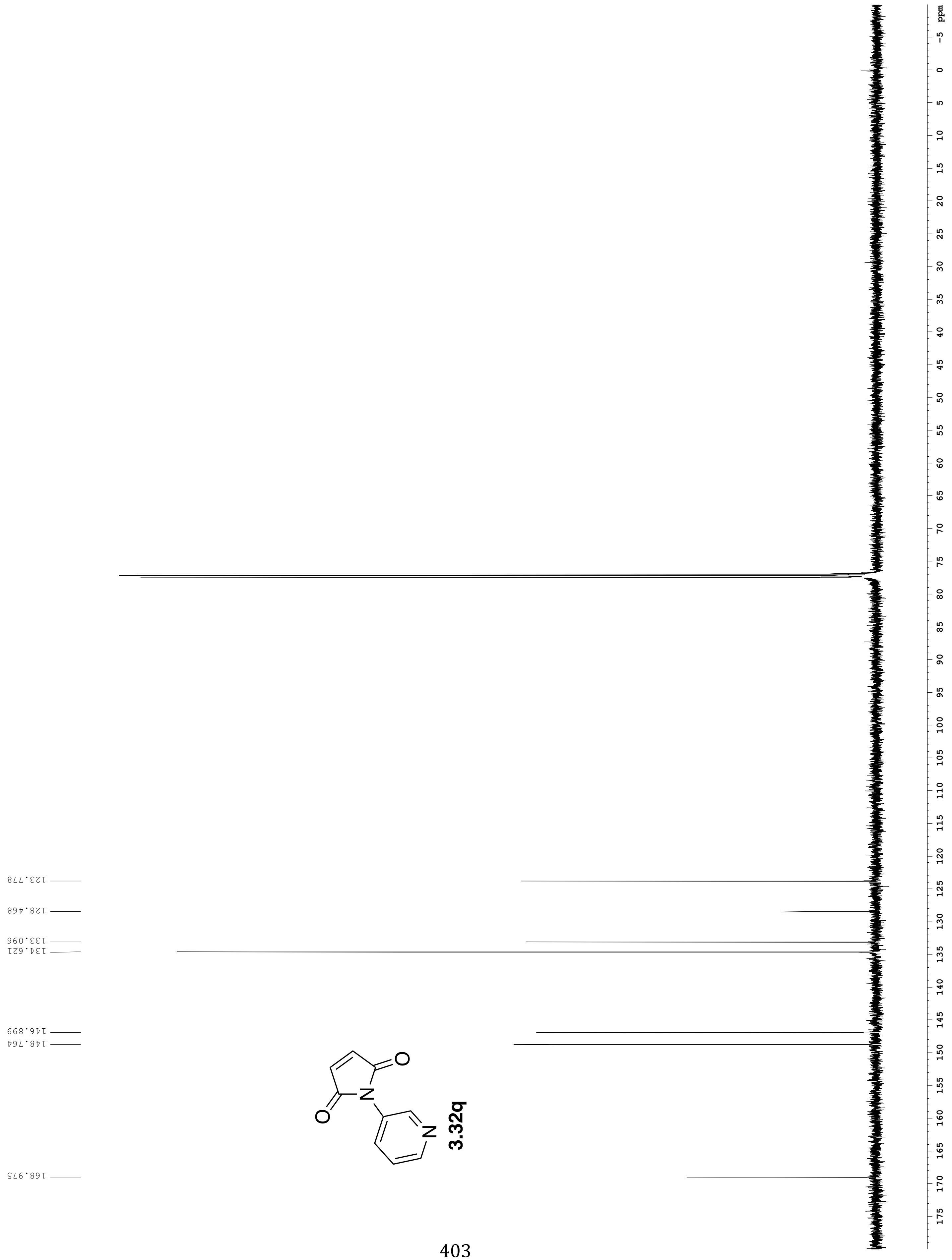
**3.32n**


2.0842
2.0850
6.8777
7.3102
6.118
2.000
2.008
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
N
O
Br

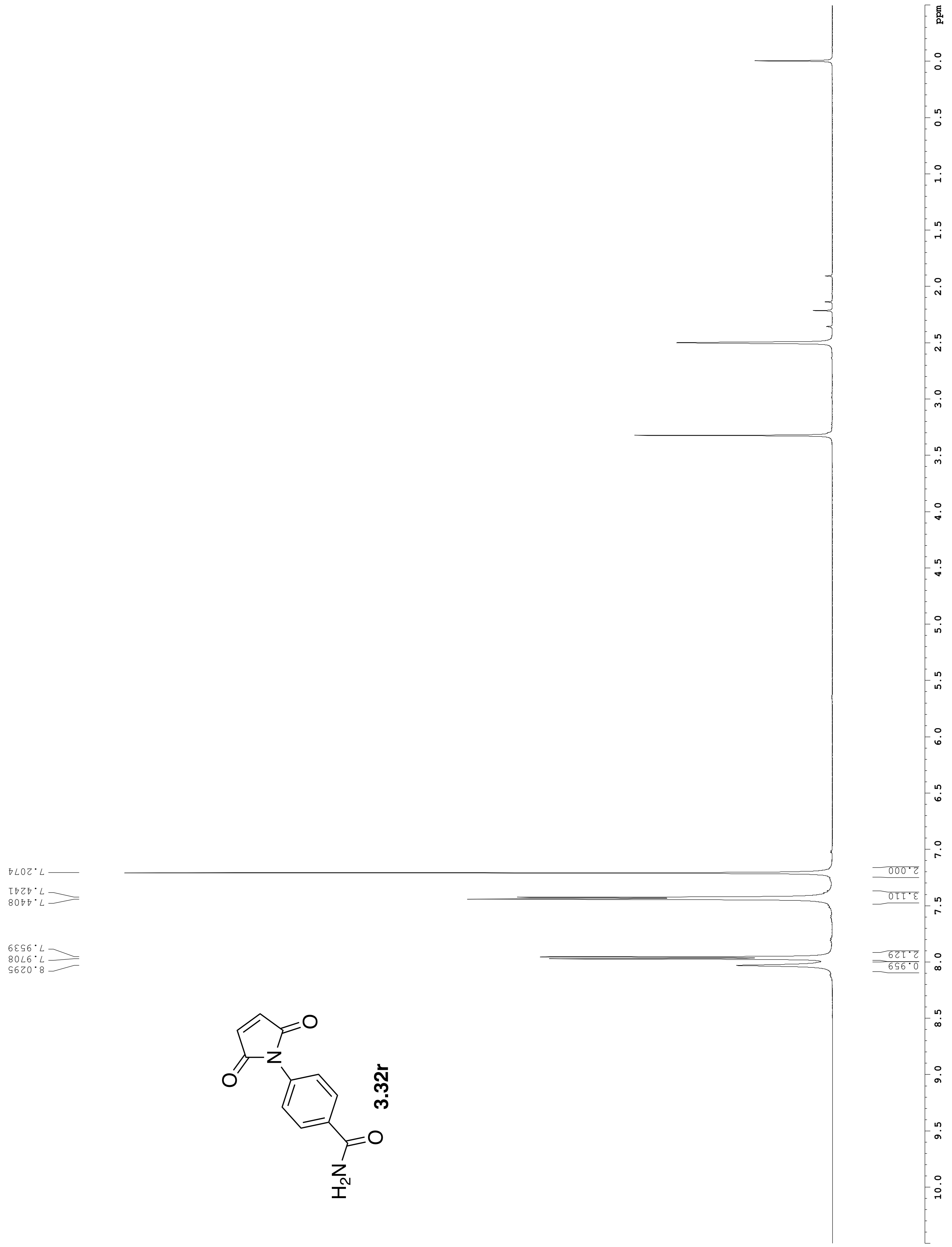
**3.32o**


17.930
123.501
128.470
131.563
134.579
139.239
169.256
3.32o
Br
N
O
O
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

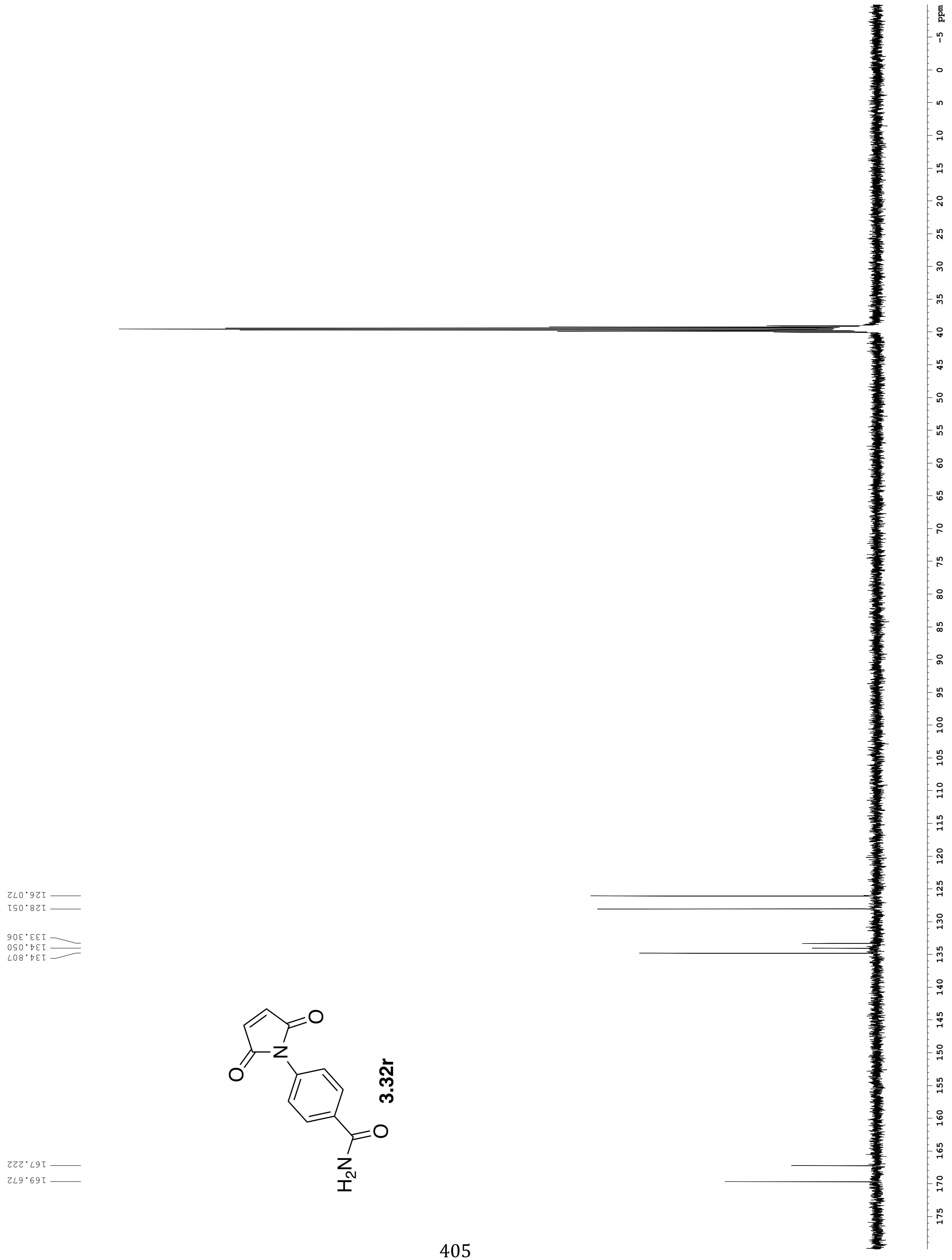

6.8924
7.3883
7.3979
7.4047
7.4143
7.7131
7.7163
7.7207
7.7295
7.7327
7.7371
8.5849
8.5874
8.5944
8.5969
8.6746
8.6792
2.068
1.072
1.048
1.053
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
N
N
O
3.32q


123.778
128.468
133.096
134.621
146.899
148.764
168.975
O
N
O
N
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175

**3.32q**

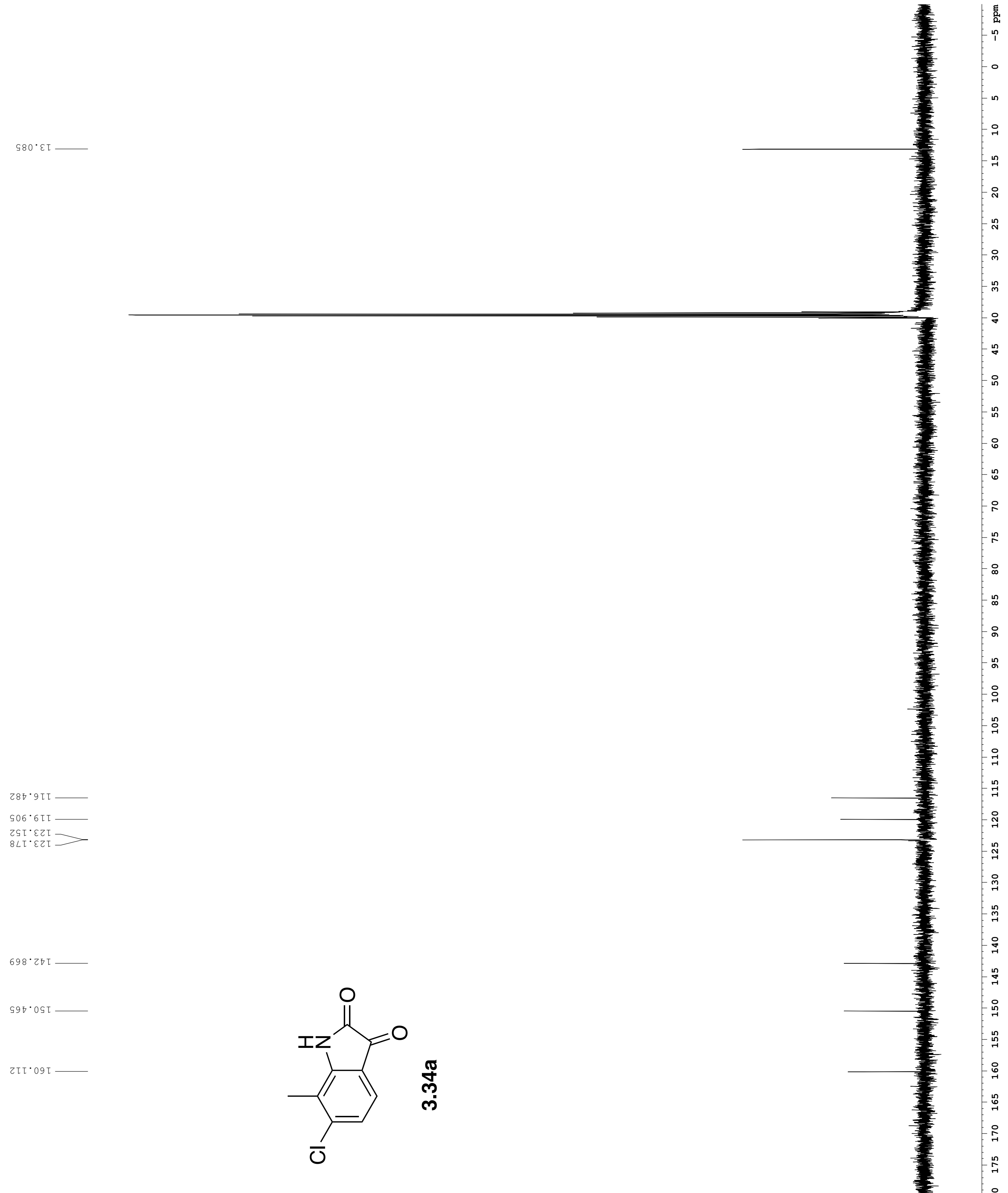

7.2074
7.4241
7.4408
7.9539
7.9708
8.0295
2.000
3.110
2.129
0.959
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
N
O
O
H2N

**3.32r**


126.072
128.051
133.306
134.050
134.807
167.222
169.672
3.32r
O
N
O
O
H2N
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175


2.2148
7.1279
7.1440
7.3540
7.3700
11.2975
2.941
0.949
1.000
0.995
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
O
O
HN
Cl

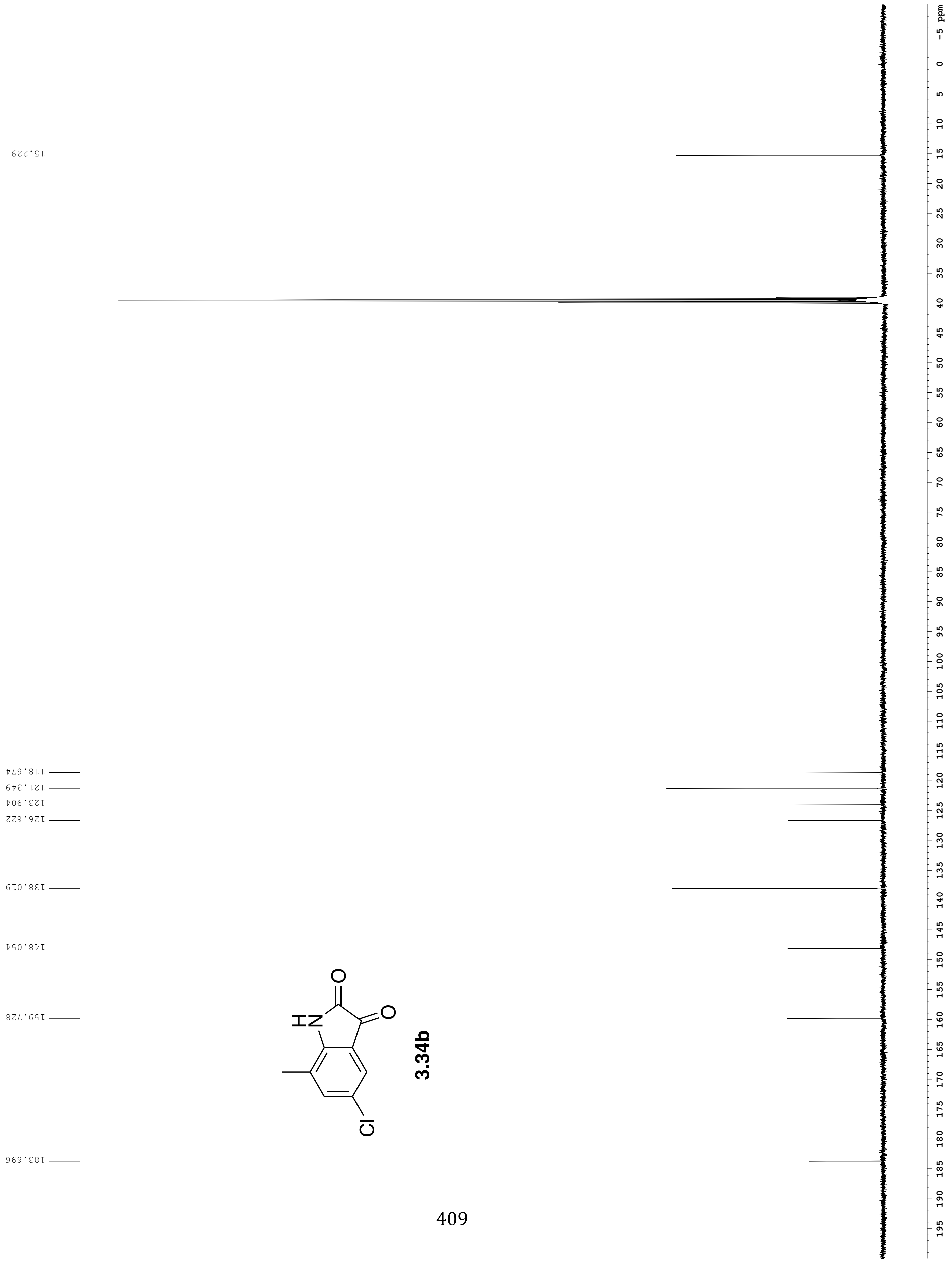
**3.34a**


13.085
116.482
119.905
123.152
123.178
142.869
150.465
160.112
183.699
O
O
HN
Cl
-5 ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195

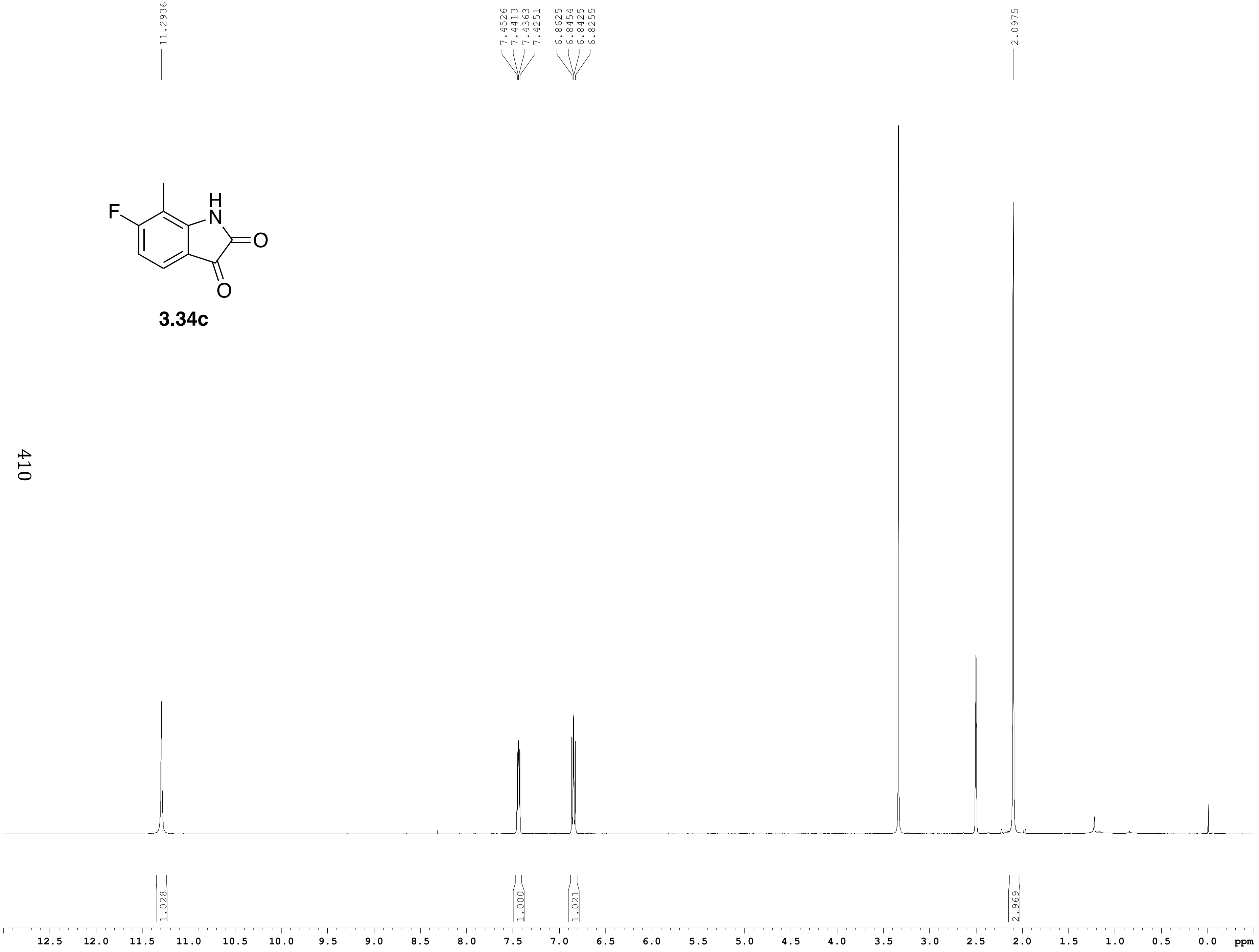
**3.34a**


2.1783
7.3606
7.3637
7.5008
7.5047
11.1997
3.087
0.967
1.000
1.003
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
HN
O
O
Cl

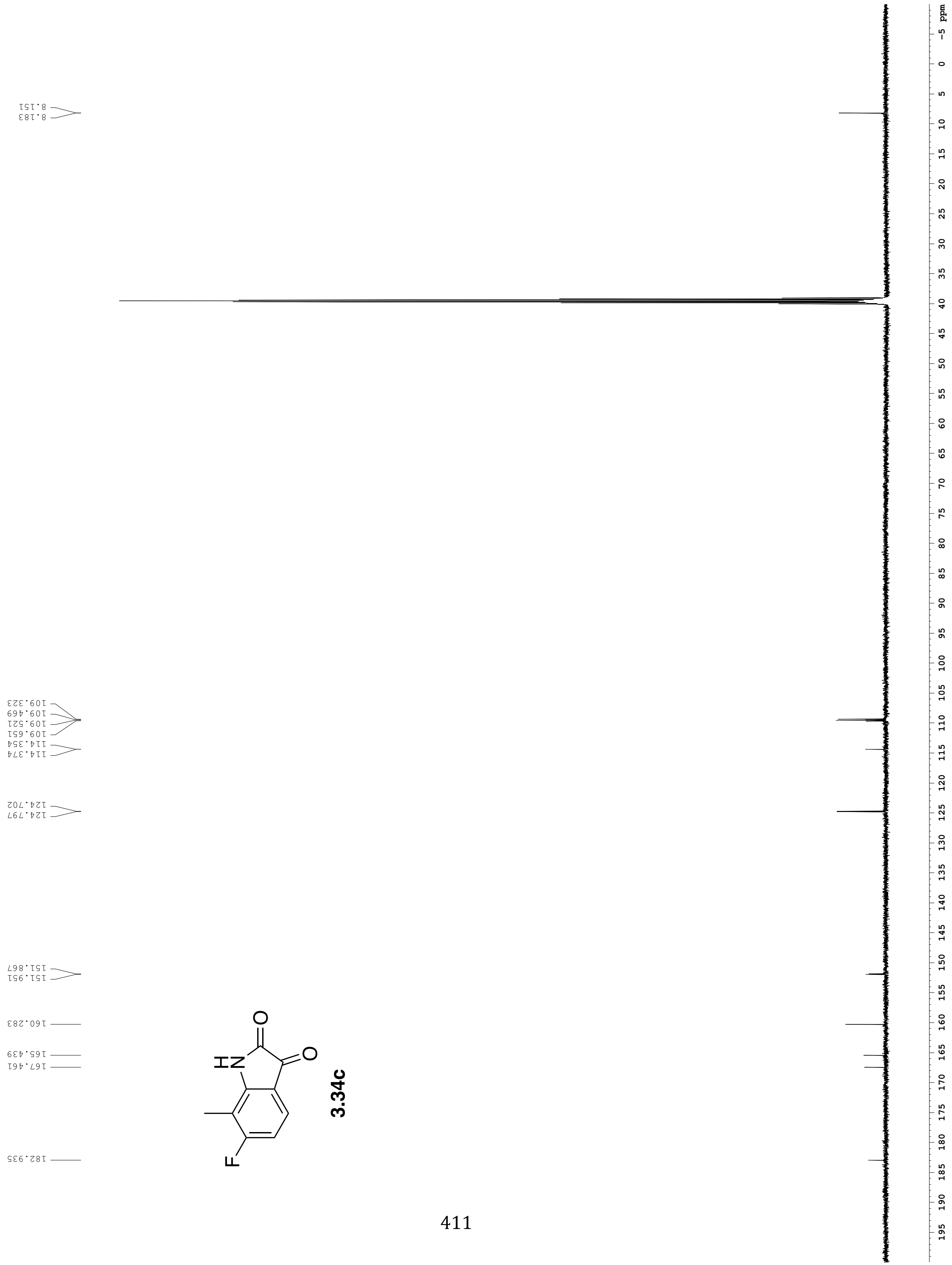
**3.34b**


15.229
118.674
121.349
123.904
126.622
138.019
148.054
159.728
183.696
O
O
N
H
Cl
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195

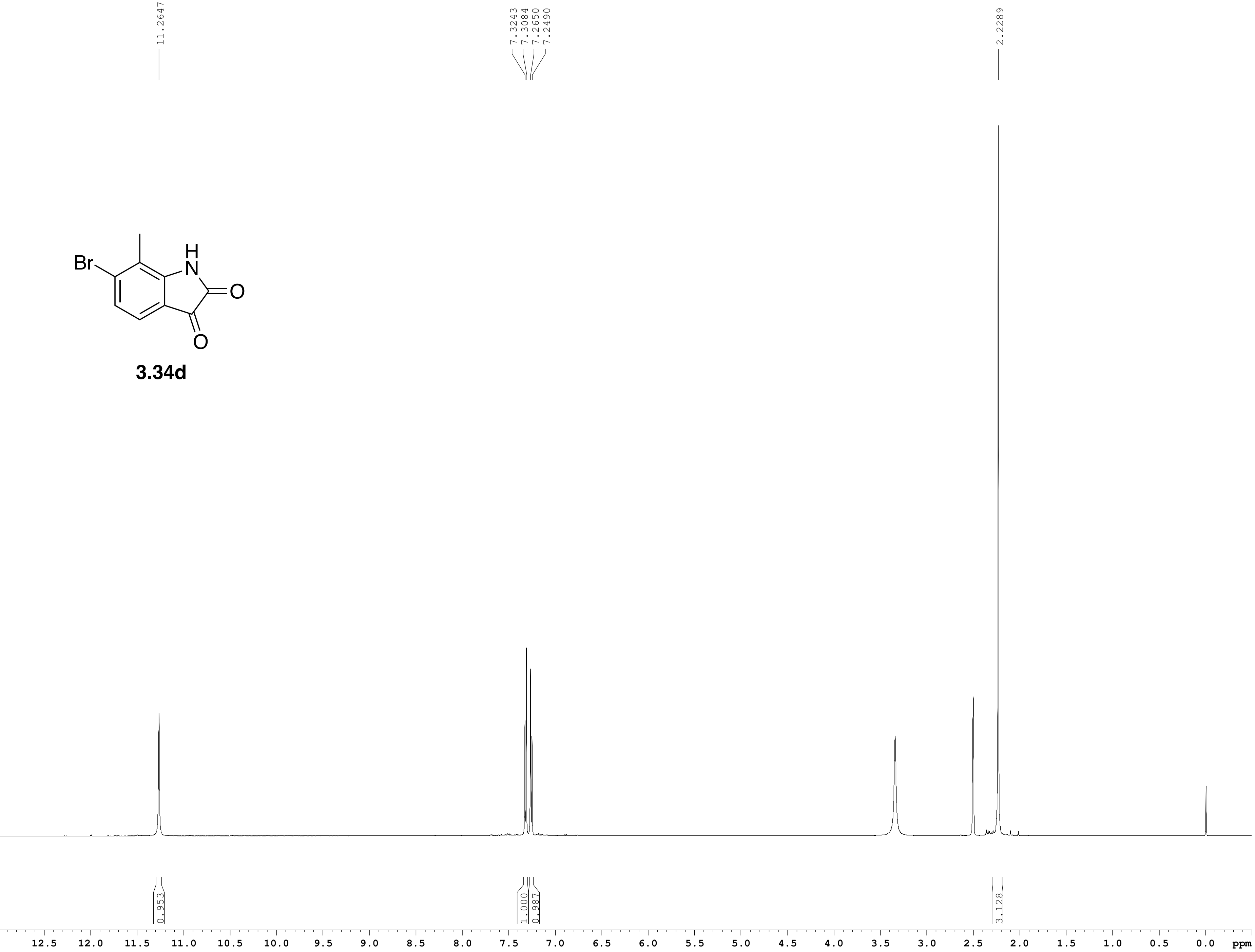
**3.34b**


11.2936
7.4526
7.4413
7.4363
7.4251
6.8625
6.8454
6.8425
6.8255
2.0975
1.028
1.000
1.021
2.969
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm
F
H
N
O
O

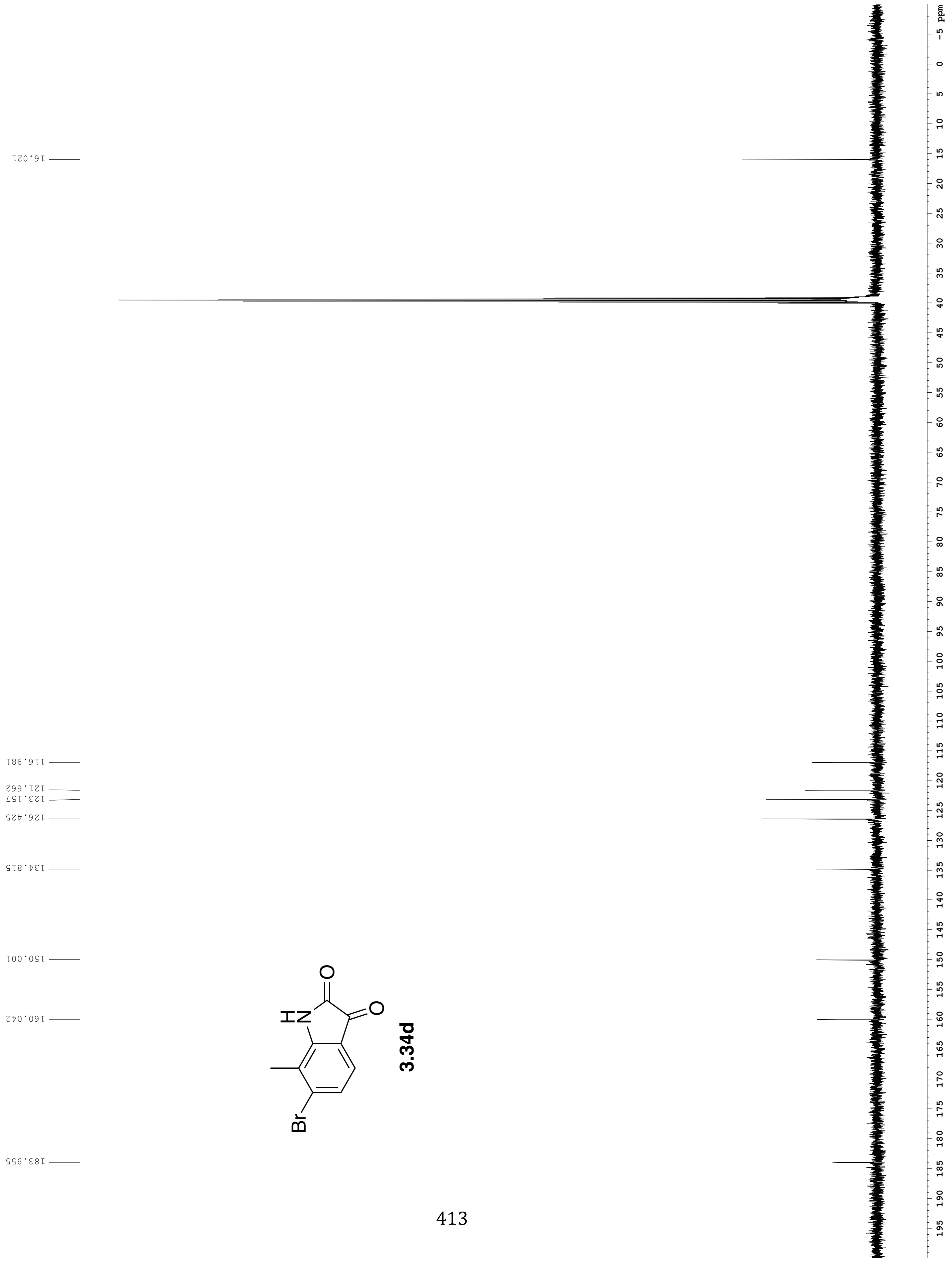
**3.34c**


8.151
8.183
109.323
109.469
109.521
109.651
114.354
114.374
124.702
124.797
151.867
151.951
160.283
165.439
167.461
182.935
HN
O
O
F
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195

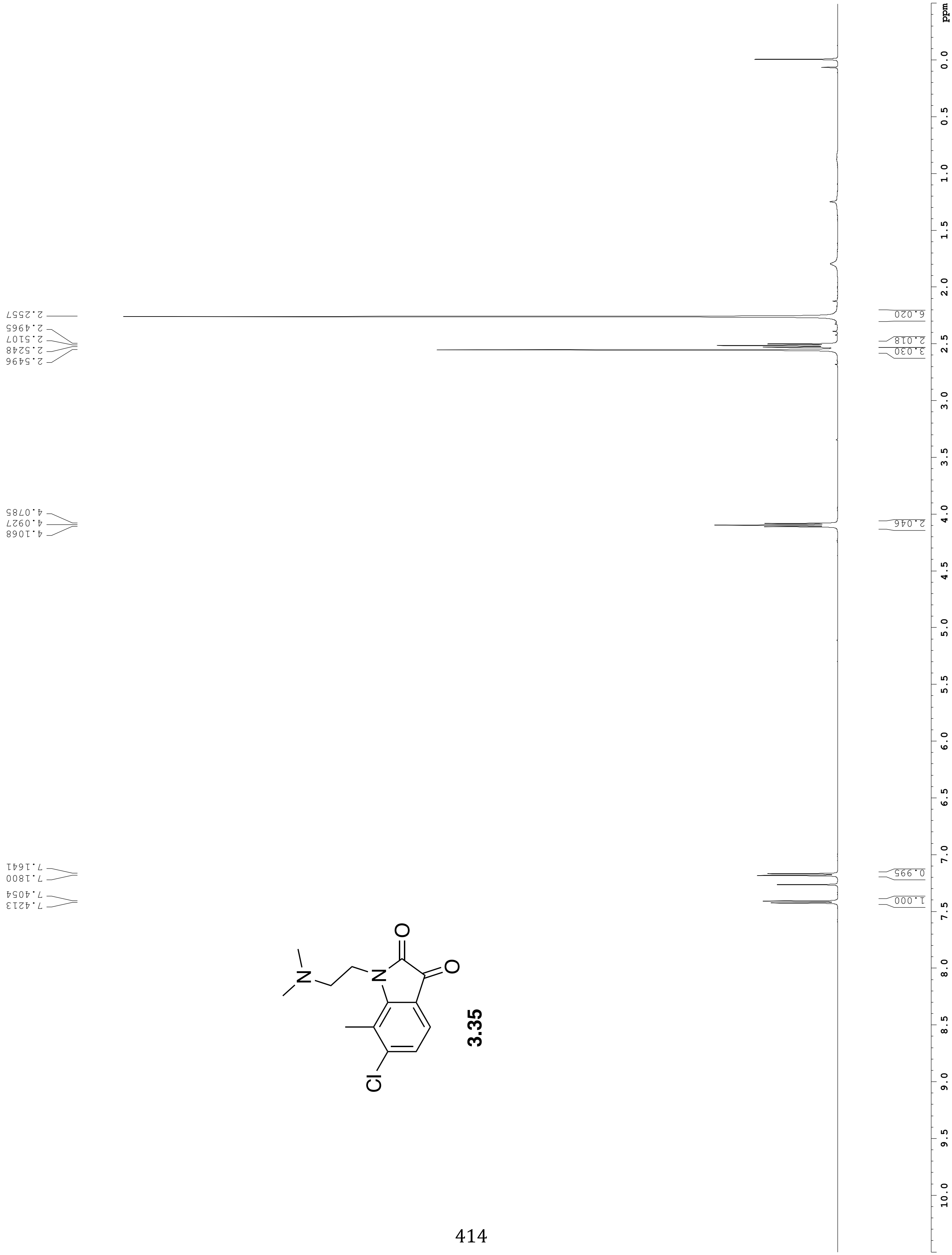
**3.34c**



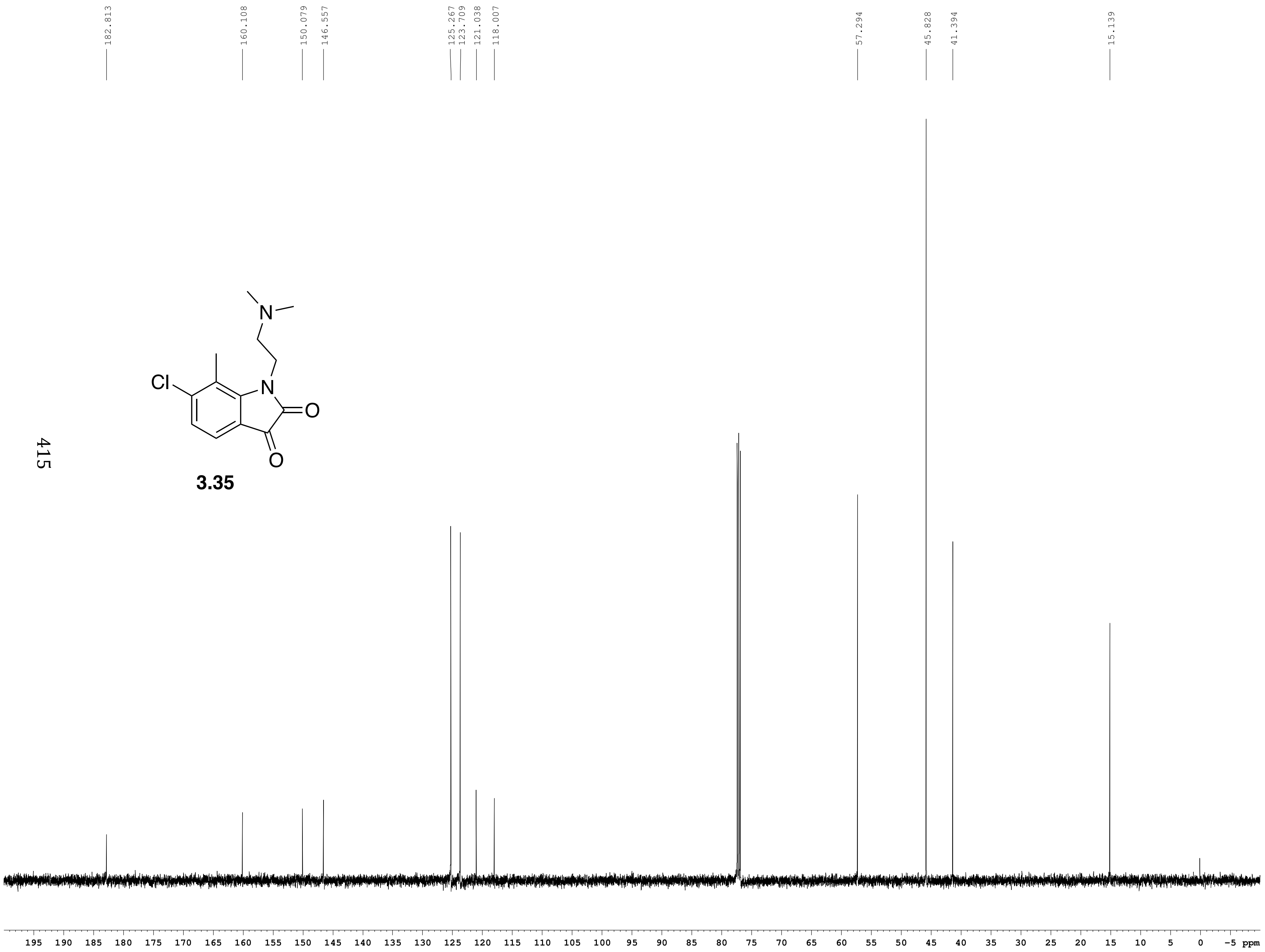
11.2647
7.3243
7.3084
7.2650
7.2490
2.2289
Br
H
N
O
O
3.34d
0.953
1.000
0.987
3.128
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm


16.021
116.981
121.662
123.157
126.425
134.815
150.001
160.042
183.955
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
O
O
NH
Br

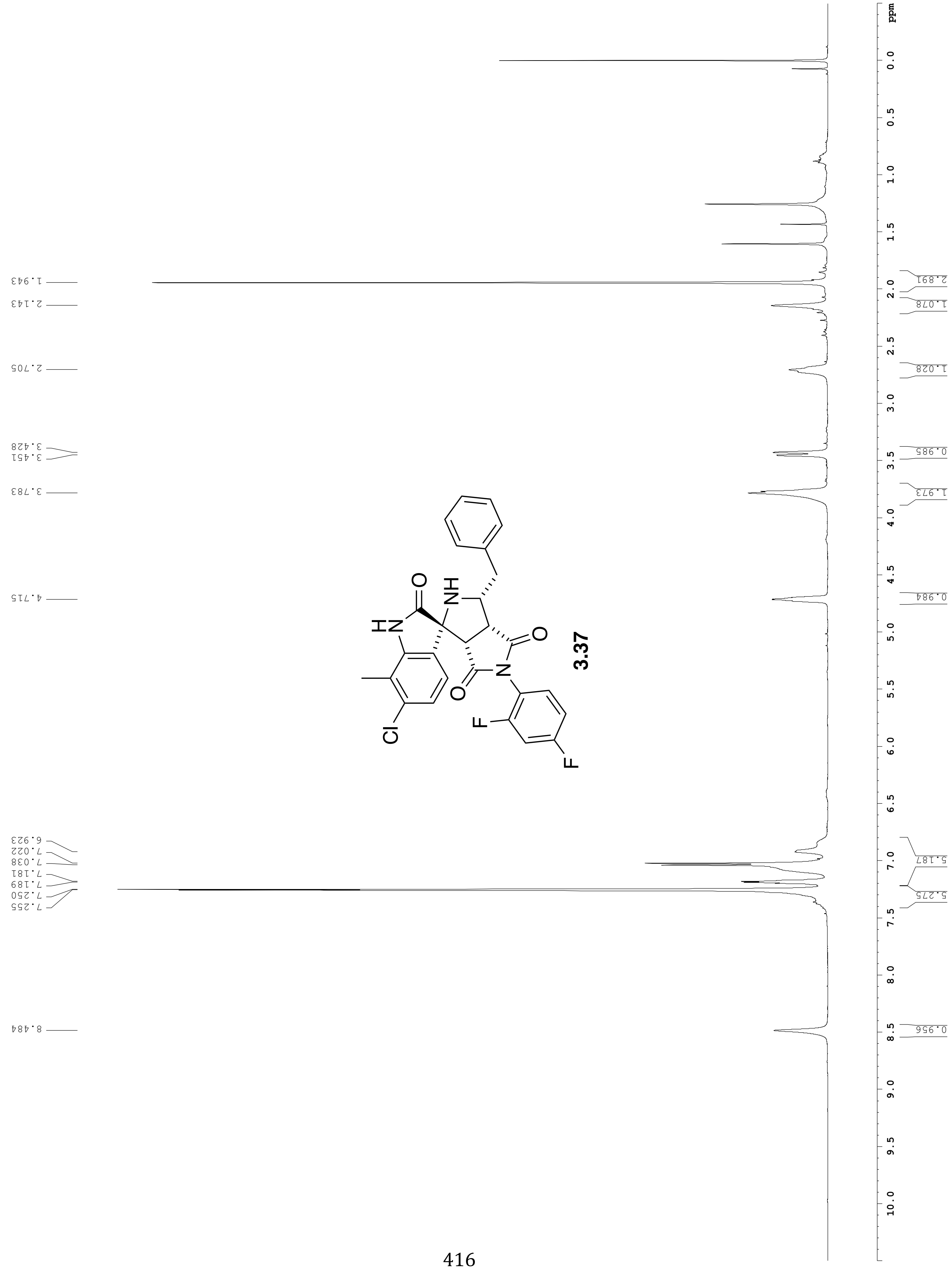
**3.34d**


2.2557
2.4965
2.5107
2.5248
2.5496
4.0785
4.0927
4.1068
7.1641
7.1800
7.4054
7.4213
6.020
2.018
3.030
2.046
0.995
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
O
N
N
Cl

**3.35**

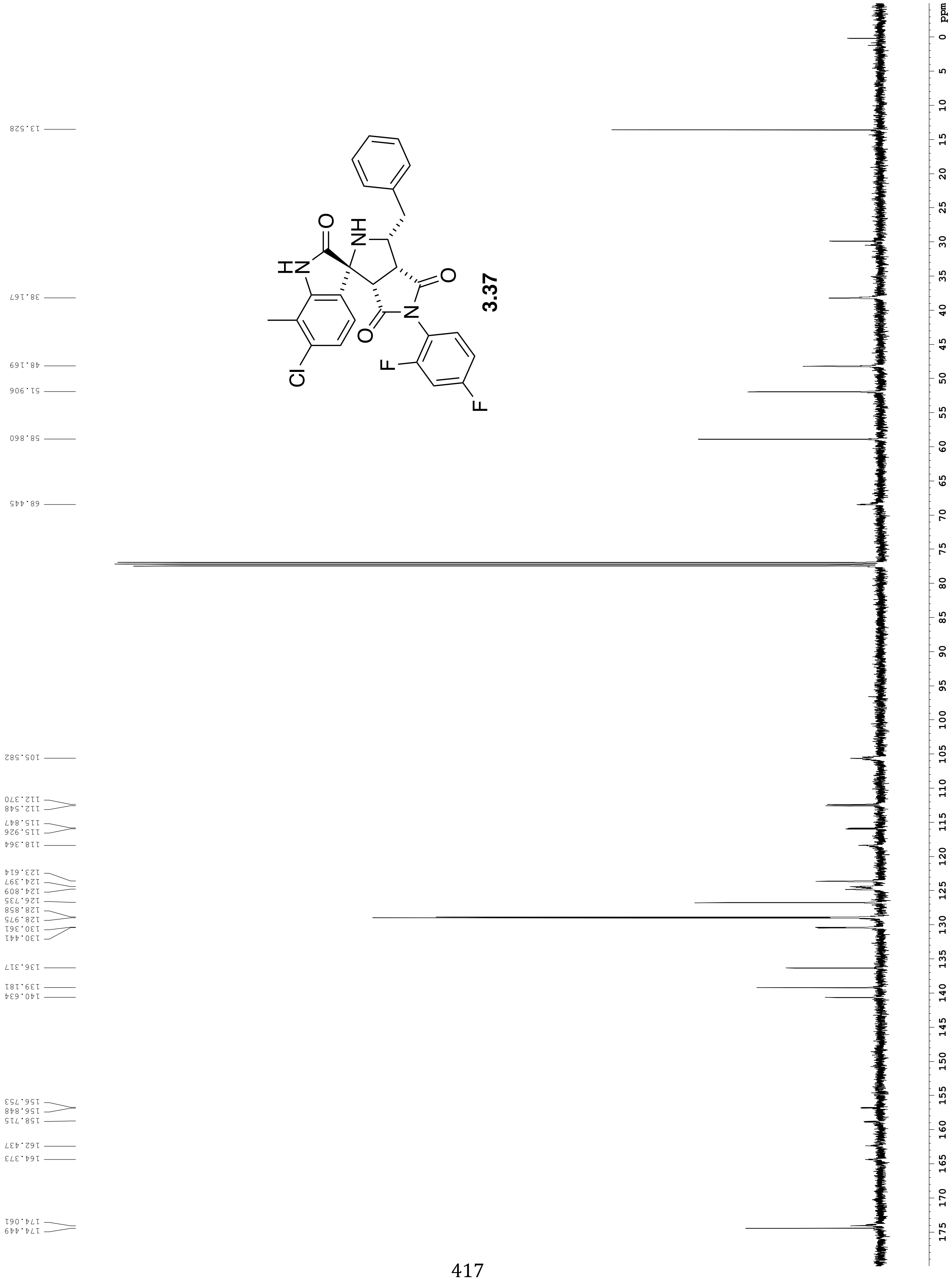

182.813
160.108
150.079
146.557
125.267
123.709
121.038
118.007
57.294
45.828
41.394
15.139
Cl
N
O
O
N
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5 ppm

**3.35**

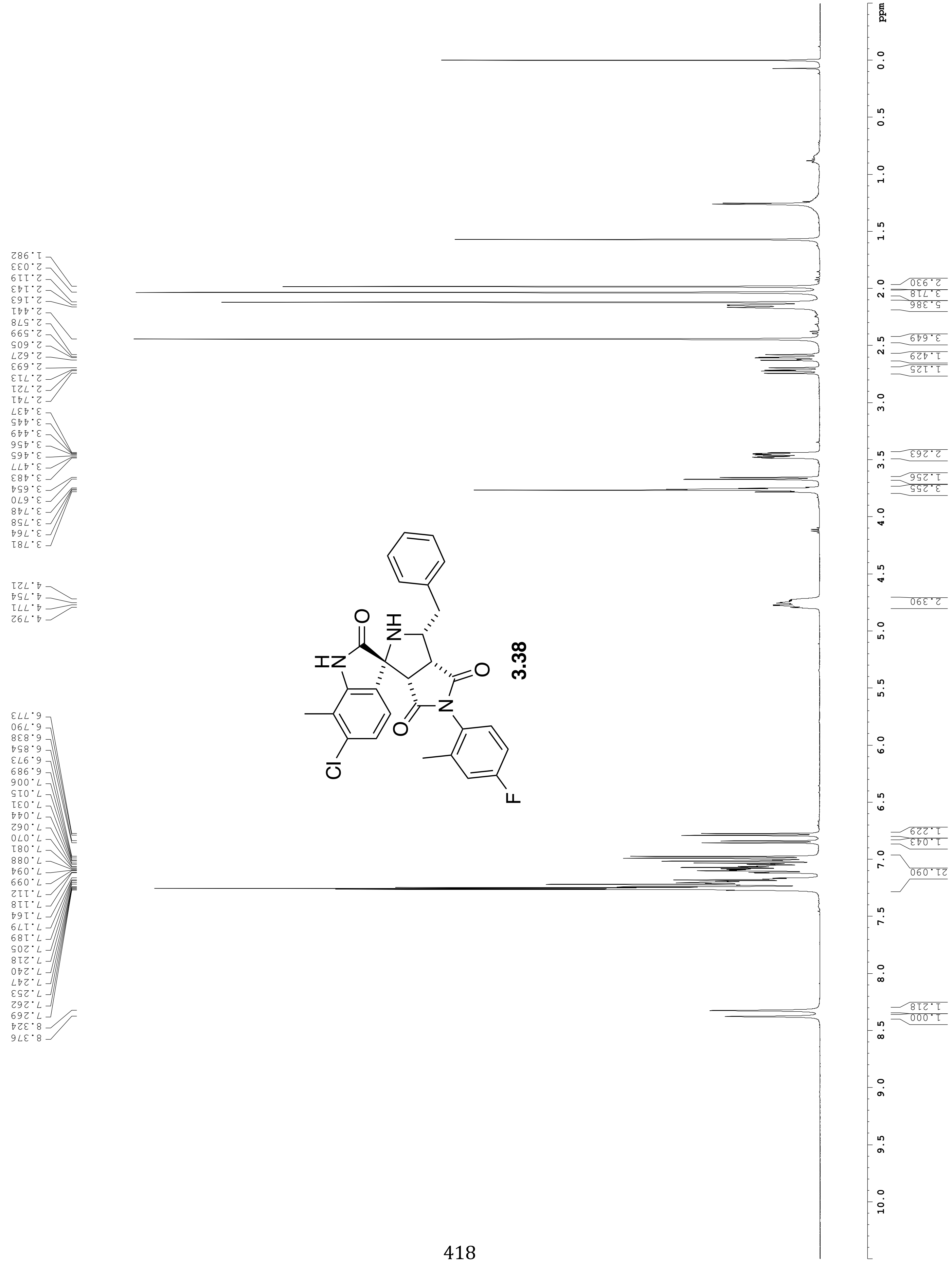


**3.37**

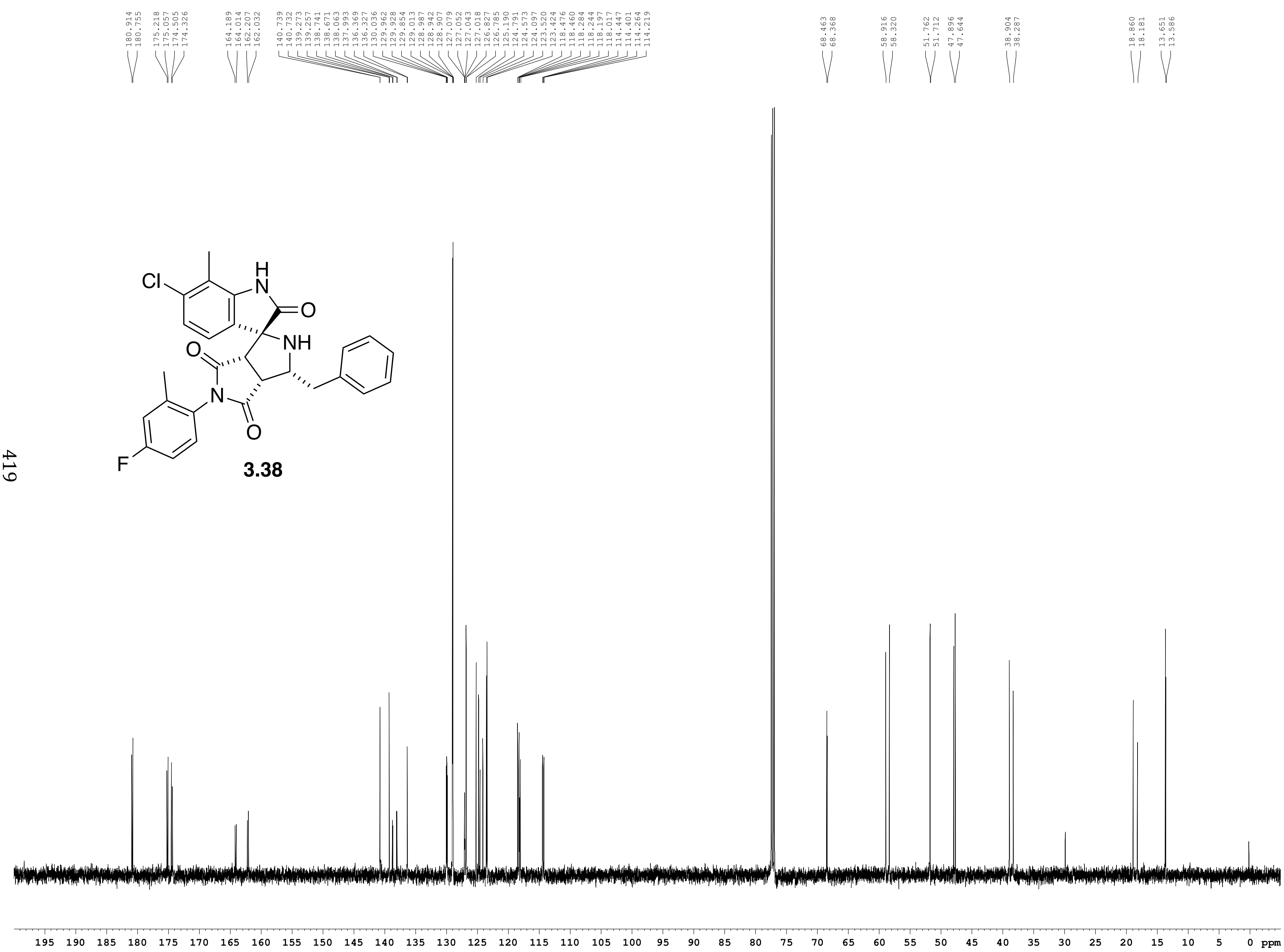
1.943
2.143
2.705
3.428
3.451
3.783
4.715
6.923
7.022
7.038
7.181
7.189
7.250
7.255
8.484
2.891
1.078
1.028
0.985
1.973
0.984
5.187
5.275
0.956
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
NH
H
N
O
O
O
N
F
F
Cl


13.528
38.167
48.169
51.906
58.860
68.445
105.582
112.370
112.548
115.847
115.926
118.364
123.614
124.397
124.809
126.735
128.858
128.975
130.361
130.441
136.317
139.181
140.634
156.753
156.848
158.715
162.437
164.373
174.061
174.449
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
H
N
O
NH
O
N
O
Cl
F
F

**3.37**

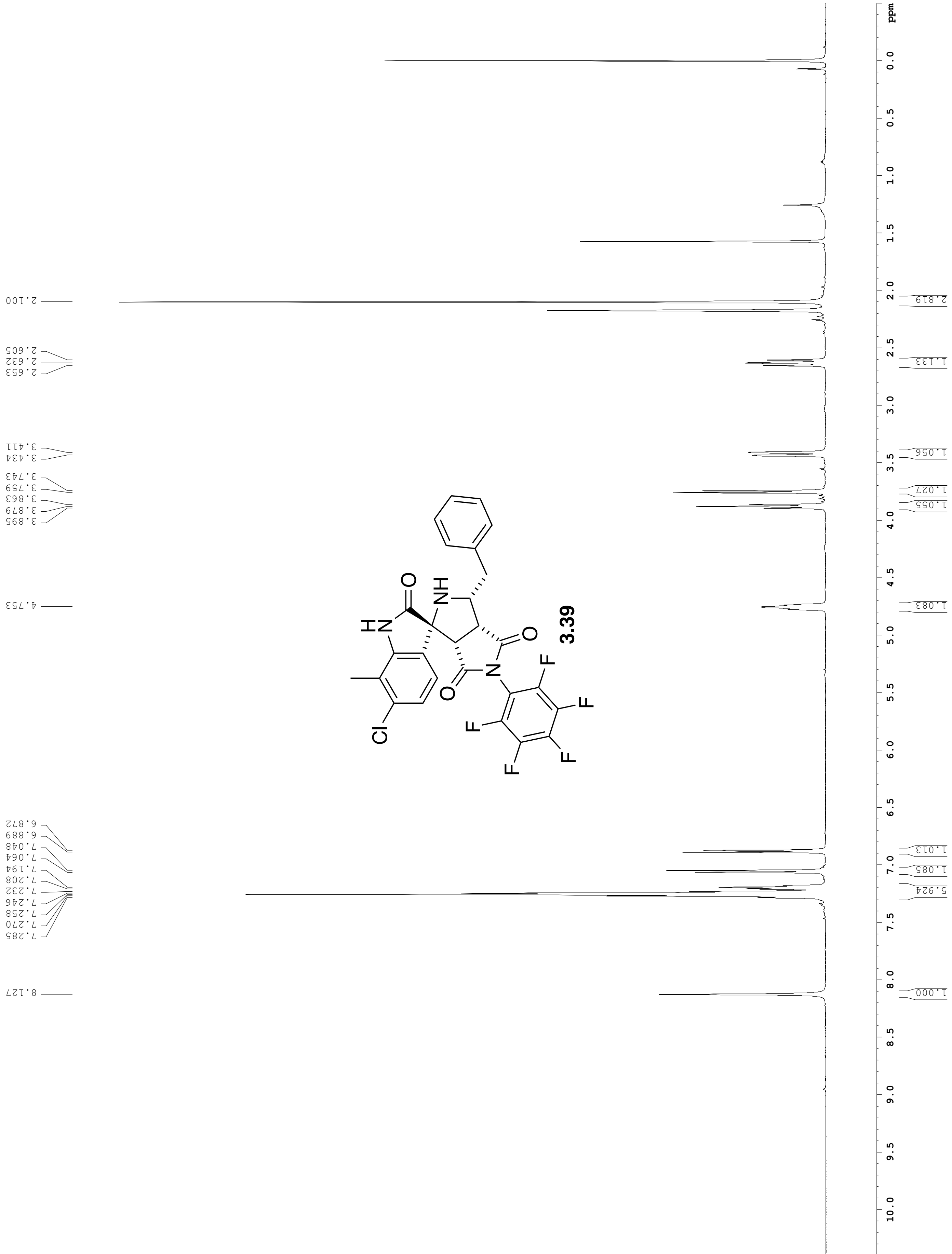

1.982
2.033
2.119
2.143
2.163
2.441
2.578
2.599
2.605
2.627
2.693
2.713
2.721
2.741
3.437
3.445
3.449
3.456
3.465
3.477
3.483
3.654
3.670
3.748
3.758
3.764
3.781
4.721
4.754
4.771
4.792
6.773
6.790
6.838
6.854
6.973
6.989
7.006
7.015
7.031
7.044
7.062
7.070
7.081
7.088
7.094
7.099
7.112
7.118
7.164
7.179
7.189
7.205
7.218
7.240
7.247
7.253
7.262
7.269
8.324
8.376
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
2.930
3.718
5.386
3.649
1.429
1.125
2.263
1.256
3.255
2.390
1.229
1.043
21.090
1.218
1.000
O
NH
HN
Cl
O
N
O
F

**3.38**



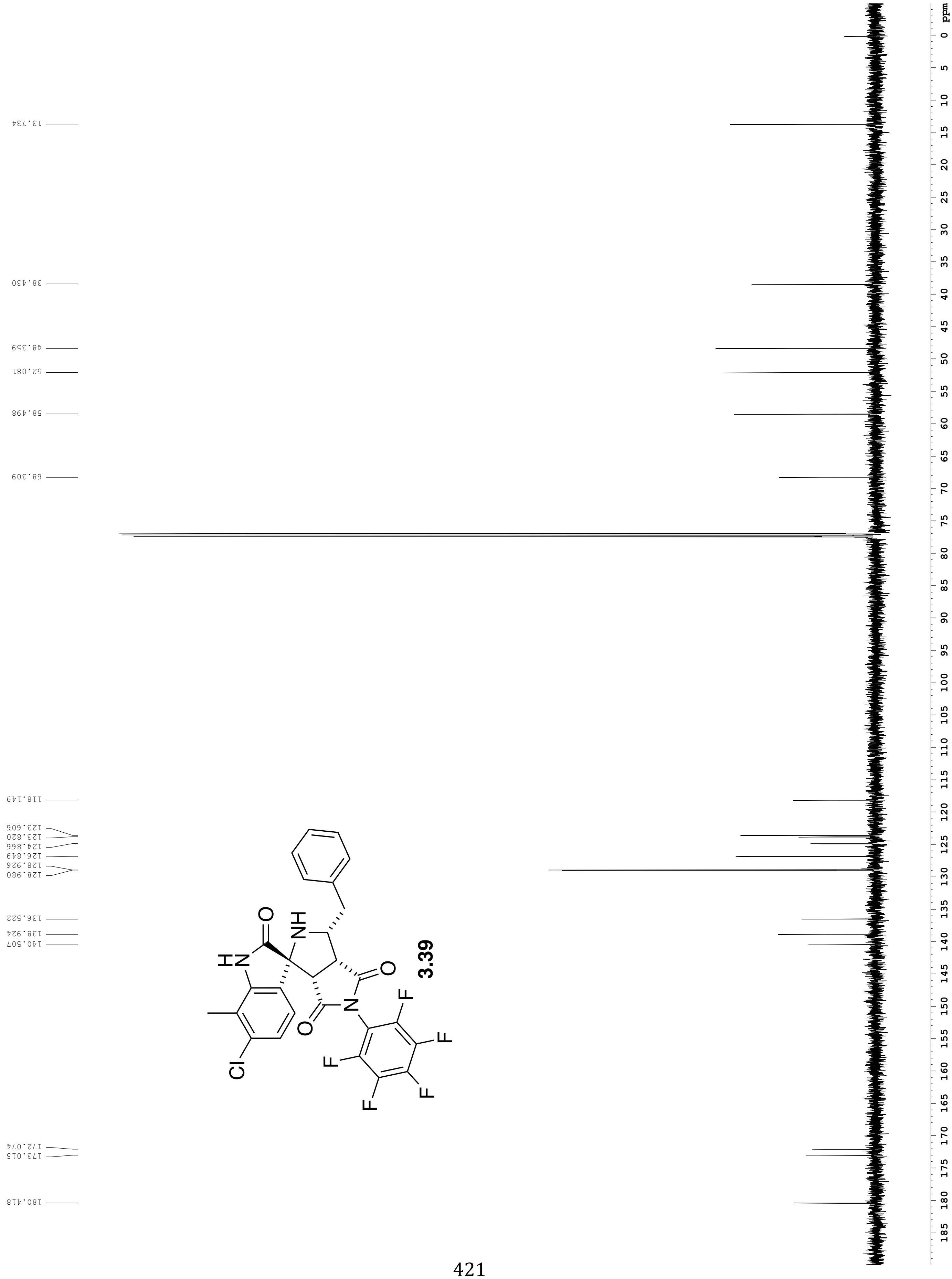
**3.38**

180.914
180.755
175.218
175.057
174.505
174.326
164.189
164.014
162.207
162.032
140.739
140.732
139.273
139.257
138.741
138.671
138.063
137.993
136.369
136.327
130.036
129.962
129.928
129.854
129.013
128.987
128.942
128.907
127.079
127.052
127.043
127.018
126.827
126.785
125.190
124.791
124.573
124.097
123.520
123.424
118.476
118.460
118.284
118.244
118.197
118.017
114.447
114.401
114.264
114.219
68.463
68.368
58.916
58.320
51.762
51.712
47.896
47.644
38.904
38.287
18.860
18.181
13.651
13.586
Cl
H
N
O
NH
O
N
O
F
195 190 185 180 175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 ppm

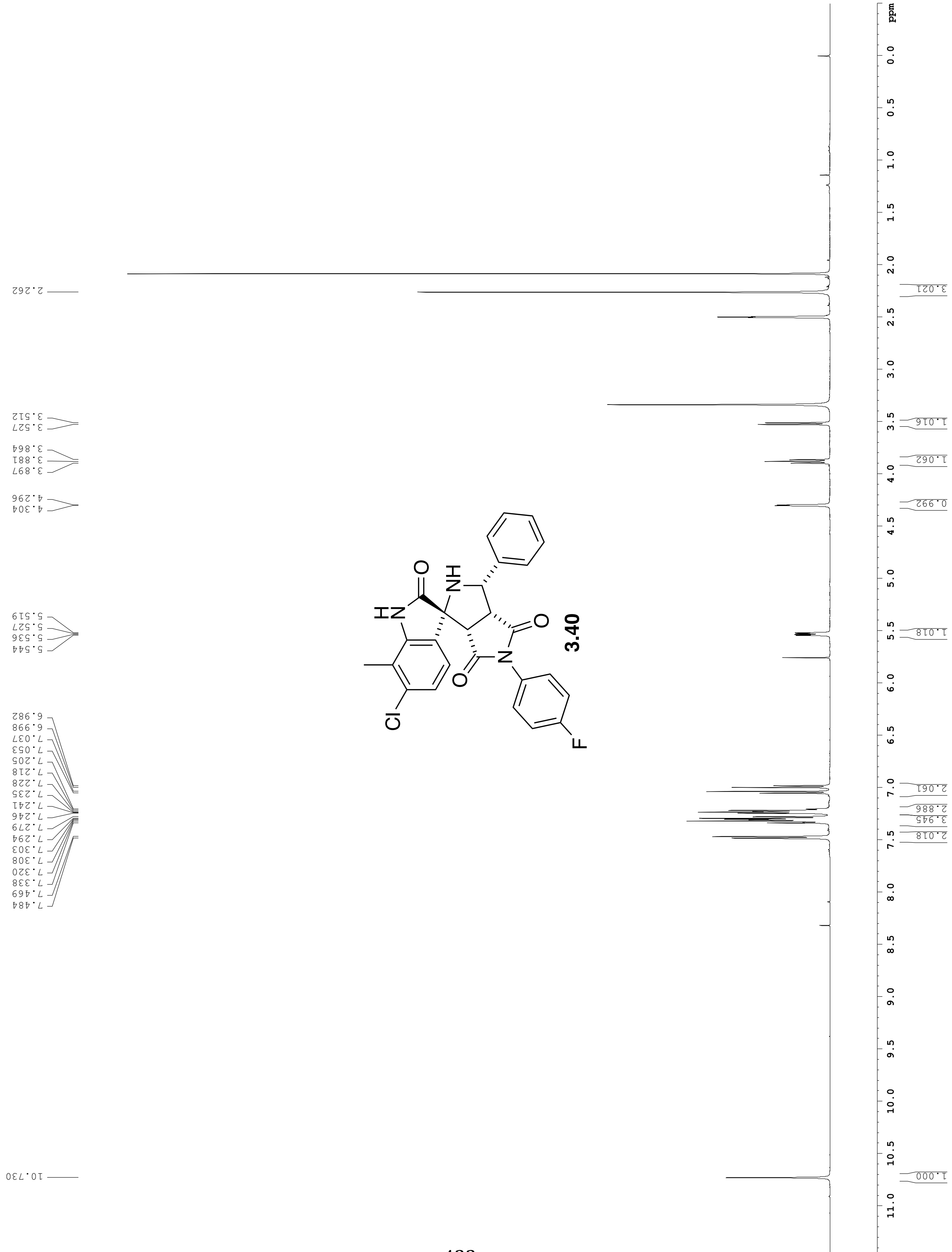


**3.39**

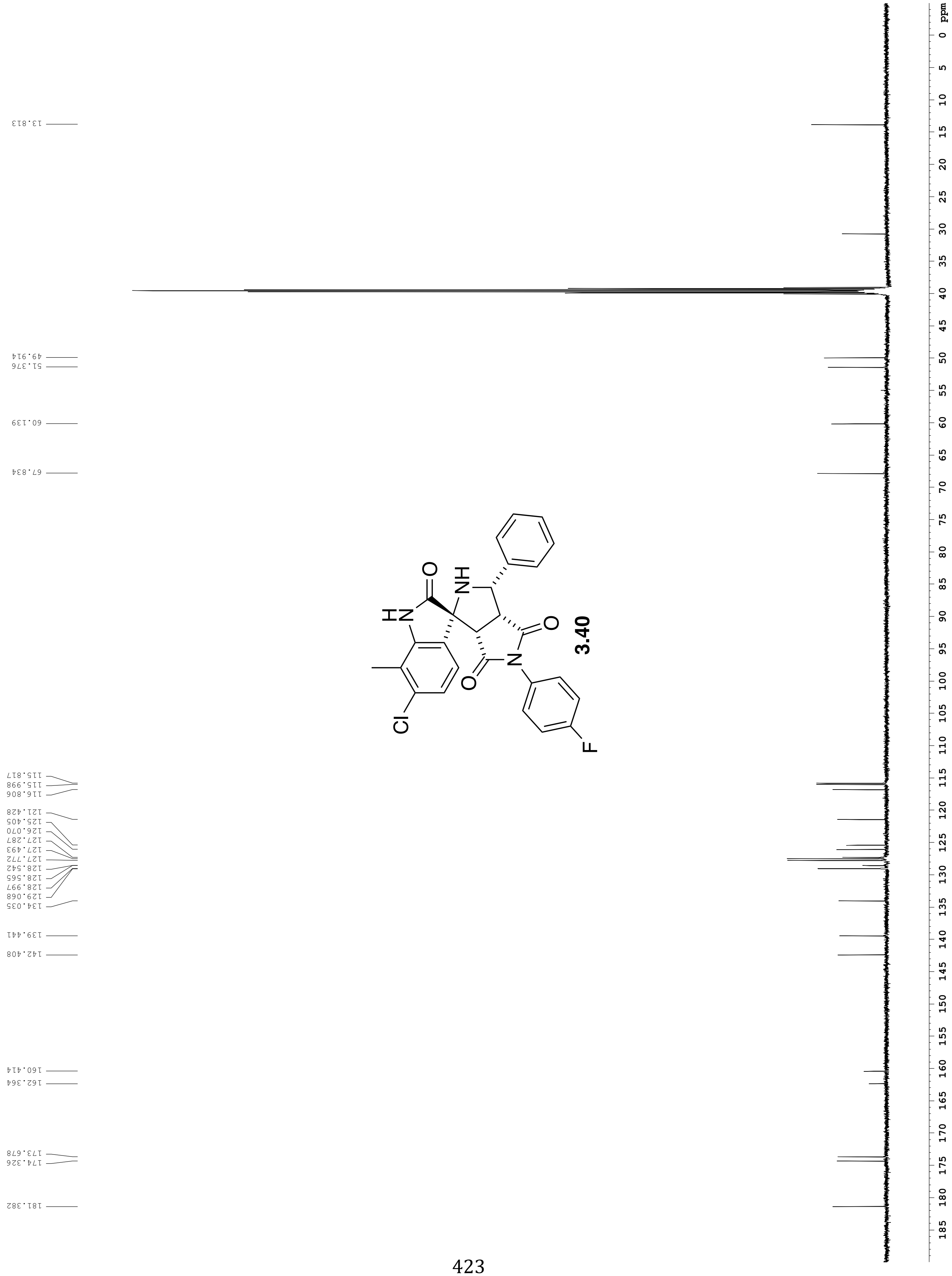
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
2.100
2.605
2.632
2.653
3.411
3.434
3.743
3.759
3.863
3.879
3.895
4.753
6.872
6.889
7.048
7.064
7.194
7.208
7.232
7.246
7.258
7.270
7.285
8.127
2.819
1.133
1.056
1.027
1.055
1.083
1.013
1.085
5.924
1.000
O
NH
HN
Cl
O
N
O
F
F
F
F
F


13.734
38.430
48.359
52.081
58.498
68.309
118.149
123.606
123.820
124.866
126.849
128.926
128.980
136.522
138.924
140.507
172.074
173.015
180.418
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
O
NH
H
N
O
N
O
F
F
F
F
F
Cl

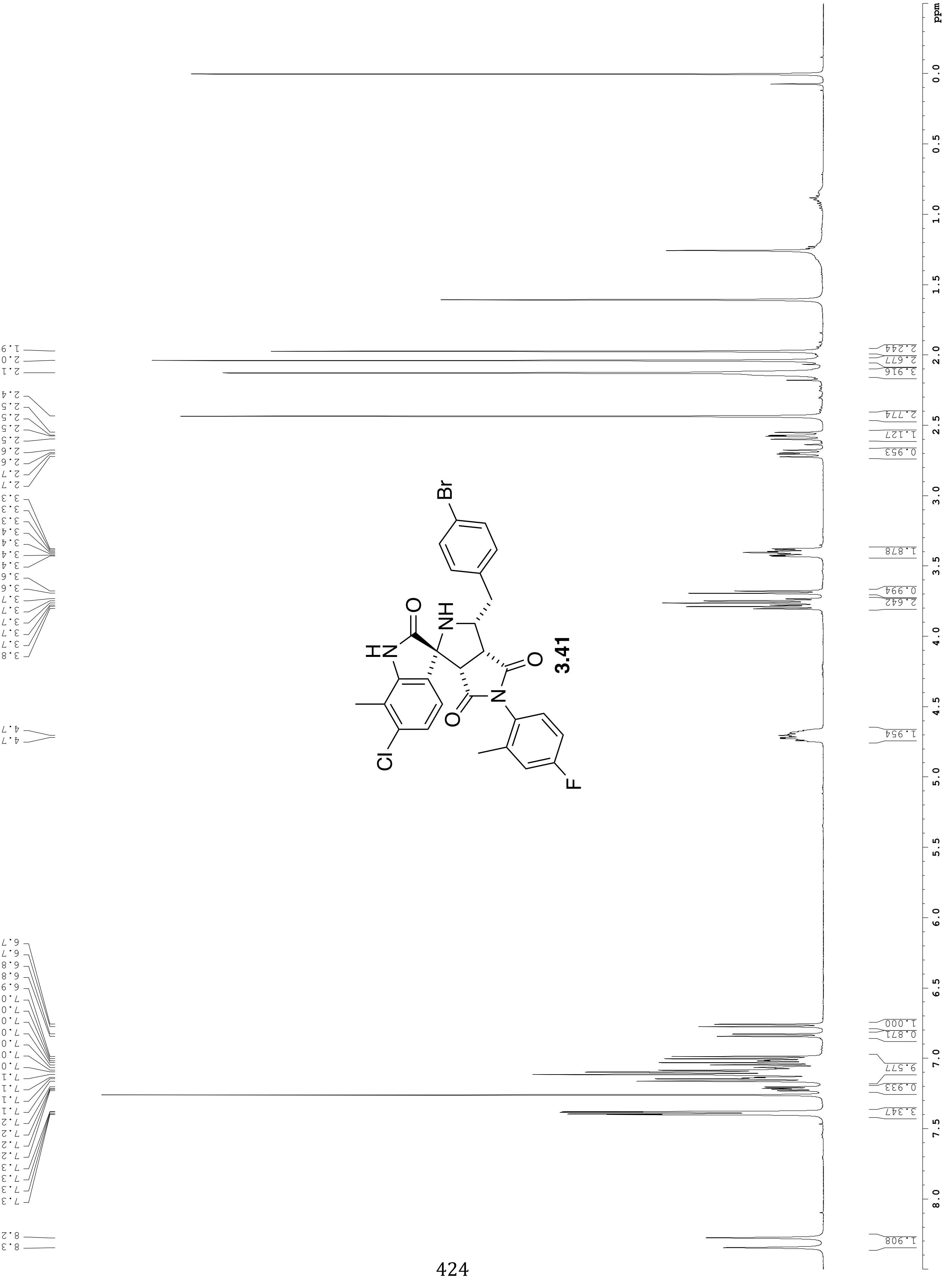
3.39


2.262
3.512
3.527
3.864
3.881
3.897
4.296
4.304
5.519
5.527
5.536
5.544
6.982
6.998
7.037
7.053
7.205
7.218
7.228
7.235
7.241
7.246
7.279
7.294
7.303
7.308
7.320
7.338
7.469
7.484
10.730
3.021
1.016
1.062
0.992
1.018
2.061
2.886
3.945
2.018
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
O
NH
HN
O
O
N
Cl
F

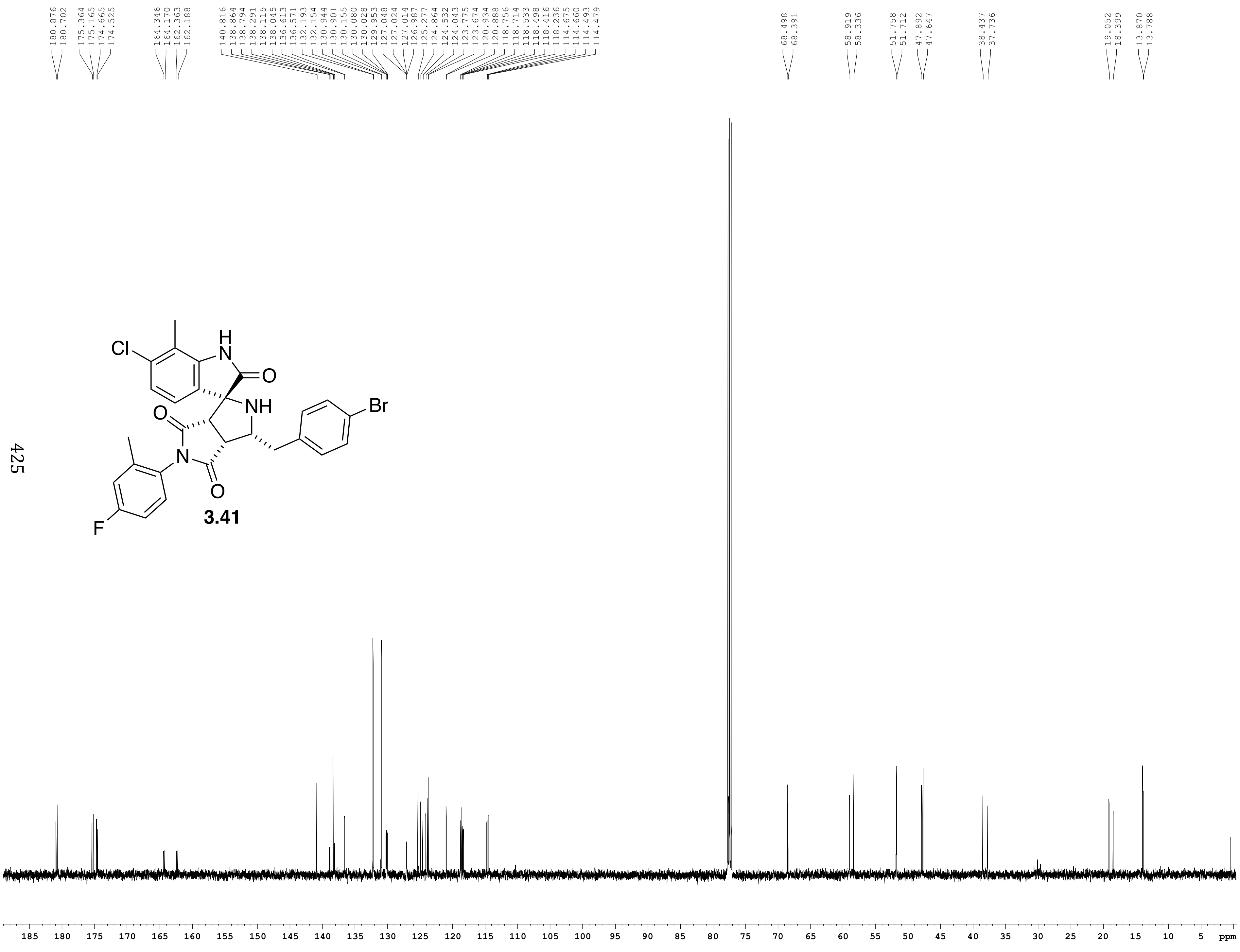
3.40


13.813
49.914
51.376
60.139
67.834
115.817
115.998
116.806
121.428
125.405
126.070
127.287
127.493
127.772
128.542
128.565
128.997
129.068
134.035
139.441
142.408
160.414
162.364
173.678
174.326
181.382
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
O
NH
HN
O
N
O
Cl
F

**3.40**

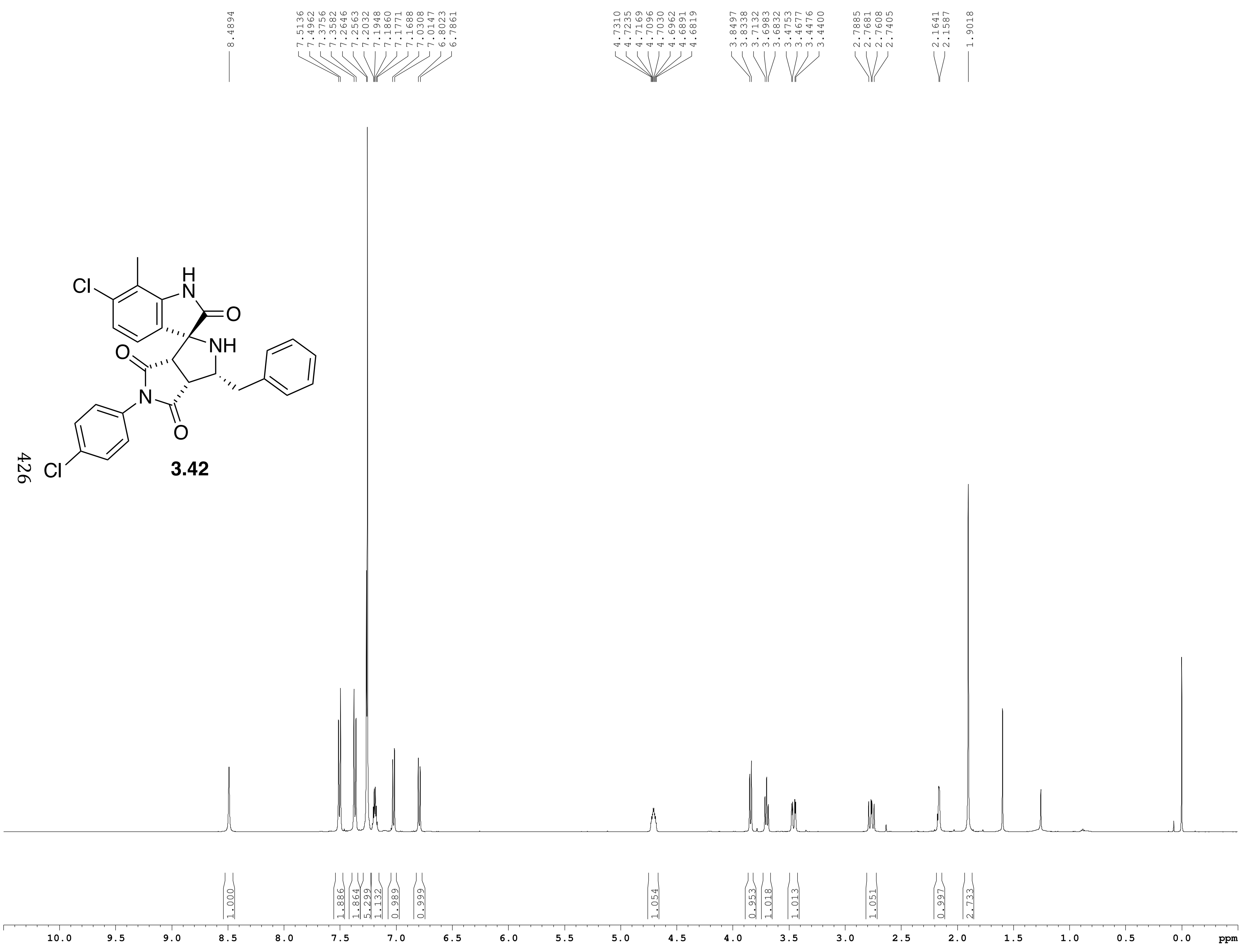

**3.41**

ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
1.9726
2.0379
2.1263
2.4343
2.5494
2.5705
2.5768
2.5981
2.6752
2.6952
2.7028
2.7230
3.3764
3.3853
3.3956
3.4034
3.4130
3.4232
3.4299
3.6772
3.6932
3.7327
3.7470
3.7620
3.7773
3.7876
3.8035
4.7036
4.7196
6.7577
6.7740
6.8271
6.8434
6.9864
7.0027
7.0188
7.0302
7.0465
7.0651
7.0846
7.0976
7.1144
7.1345
7.1456
7.1622
7.2032
7.2135
7.2199
7.2302
7.3782
7.3830
7.3949
7.3997
8.2759
8.3459
2.244
2.677
3.916
2.774
1.127
0.953
1.878
0.994
2.642
1.954
1.000
0.871
9.577
0.933
3.347
1.908
Br
NH
O
H
N
O
N
O
Cl
F

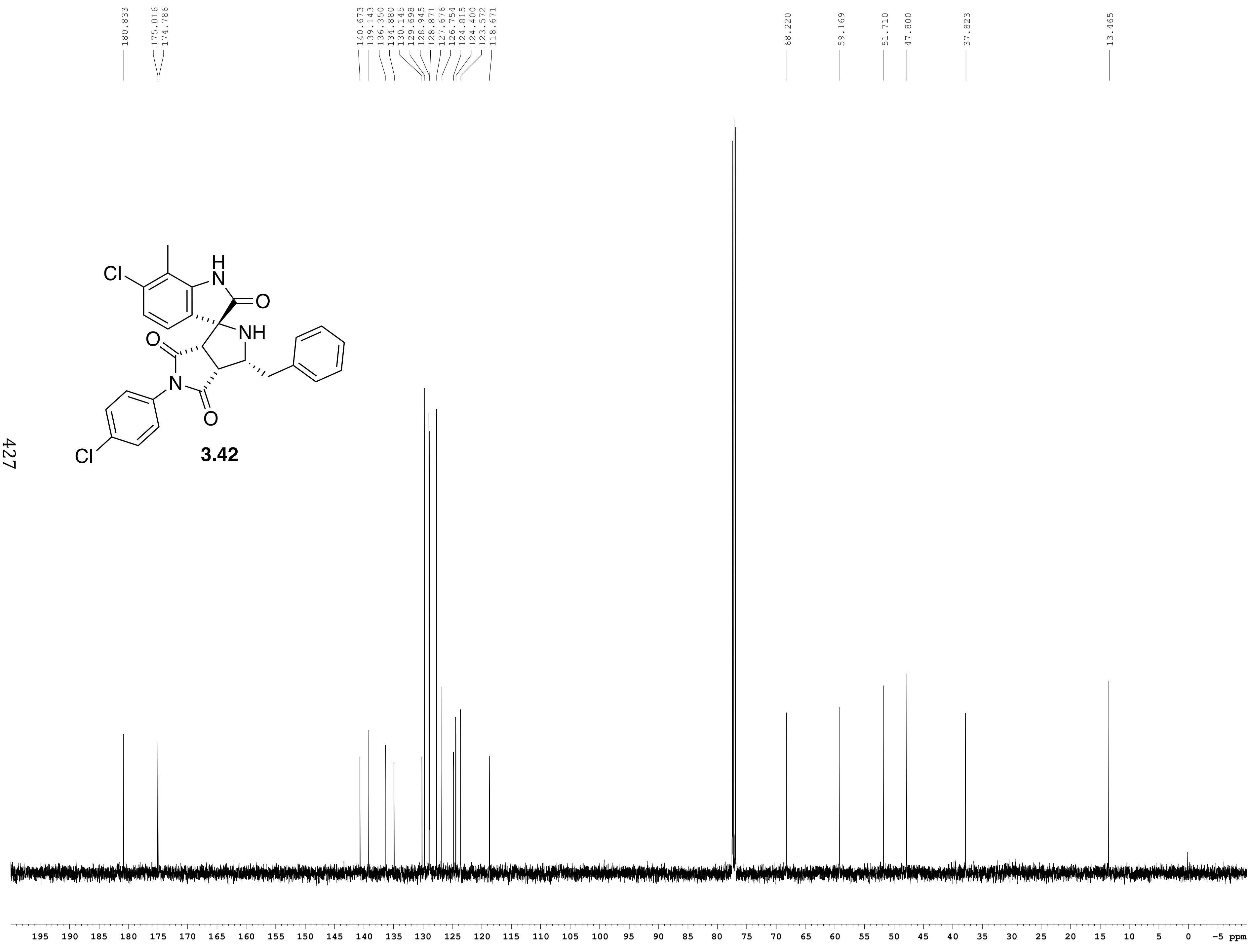


**3.41**

180.876
180.702
175.364
175.165
174.665
174.525
164.346
164.170
162.363
162.188
140.816
138.864
138.794
138.291
138.115
138.045
136.613
136.571
132.193
132.154
130.944
130.901
130.155
130.080
130.028
129.953
127.048
127.024
127.014
126.987
125.277
124.864
124.532
124.043
123.775
123.674
120.934
120.888
118.756
118.714
118.533
118.498
118.416
118.236
114.675
114.660
114.493
114.479
68.498
68.391
58.919
58.336
51.758
51.712
47.892
47.647
38.437
37.736
19.052
18.399
13.870
13.788
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
ppm

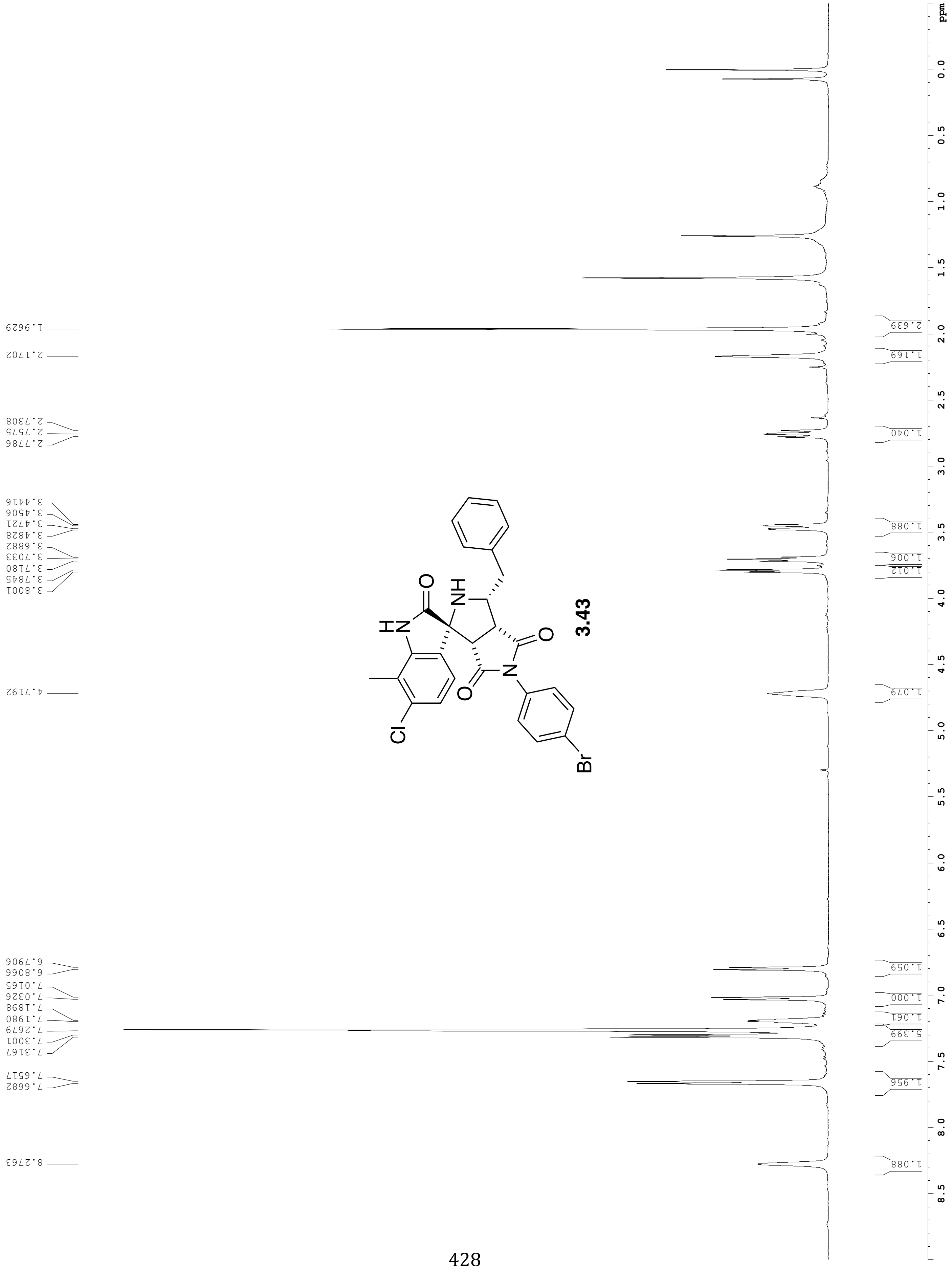

8.4894
7.5136
7.4962
7.3756
7.3582
7.2646
7.2563
7.2032
7.1948
7.1860
7.1771
7.1688
7.0308
7.0147
6.8023
6.7861
4.7310
4.7235
4.7169
4.7096
4.7030
4.6962
4.6891
4.6819
3.8497
3.8338
3.7132
3.6983
3.6832
3.4753
3.4677
3.4476
3.4400
2.7885
2.7681
2.7608
2.7405
2.1641
2.1587
1.9018
Cl
H
N
O
NH
O
N
O
Cl
1.000
1.886
1.864
5.299
1.132
0.989
0.999
1.054
0.953
1.018
1.013
1.051
0.997
2.733
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

**3.42**

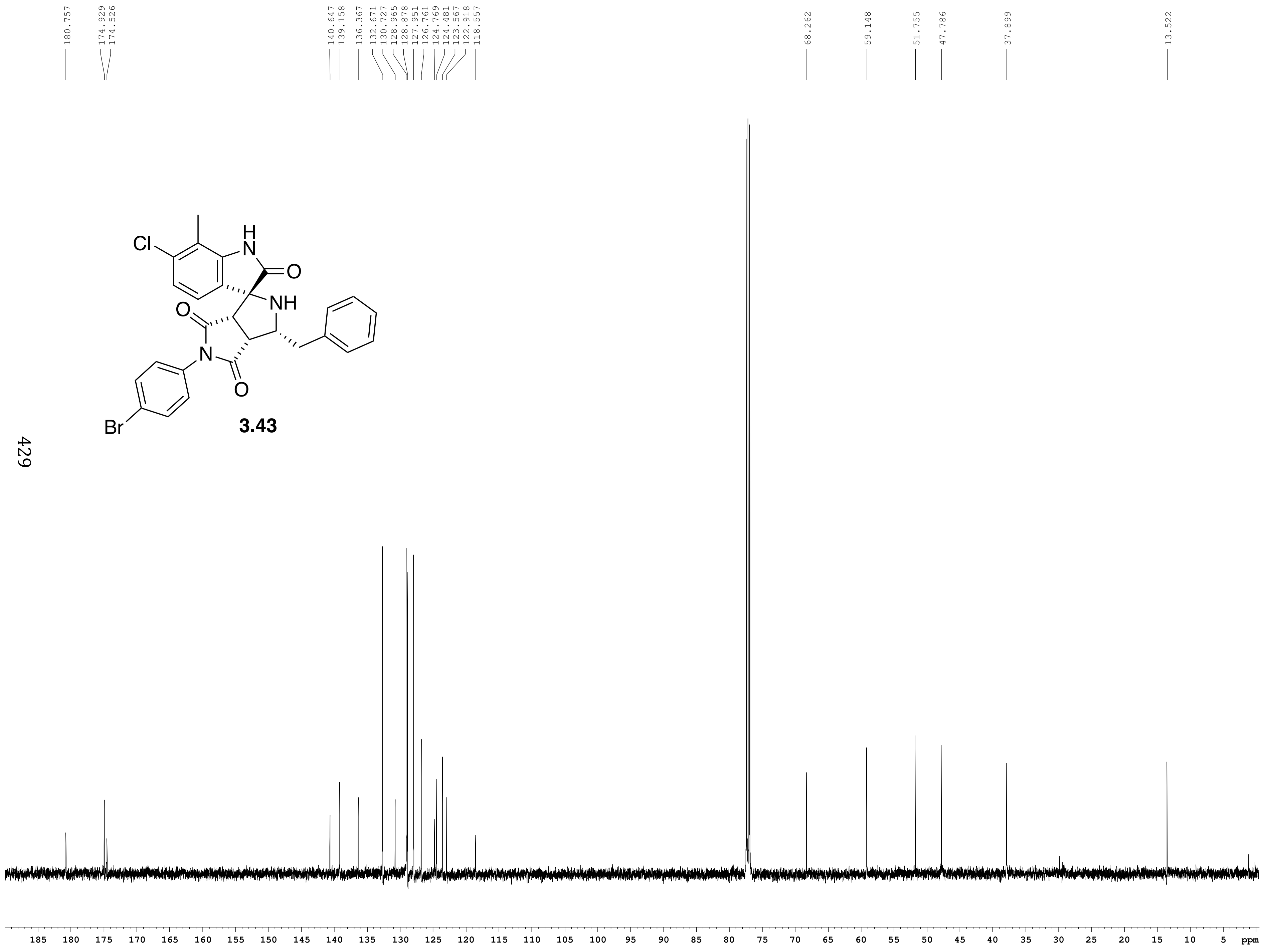


**3.42**

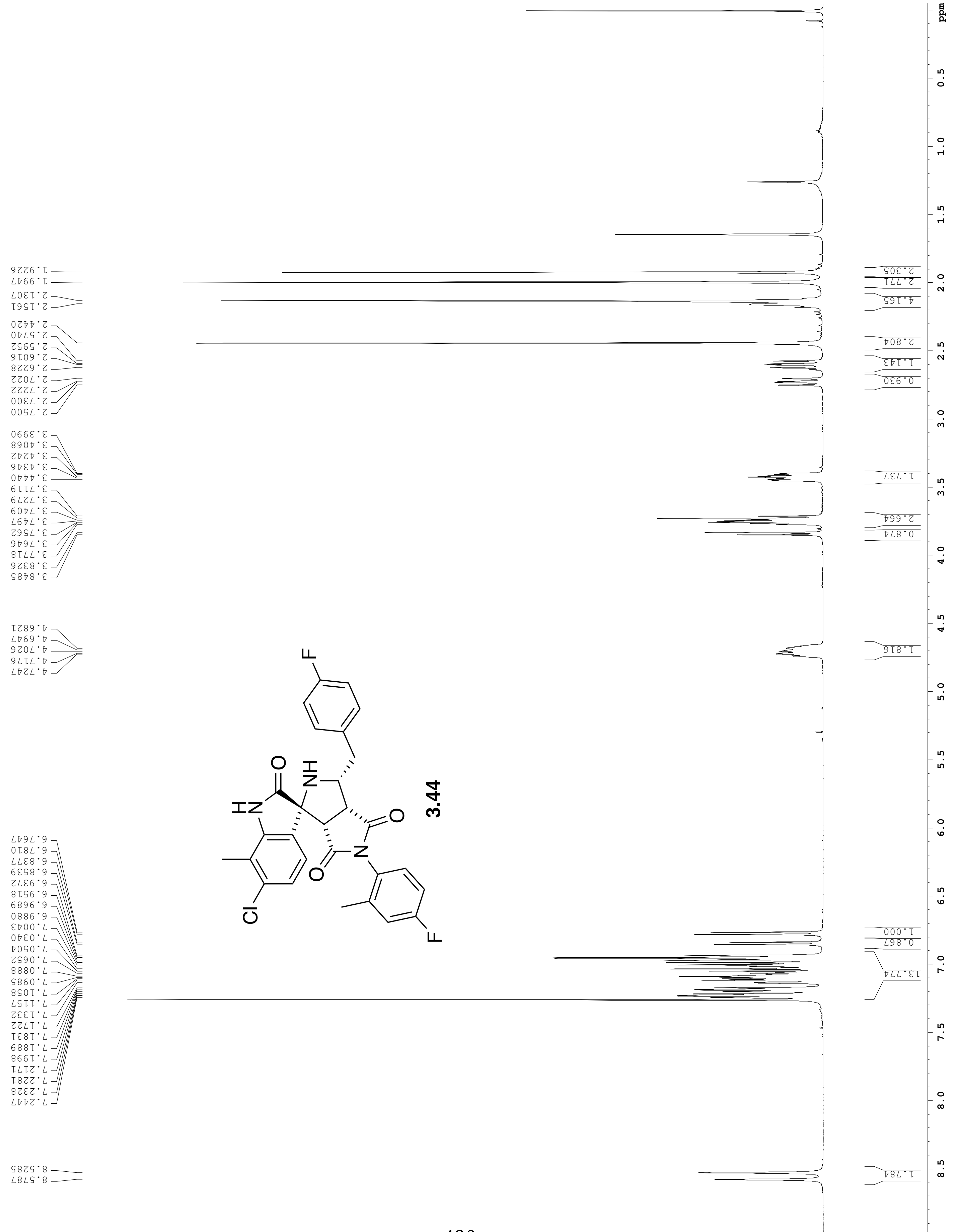
180.833
175.016
174.786
140.673
139.143
136.350
134.880
130.145
129.698
128.945
128.871
127.676
126.754
124.815
124.400
123.572
118.671
68.220
59.169
51.710
47.800
37.823
13.465
Cl
H
N
O
NH
O
N
O
Cl
195 190 185 180 175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 −5 ppm


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
1.9629
2.1702
2.7308
2.7575
2.7786
3.4416
3.4506
3.4721
3.4828
3.6882
3.7033
3.7180
3.7845
3.8001
4.7192
6.7906
6.8066
7.0165
7.0326
7.1898
7.1980
7.2679
7.3001
7.3167
7.6517
7.6682
8.2763
2.639
1.169
1.040
1.088
1.006
1.012
1.079
1.059
1.000
1.061
5.399
1.956
1.088
O
NH
HN
Cl
O
N
O
Br

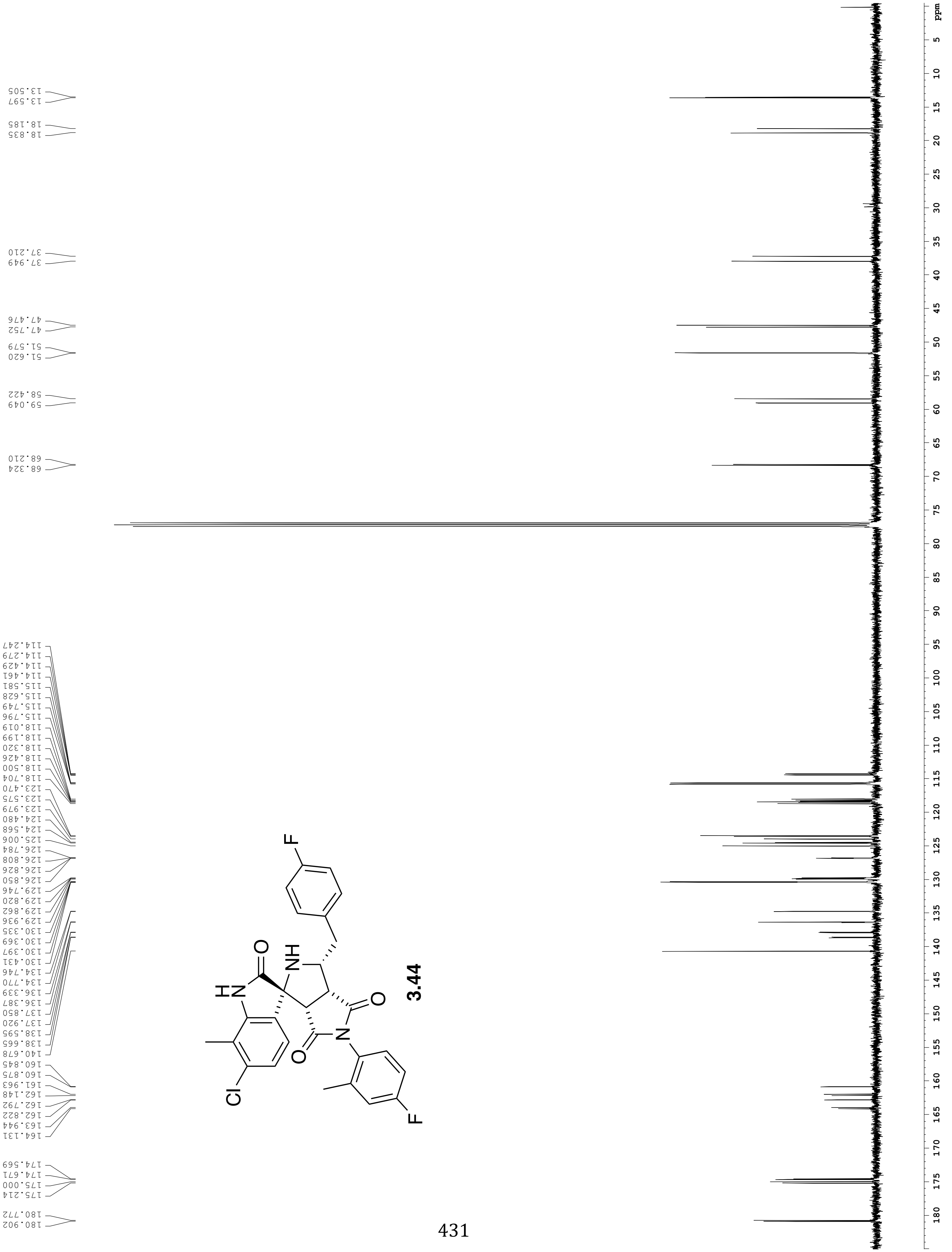
**3.43**


180.757
174.929
174.526
140.647
139.158
136.367
132.671
130.727
128.965
128.878
127.951
126.761
124.769
124.481
123.567
122.918
118.557
68.262
59.148
51.755
47.786
37.899
13.522
Cl
H
N
O
NH
O
N
O
Br
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
ppm

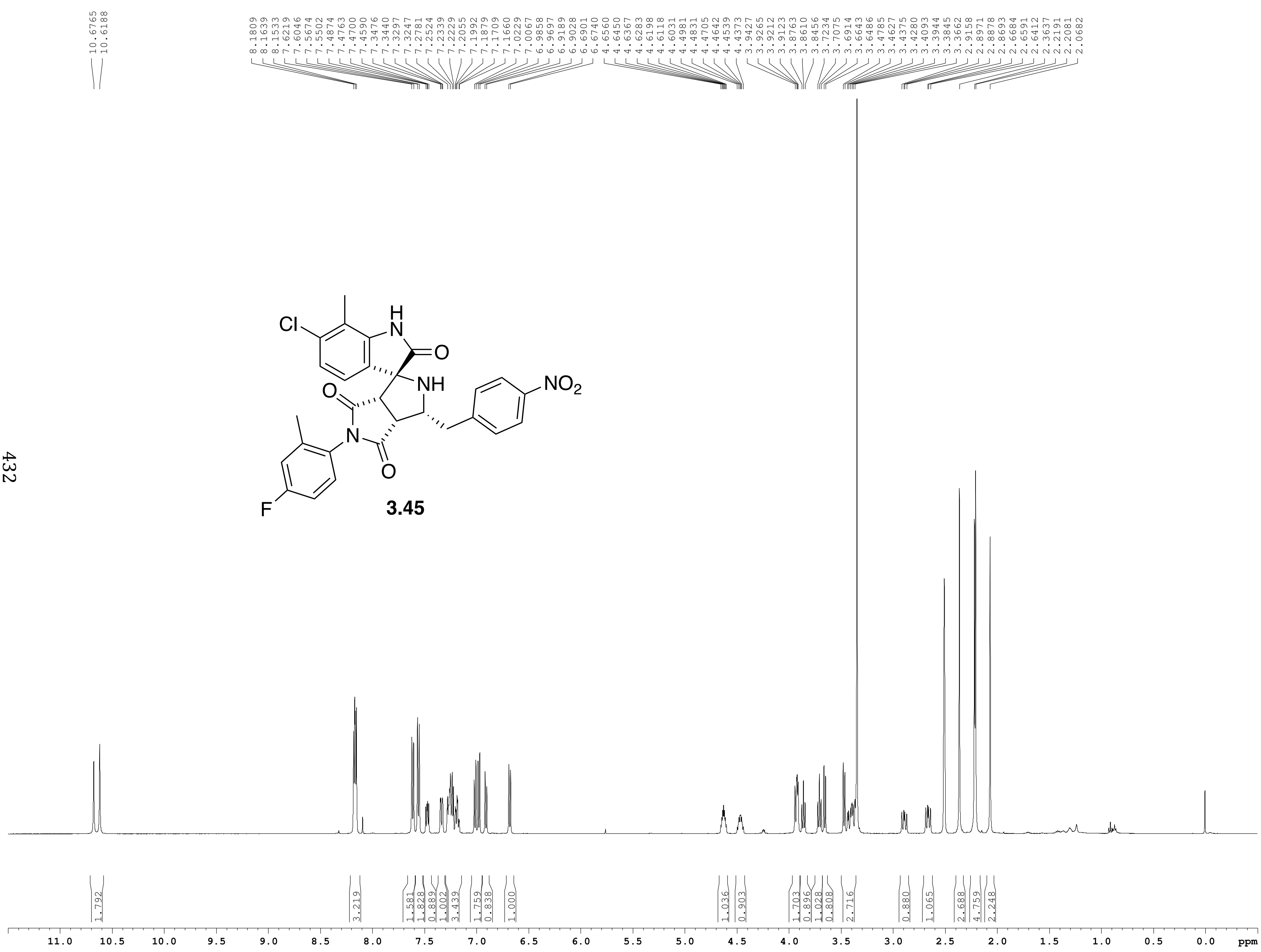
**3.43**


1.9226
1.9947
2.1307
2.1561
2.4420
2.5740
2.5952
2.6016
2.6228
2.7022
2.7222
2.7300
2.7500
3.3990
3.4068
3.4242
3.4346
3.4440
3.7119
3.7279
3.7409
3.7497
3.7562
3.7646
3.7718
3.8326
3.8485
4.6821
4.6947
4.7026
4.7176
4.7247
6.7647
6.7810
6.8377
6.8539
6.9372
6.9518
6.9689
6.9880
7.0043
7.0340
7.0504
7.0652
7.0888
7.0985
7.1058
7.1157
7.1332
7.1722
7.1831
7.1889
7.1998
7.2171
7.2281
7.2328
7.2447
8.5285
8.5787
2.305
2.771
4.165
2.804
1.143
0.930
1.737
2.664
0.874
1.816
1.000
0.867
13.774
1.784
ppm
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
F
O
NH
H
N
O
N
O
Cl
F

**3.44**

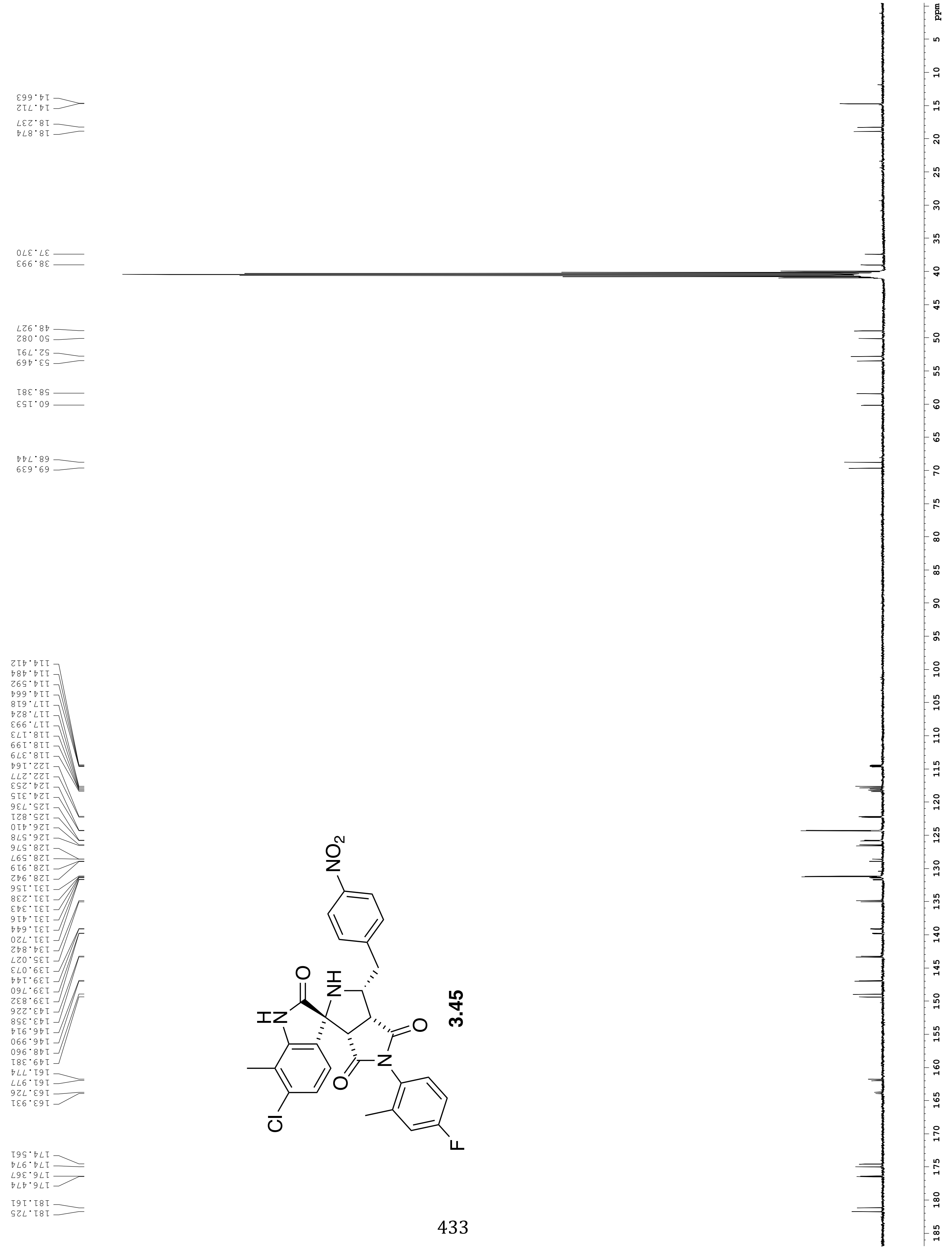

13.505
13.597
18.185
18.835
37.210
37.949
47.476
47.752
51.579
51.620
58.422
59.049
68.210
68.324
114.247
114.279
114.429
114.461
115.581
115.628
115.749
115.796
118.019
118.199
118.320
118.426
118.500
118.704
123.470
123.575
123.979
124.480
124.568
125.006
126.784
126.808
126.826
126.850
129.746
129.820
129.862
129.936
130.335
130.369
130.397
130.431
134.746
134.770
136.339
136.387
137.850
137.920
138.595
138.665
140.678
160.845
160.875
161.963
162.148
162.792
162.822
163.944
164.131
174.569
174.671
175.000
175.214
180.772
180.902
ppm
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
F
O
NH
HN
O
N
O
Cl
F

**3.44**

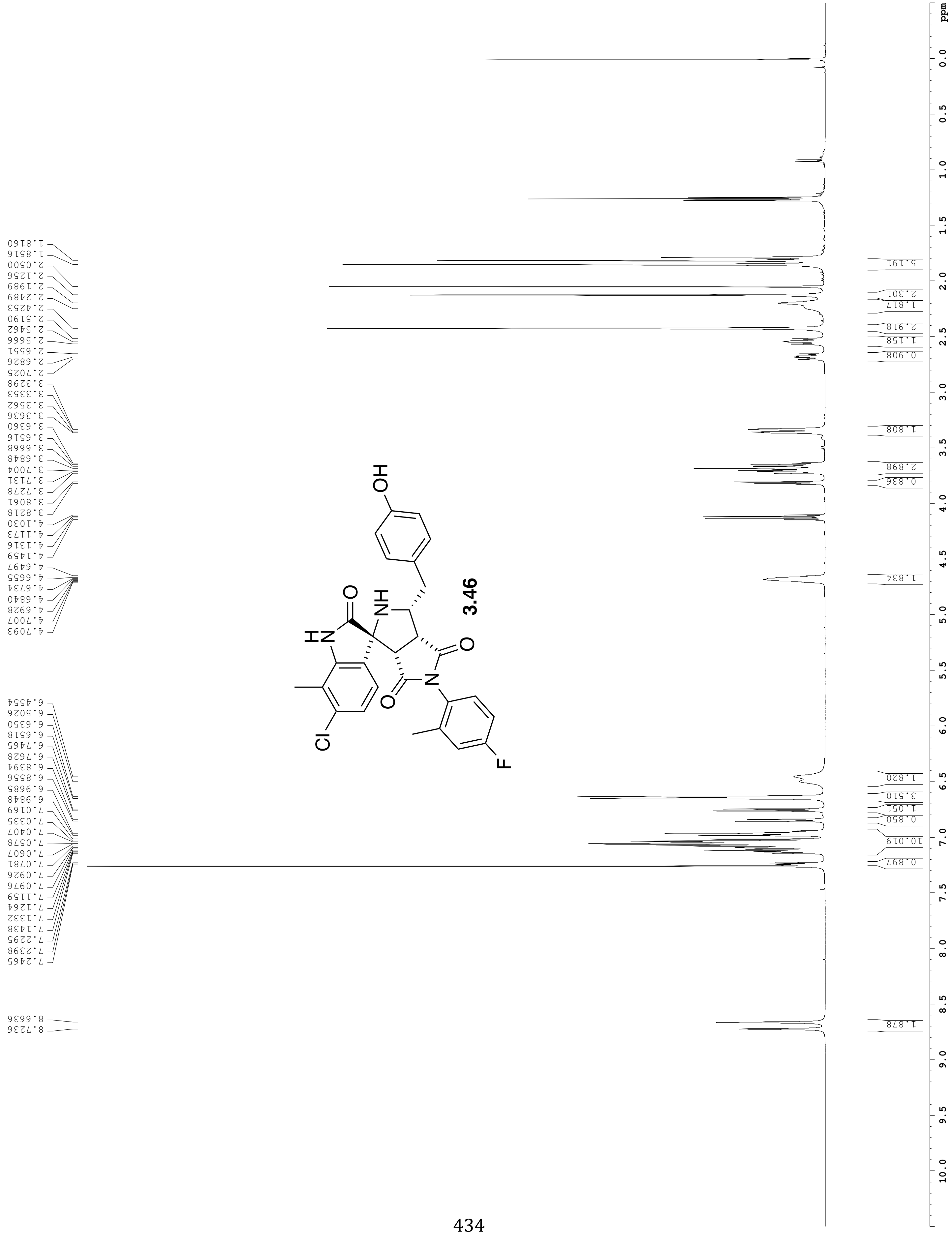


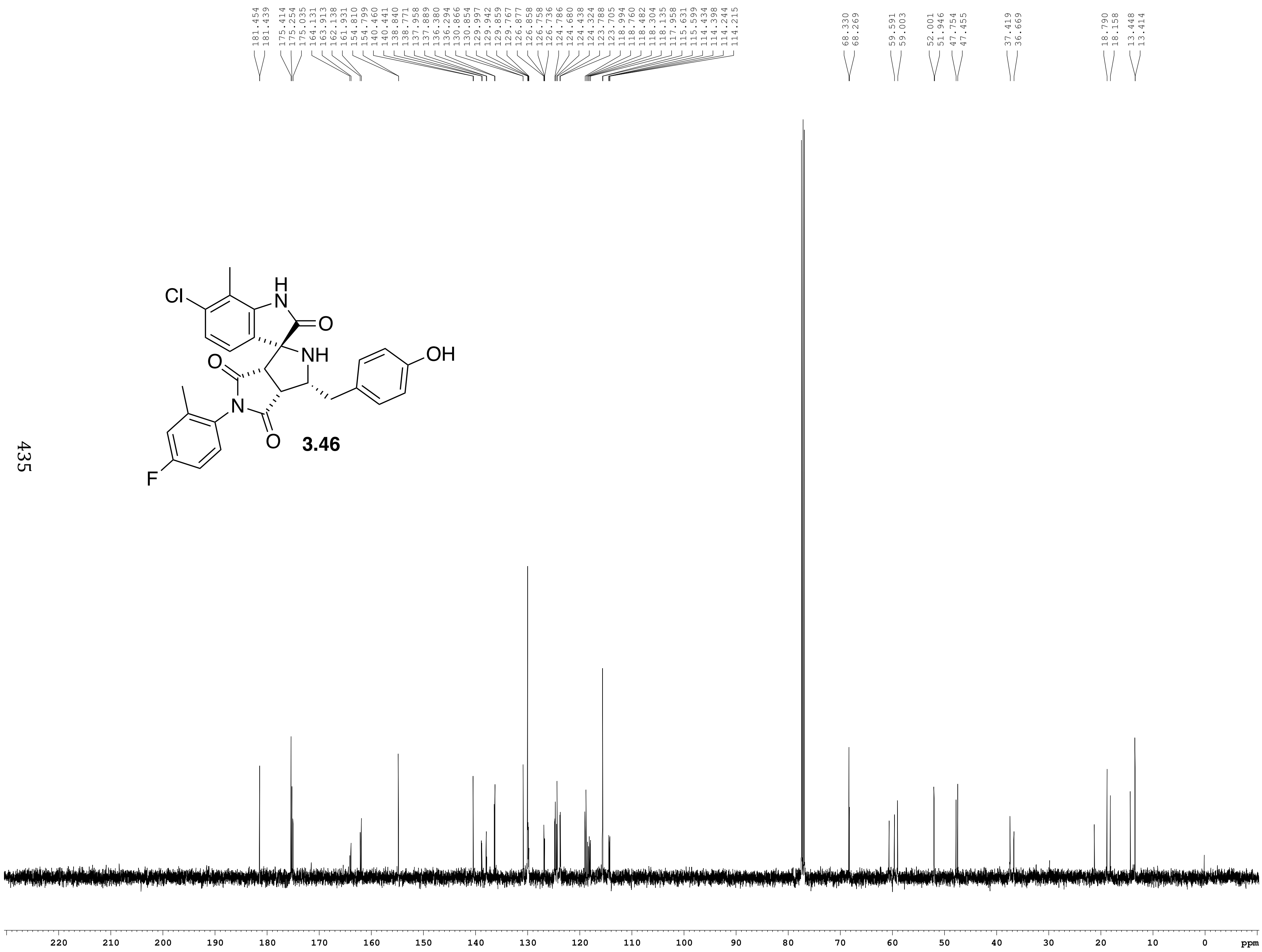
3.45

10.6765
10.6188
8.1809
8.1639
8.1533
7.6219
7.6046
7.5674
7.5502
7.4874
7.4763
7.4700
7.4590
7.3476
7.3440
7.3297
7.3247
7.2781
7.2524
7.2339
7.2229
7.2055
7.1992
7.1879
7.1709
7.1660
7.0229
7.0067
6.9858
6.9697
6.9189
6.9028
6.6901
6.6740
4.6560
4.6450
4.6367
4.6283
4.6198
4.6118
4.6031
4.4981
4.4831
4.4705
4.4642
4.4539
4.4373
3.9427
3.9265
3.9212
3.9123
3.8763
3.8610
3.8456
3.7234
3.7075
3.6914
3.6643
3.6486
3.4785
3.4627
3.4375
3.4280
3.4093
3.3944
3.3845
3.3662
2.9158
2.8971
2.8878
2.8693
2.6684
2.6591
2.6412
2.3637
2.2191
2.2081
2.0682
Cl
H
N
O
NH
NO2
O
N
O
F
1.792
3.219
1.581
1.828
0.889
1.002
3.439
1.759
0.838
1.000
1.036
0.903
1.703
0.896
1.028
0.808
2.716
0.880
1.065
2.688
4.759
2.248
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm


14.663
14.712
18.237
18.874
37.370
38.993
48.927
50.082
52.791
53.469
58.381
60.153
68.744
69.639
114.412
114.484
114.592
114.664
117.618
117.824
117.993
118.173
118.199
118.379
122.164
122.277
124.253
124.315
125.736
125.821
126.410
126.578
128.576
128.597
128.919
128.942
131.156
131.238
131.343
131.416
131.644
131.720
134.842
135.027
139.073
139.144
139.760
139.832
143.226
143.358
146.914
146.990
148.960
149.381
161.774
161.977
163.726
163.931
174.561
174.974
176.367
176.474
181.161
181.725
ppm
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
$NO_2$
O
NH
H
N
O
N
O
Cl
F

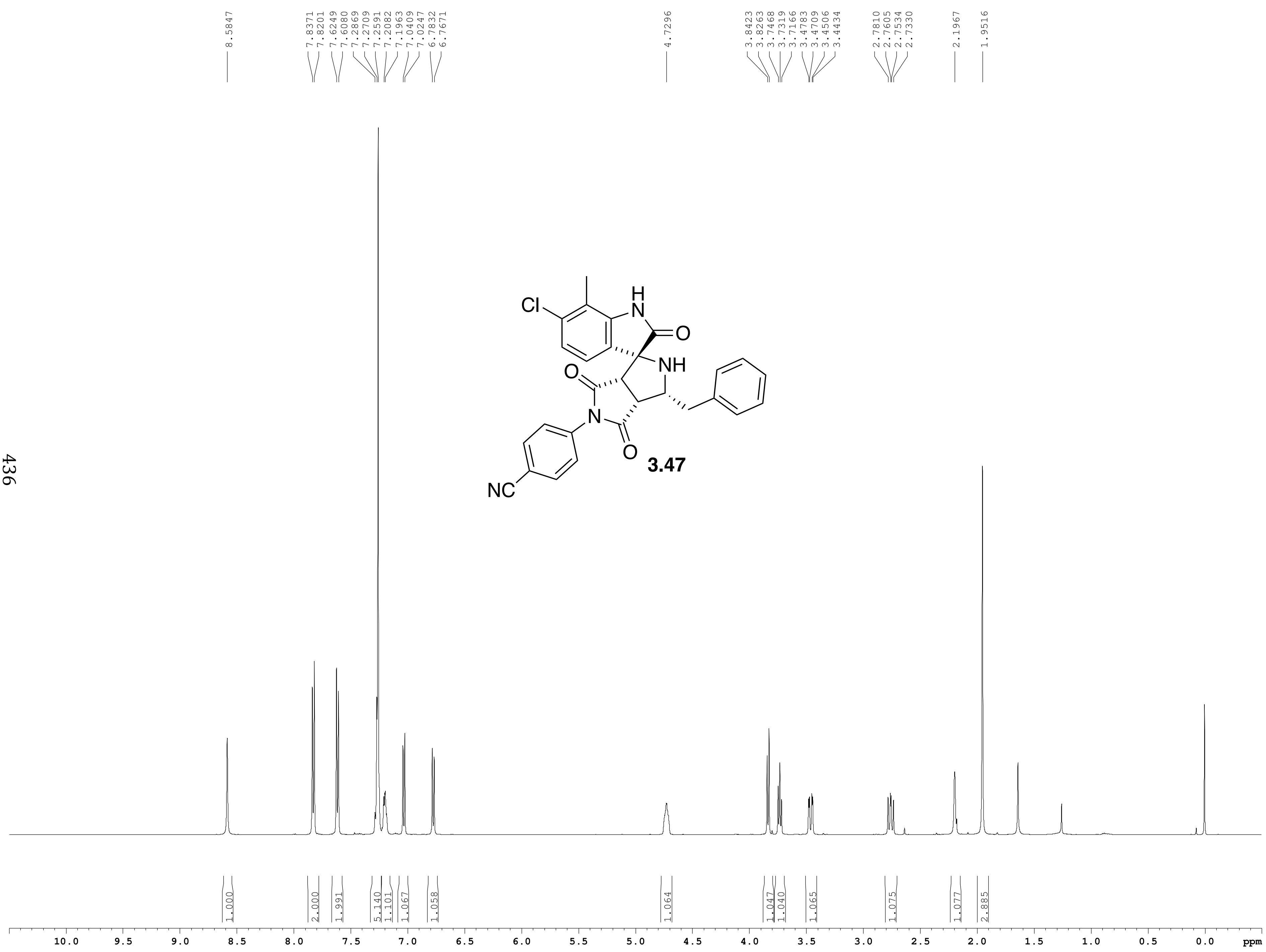
**3.45**

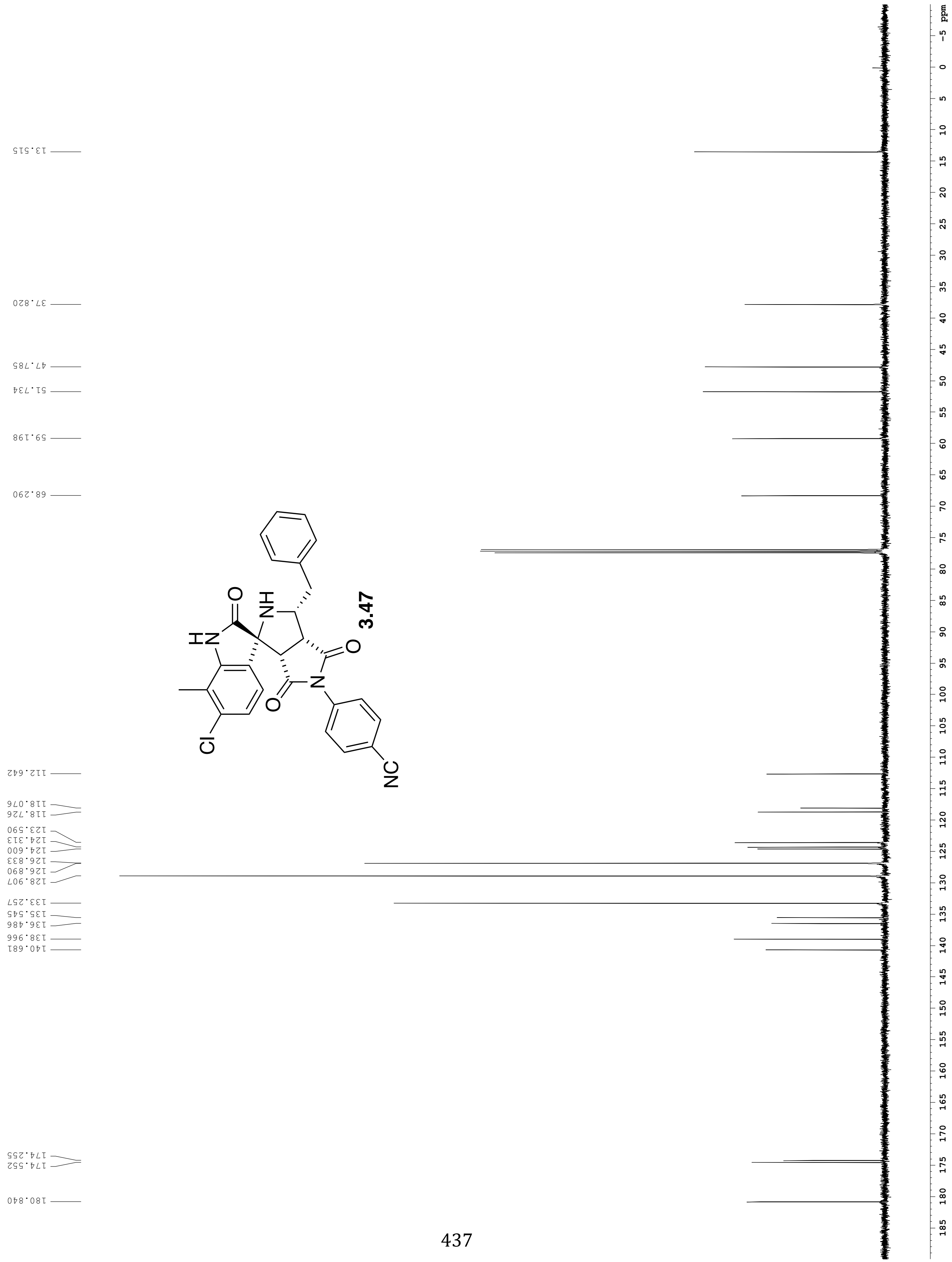

1.8160
1.8516
2.0500
2.1256
2.1989
2.2489
2.4253
2.5190
2.5462
2.5666
2.6551
2.6826
2.7025
3.3298
3.3353
3.3562
3.3636
3.6360
3.6516
3.6668
3.6848
3.7004
3.7131
3.7278
3.8061
3.8218
4.1030
4.1173
4.1316
4.1459
4.6497
4.6655
4.6734
4.6840
4.6928
4.7007
4.7093
6.4554
6.5026
6.6350
6.6518
6.7465
6.7628
6.8394
6.8556
6.9685
6.9848
7.0169
7.0335
7.0407
7.0578
7.0607
7.0781
7.0926
7.0976
7.1159
7.1264
7.1332
7.1438
7.2295
7.2398
7.2465
8.6636
8.7236
5.191
2.301
1.817
2.918
1.158
0.908
1.808
2.898
0.836
1.834
1.820
3.510
1.051
0.850
10.019
0.897
1.878
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
OH
O
NH
H
N
O
N
O
Cl
F
3.46



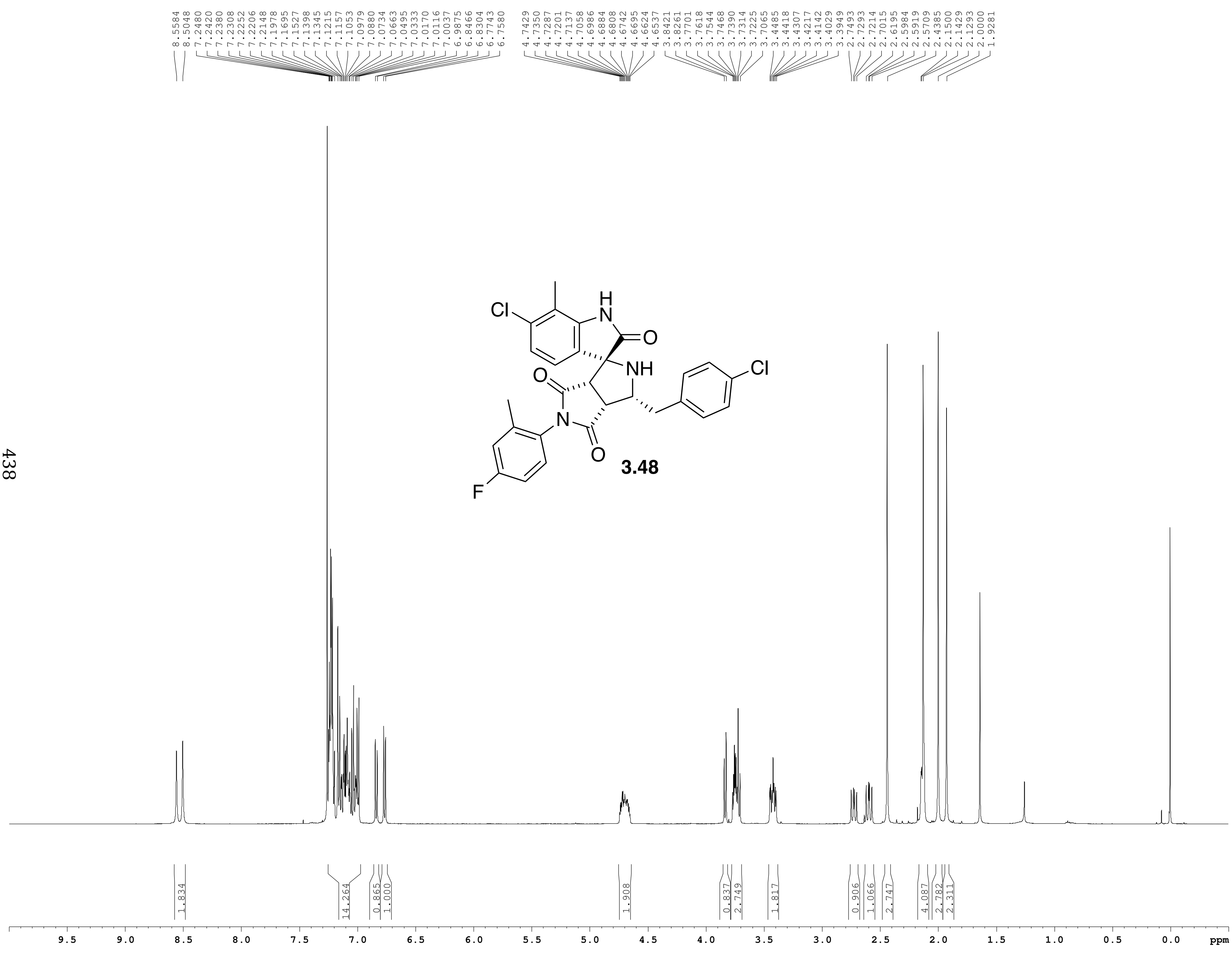
**3.46**

181.454
181.439
175.414
175.254
175.035
164.131
163.913
162.138
161.931
154.810
154.799
140.460
140.441
138.840
138.771
137.958
137.889
136.380
136.294
130.866
130.854
129.997
129.942
129.859
129.767
126.877
126.858
126.758
126.736
124.786
124.680
124.438
124.324
123.788
123.705
118.994
118.760
118.482
118.304
118.135
117.958
115.631
115.599
114.434
114.398
114.244
114.215
68.330
68.269
59.591
59.003
52.001
51.946
47.754
47.455
37.419
36.669
18.790
18.158
13.448
13.414
Cl
H
N
O
NH
OH
O
N
O
F
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

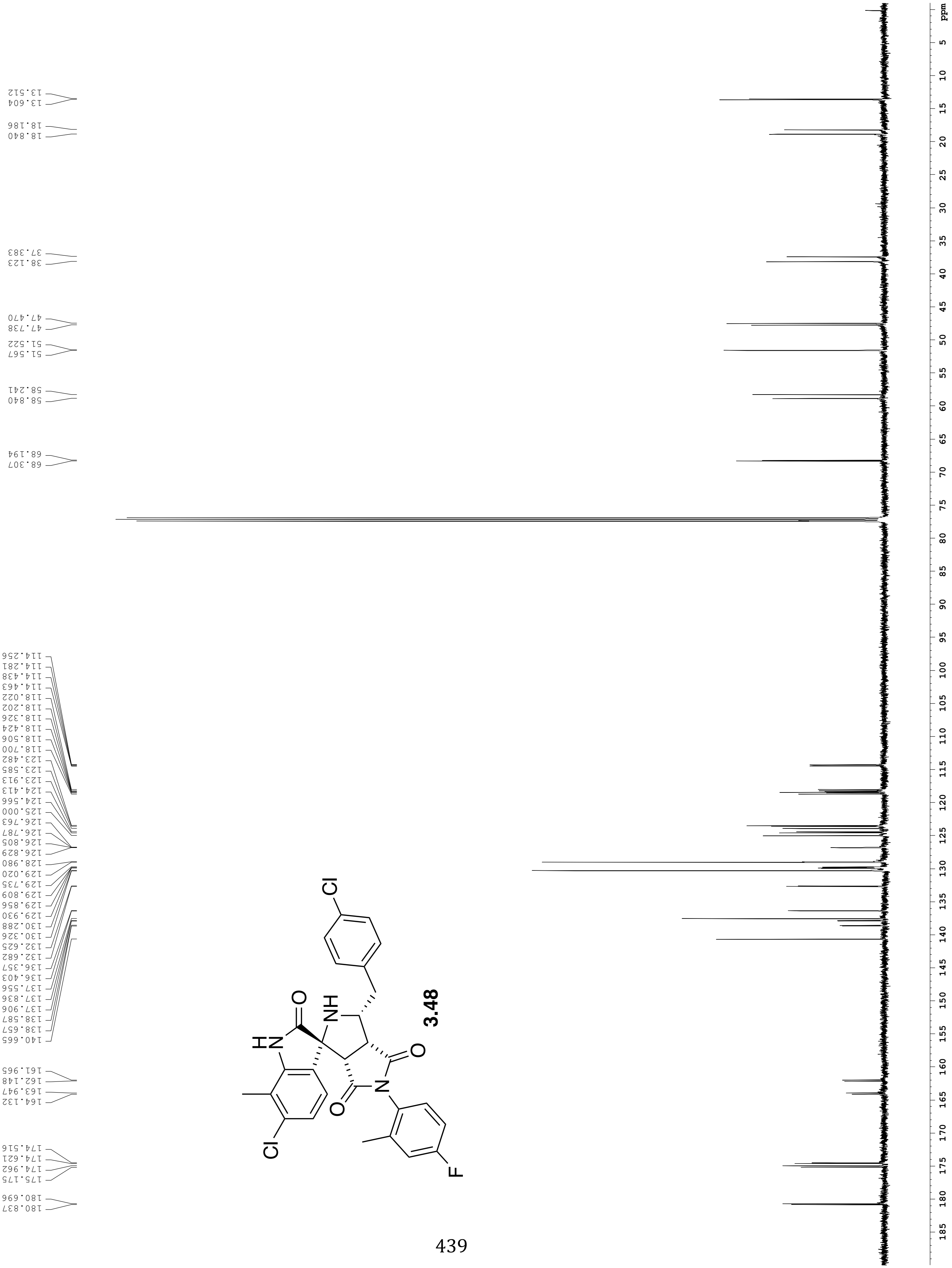

8.5847
7.8371
7.8201
7.6249
7.6080
7.2869
7.2709
7.2591
7.2082
7.1963
7.0409
7.0247
6.7832
6.7671
4.7296
3.8423
3.8263
3.7468
3.7319
3.7166
3.4783
3.4709
3.4506
3.4434
2.7810
2.7605
2.7534
2.7330
2.1967
1.9516
Cl
H
N
O
NH
O
N
O
NC
3.47
1.000
2.000
1.991
5.140
1.101
1.067
1.058
1.064
1.047
1.040
1.065
1.075
1.077
2.885
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm


13.515
37.820
47.785
51.734
59.198
68.290
112.642
118.076
118.726
123.590
124.313
124.600
126.833
126.890
128.907
133.257
135.545
136.486
138.966
140.681
174.255
174.552
180.840
NH
O
H
N
Cl
O
N
O
NC
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185

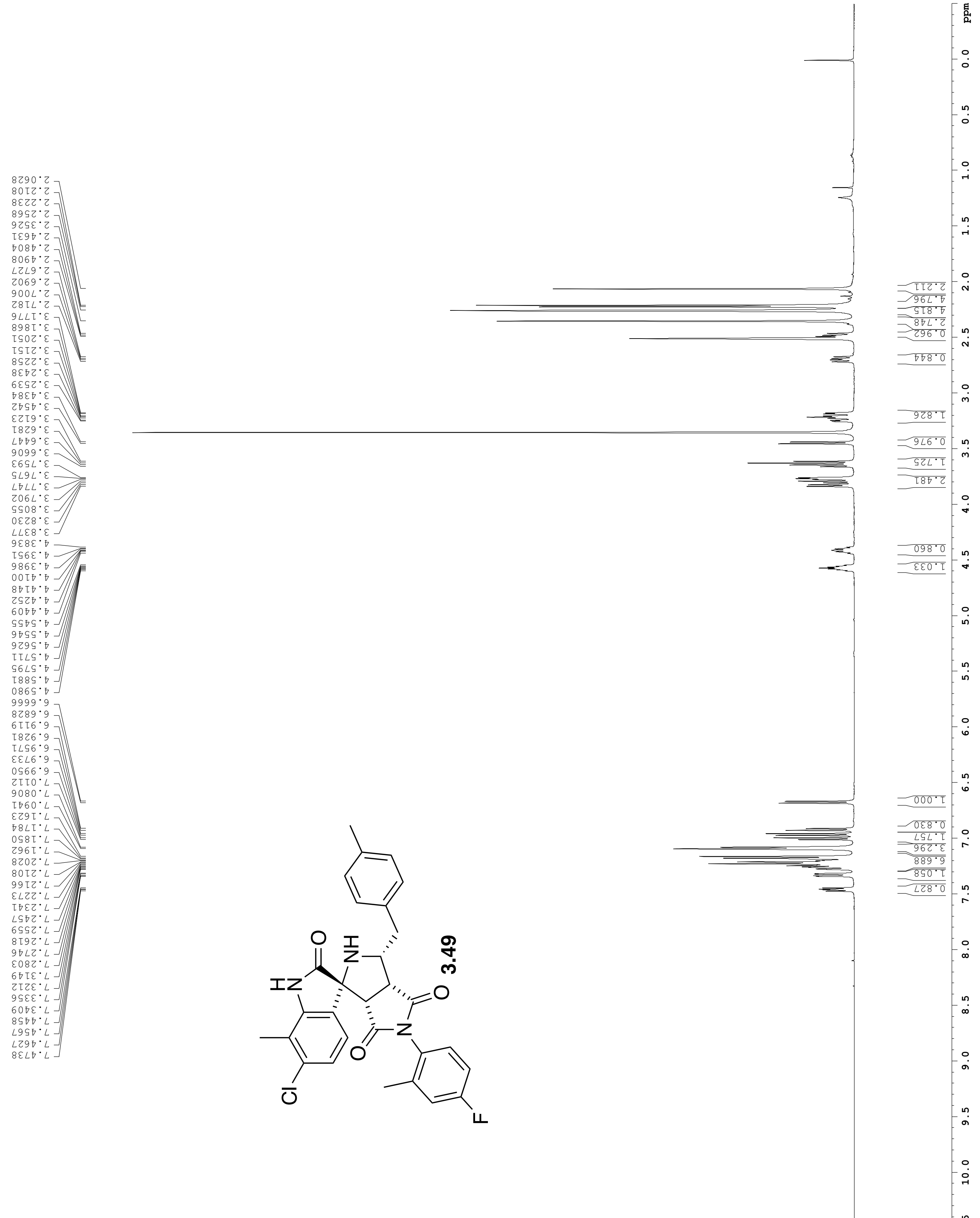
**3.47**

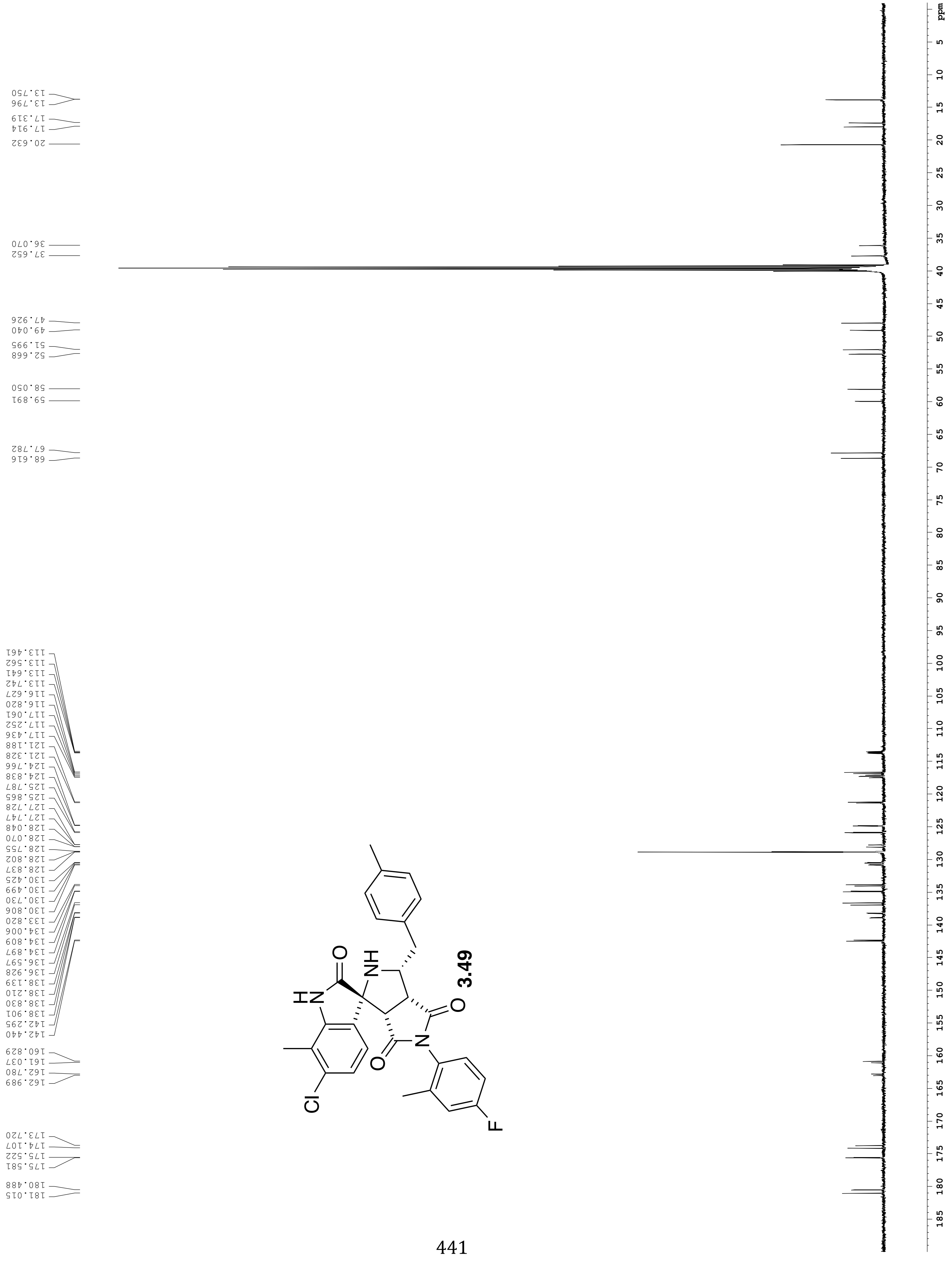

8.5584
8.5048
7.2480
7.2420
7.2380
7.2308
7.2252
7.2206
7.2148
7.1978
7.1695
7.1527
7.1398
7.1345
7.1215
7.1157
7.1053
7.0979
7.0880
7.0734
7.0663
7.0495
7.0333
7.0170
7.0116
7.0037
6.9875
6.8466
6.8304
6.7743
6.7580
4.7429
4.7350
4.7287
4.7201
4.7137
4.7058
4.6986
4.6884
4.6808
4.6742
4.6695
4.6624
4.6537
3.8421
3.8261
3.7701
3.7618
3.7544
3.7468
3.7390
3.7314
3.7225
3.7065
3.4485
3.4418
3.4307
3.4217
3.4142
3.4029
3.3949
2.7493
2.7293
2.7214
2.7015
2.6195
2.5984
2.5919
2.5709
2.4385
2.1500
2.1429
2.1293
2.0000
1.9281
Cl
H
N
O
NH
Cl
O
N
O
F
1.834
14.264
0.865
1.000
1.908
0.837
2.749
1.817
0.906
1.066
2.747
4.087
2.782
2.311
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

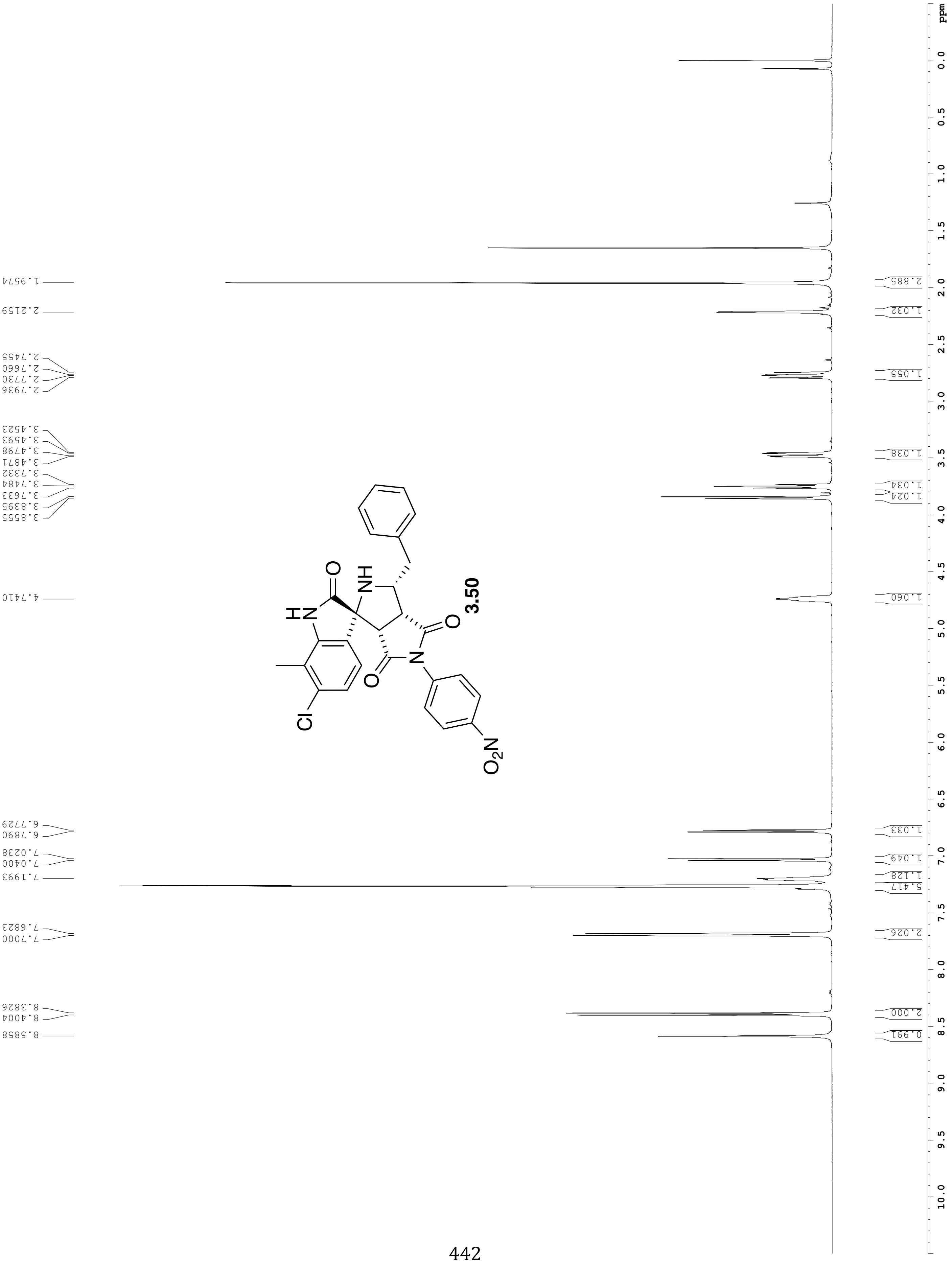
**3.48**

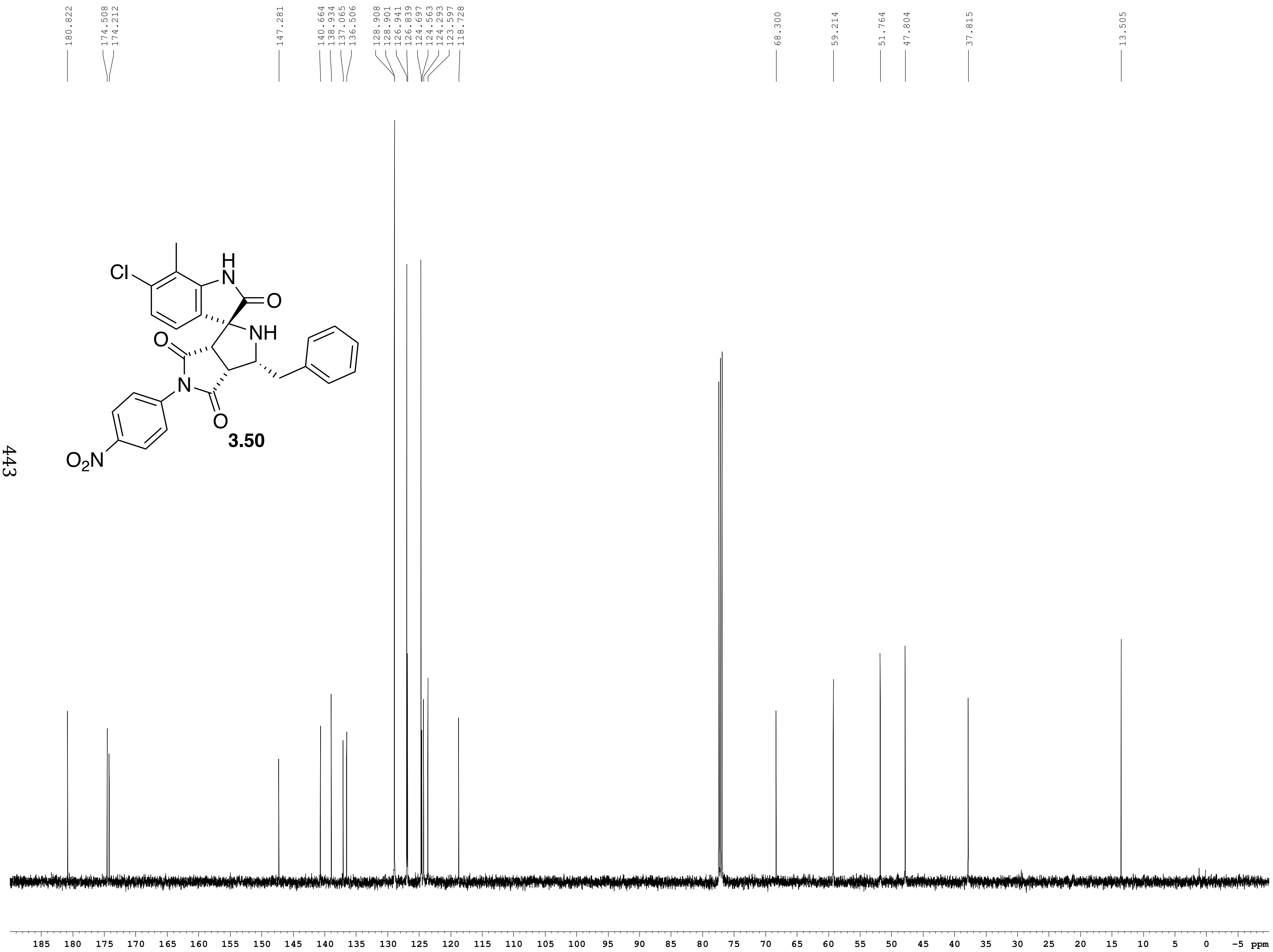

13.512
13.604
18.186
18.840
37.383
38.123
47.470
47.738
51.522
51.567
58.241
58.840
68.194
68.307
114.256
114.281
114.438
114.463
118.022
118.202
118.326
118.424
118.506
118.700
123.482
123.585
123.913
124.413
124.566
125.000
126.763
126.787
126.805
126.829
128.980
129.020
129.735
129.809
129.856
129.930
130.288
130.326
132.625
132.682
136.357
136.403
137.556
137.836
137.906
138.587
138.657
140.665
161.965
162.148
163.947
164.132
174.516
174.621
174.962
175.175
180.696
180.837
ppm
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
Cl
NH
O
H
N
O
O
N
Cl
F

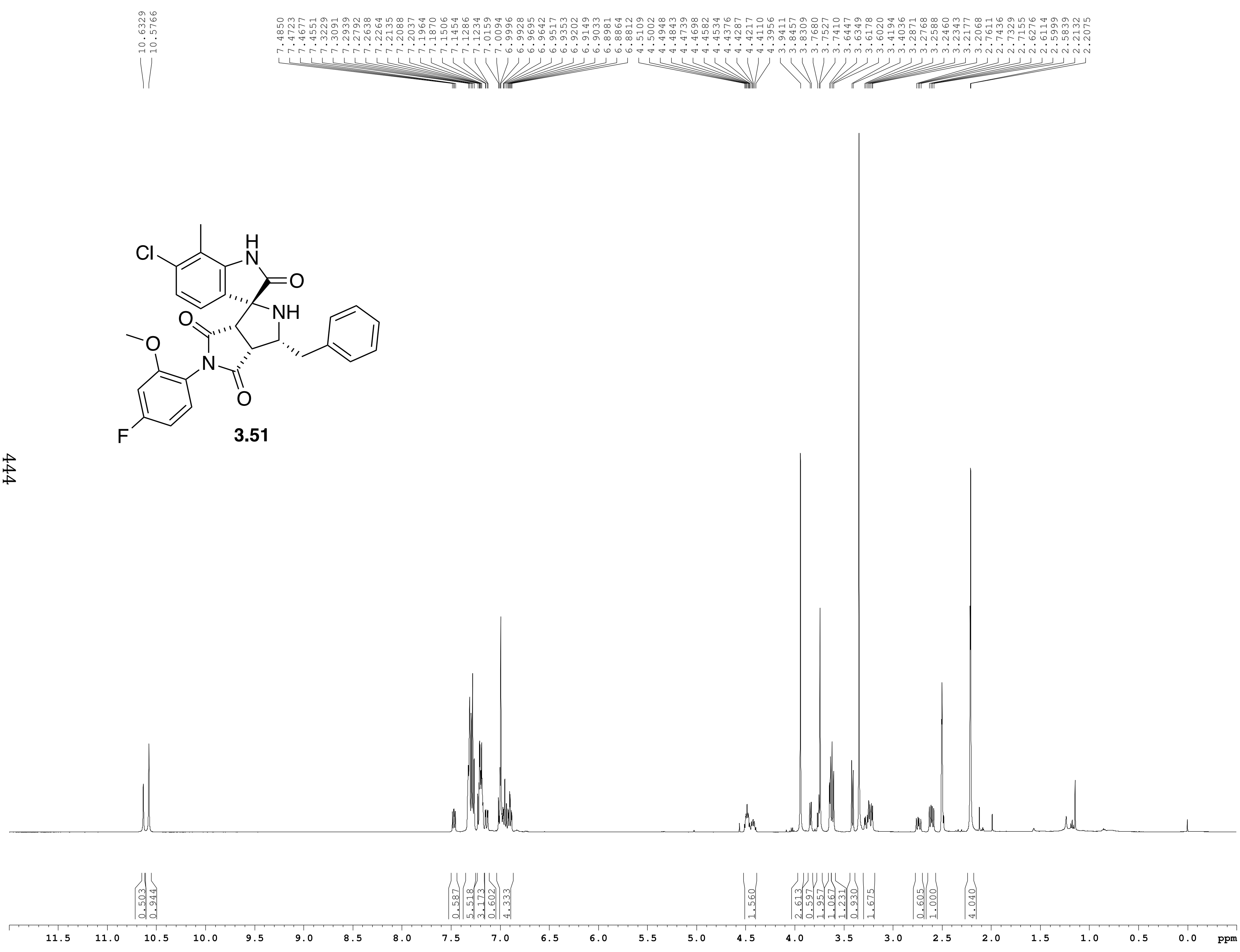
**3.48**


2.0628
2.2108
2.2238
2.2568
2.3526
2.4631
2.4804
2.4908
2.6727
2.6902
2.7006
2.7182
3.1776
3.1868
3.2051
3.2151
3.2258
3.2438
3.2539
3.4384
3.4542
3.6123
3.6281
3.6447
3.6606
3.7593
3.7675
3.7747
3.7902
3.8055
3.8230
3.8377
4.3836
4.3951
4.3986
4.4100
4.4148
4.4252
4.4409
4.5455
4.5546
4.5626
4.5711
4.5795
4.5881
4.5980
6.6666
6.6828
6.9119
6.9281
6.9571
6.9733
6.9950
7.0112
7.0806
7.0941
7.1623
7.1784
7.1850
7.1962
7.2028
7.2108
7.2166
7.2273
7.2341
7.2457
7.2559
7.2618
7.2746
7.2803
7.3149
7.3212
7.3356
7.3409
7.4458
7.4567
7.4627
7.4738
10.5914
10.6550
2.211
4.796
4.815
2.748
0.962
0.844
1.826
0.976
1.725
2.481
0.860
1.033
1.000
0.830
1.757
3.296
6.688
1.058
0.827
1.789
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
3.49
O
NH
H
N
O
N
O
Cl
F

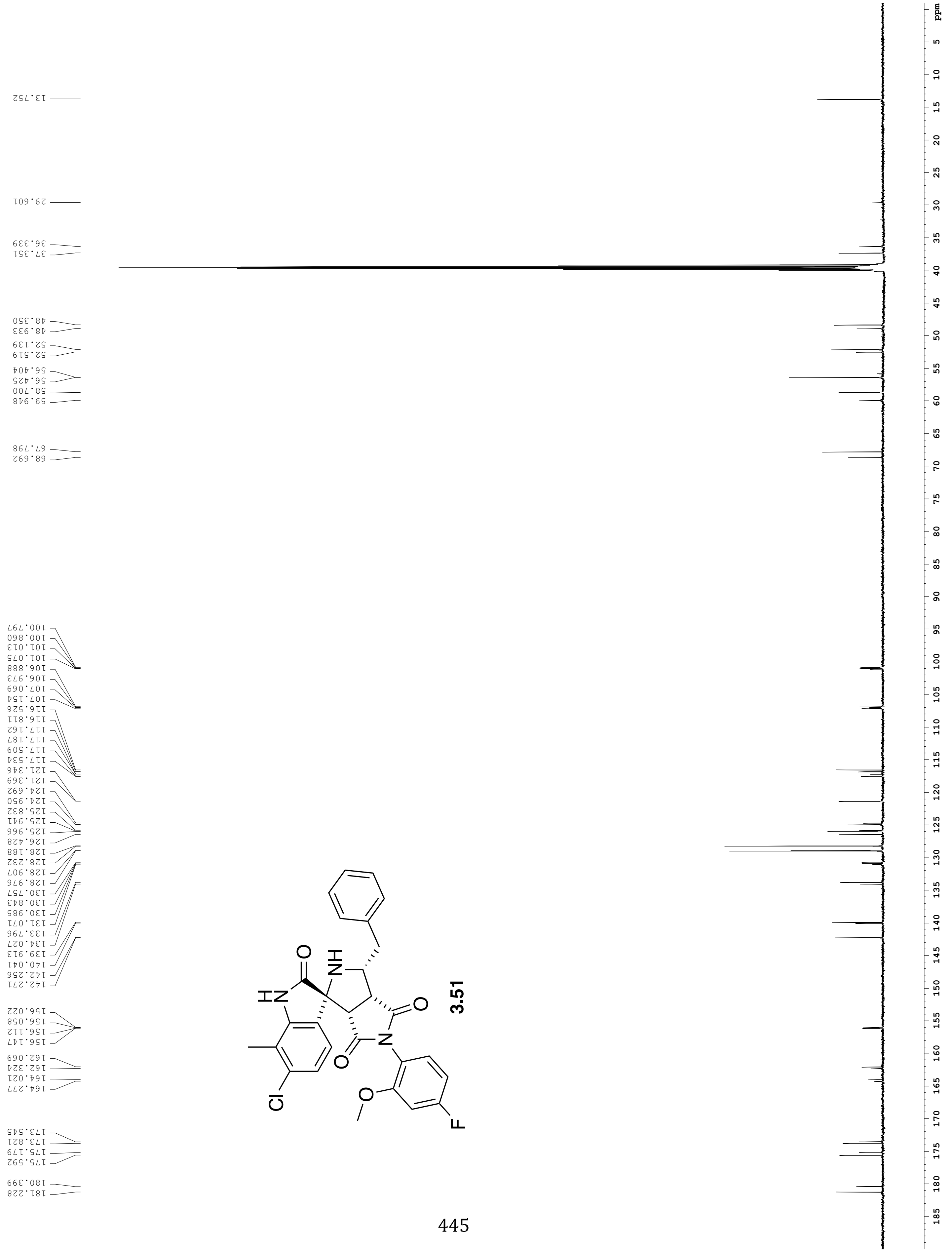

13.750
13.796
17.319
17.914
20.632
36.070
37.652
47.926
49.040
51.995
52.668
58.050
59.891
67.782
68.616
113.461
113.562
113.641
113.742
116.627
116.820
117.061
117.252
117.436
121.188
121.328
124.766
124.838
125.787
125.865
127.728
127.747
128.048
128.070
128.755
128.802
128.837
130.425
130.499
130.730
130.806
133.820
134.006
134.809
134.897
136.597
136.928
138.139
138.210
138.830
138.901
142.295
142.440
160.829
161.037
162.780
162.989
173.720
174.107
175.522
175.581
180.488
181.015
ppm
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
O
NH
HN
O
O
N
Cl
F
3.49


**3.50**
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
1.9574
2.2159
2.7455
2.7660
2.7730
2.7936
3.4523
3.4593
3.4798
3.4871
3.7332
3.7484
3.7633
3.8395
3.8555
4.7410
6.7729
6.7890
7.0238
7.0400
7.1993
7.6823
7.7000
8.3826
8.4004
8.5858
2.885
1.032
1.055
1.038
1.034
1.024
1.060
1.033
1.049
1.128
5.417
2.026
2.000
0.991
HN
NH
O
O
O
O
N
Cl
$O_2N$

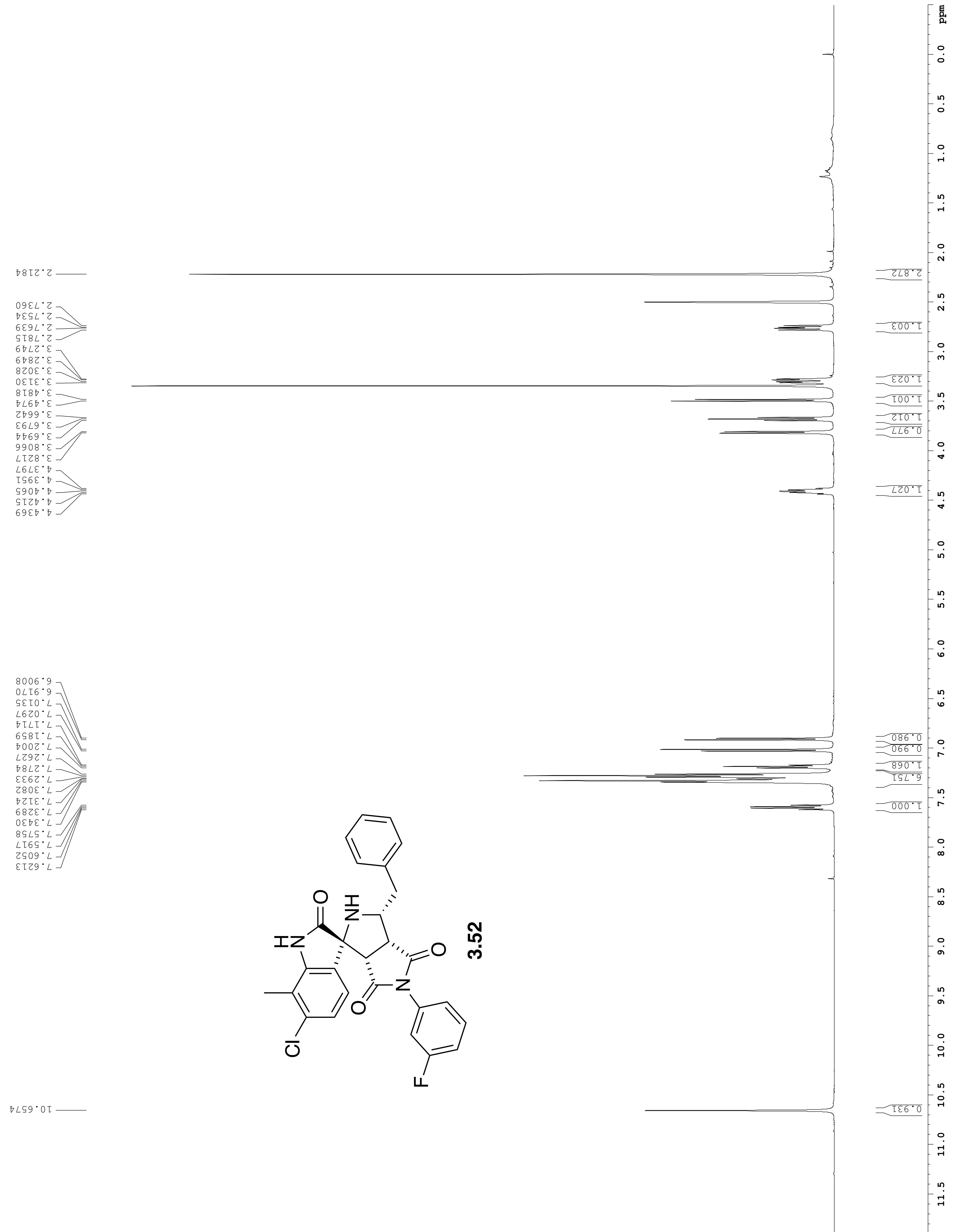

180.822
174.508
174.212
147.281
140.664
138.934
137.065
136.506
128.908
128.901
126.941
126.839
124.697
124.563
124.293
123.597
118.728
68.300
59.214
51.764
47.804
37.815
13.505
Cl
H
N
O
NH
O
N
O
O2N
3.50
185 180 175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5 ppm


10.6329
10.5766
7.4850
7.4723
7.4677
7.4551
7.3229
7.3091
7.2939
7.2792
7.2638
7.2264
7.2135
7.2088
7.2037
7.1964
7.1870
7.1506
7.1454
7.1286
7.1234
7.0159
7.0094
6.9996
6.9928
6.9695
6.9642
6.9517
6.9353
6.9202
6.9149
6.9033
6.8981
6.8864
6.8812
4.5109
4.5002
4.4948
4.4843
4.4739
4.4698
4.4582
4.4534
4.4376
4.4287
4.4217
4.4110
4.3956
3.9411
3.8457
3.8309
3.7680
3.7527
3.7410
3.6447
3.6349
3.6178
3.6020
3.4194
3.4036
3.2871
3.2768
3.2588
3.2460
3.2343
3.2177
3.2068
2.7611
2.7436
2.7329
2.7155
2.6276
2.6114
2.5999
2.5839
2.2132
2.2075
Cl
H
N
O
NH
O
O
N
O
F
0.503
0.944
0.587
5.518
3.173
0.602
4.333
1.560
2.613
0.597
1.957
1.067
1.231
0.930
1.675
0.605
1.000
4.040
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

**3.51**

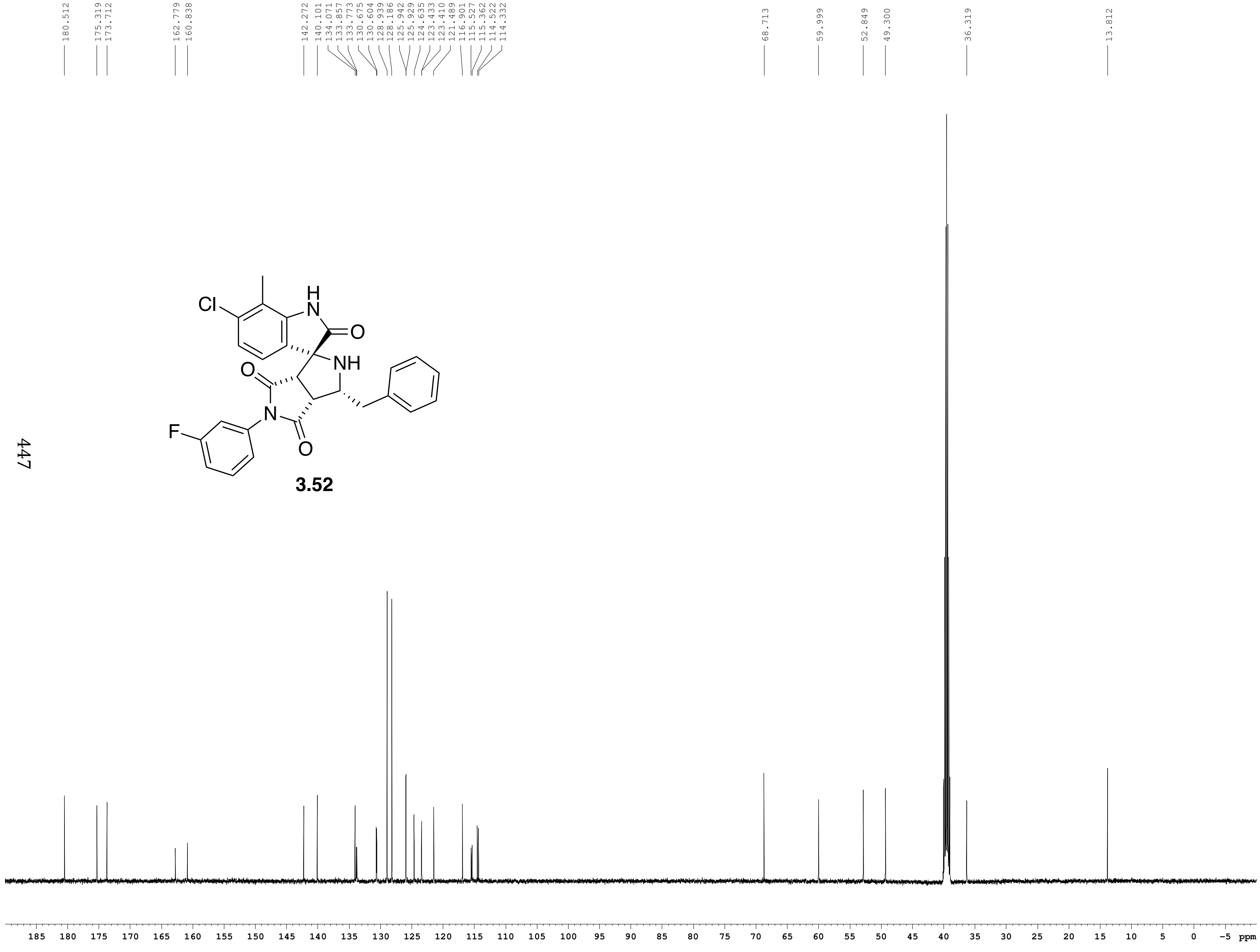

13.752
29.601
36.339
37.351
48.350
48.933
52.139
52.519
56.404
56.425
58.700
59.948
67.798
68.692
100.797
100.860
101.013
101.075
106.888
106.973
107.069
107.154
116.526
116.811
117.162
117.187
117.509
117.534
121.346
121.369
124.692
124.950
125.832
125.941
125.966
126.428
128.188
128.232
128.907
128.976
130.757
130.843
130.985
131.071
133.796
134.027
139.913
140.041
142.256
142.271
156.022
156.058
156.112
156.147
162.069
162.324
164.021
164.277
173.545
173.821
175.179
175.592
180.399
181.228
ppm
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
O
NH
HN
O
O
N
O
Cl
F

**3.51**

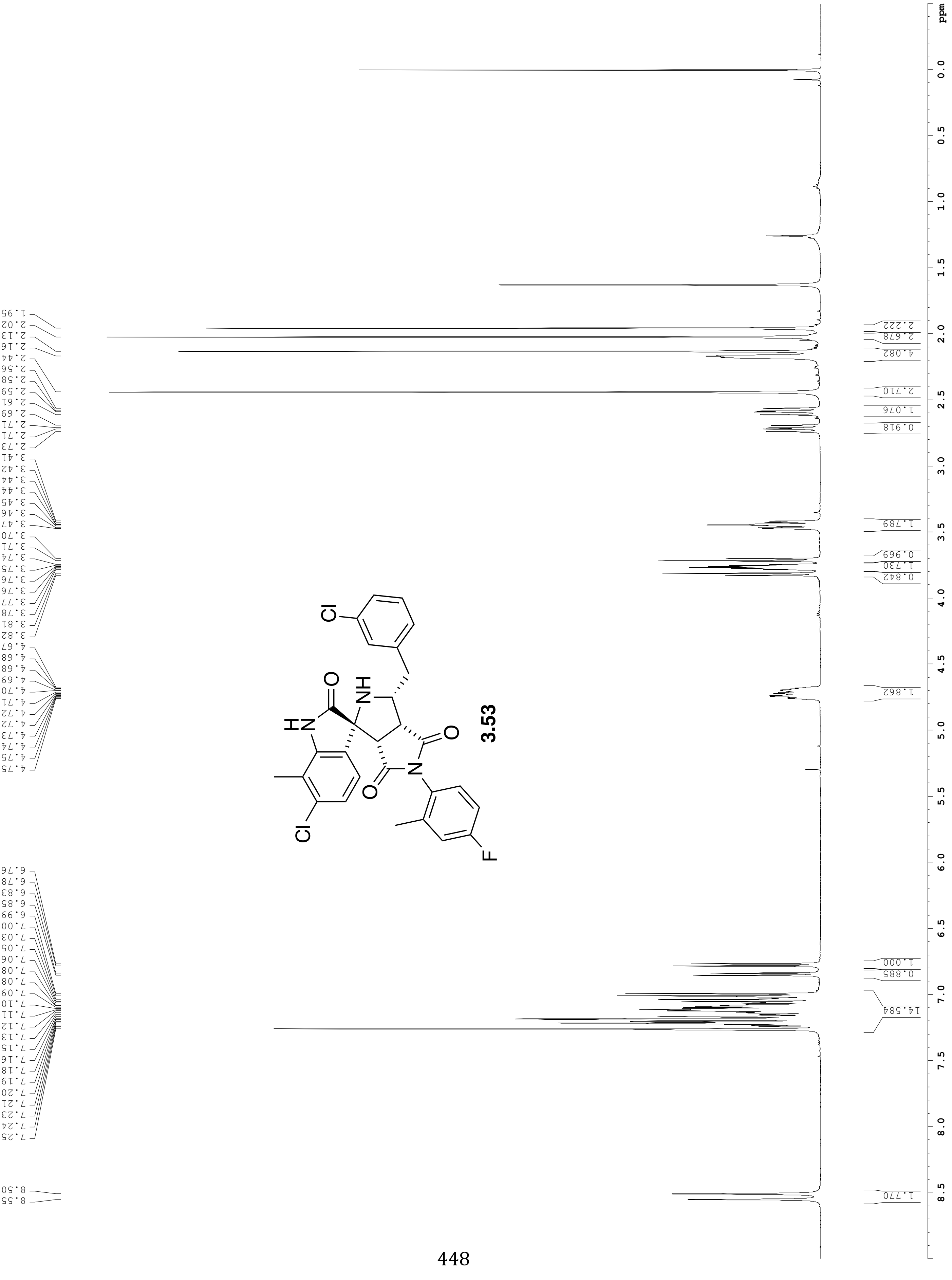


2.2184
2.7360
2.7534
2.7639
2.7815
3.2749
3.2849
3.3028
3.3130
3.4818
3.4974
3.6642
3.6793
3.6944
3.8066
3.8217
4.3797
4.3951
4.4065
4.4215
4.4369
6.9008
6.9170
7.0135
7.0297
7.1714
7.1859
7.2004
7.2627
7.2784
7.2933
7.3082
7.3124
7.3289
7.3430
7.5758
7.5917
7.6052
7.6213
10.6574
2.872
1.003
1.023
1.001
1.012
0.977
1.027
0.980
0.990
1.068
6.751
1.000
0.931
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
O
NH
H
N
O
N
O
Cl
F

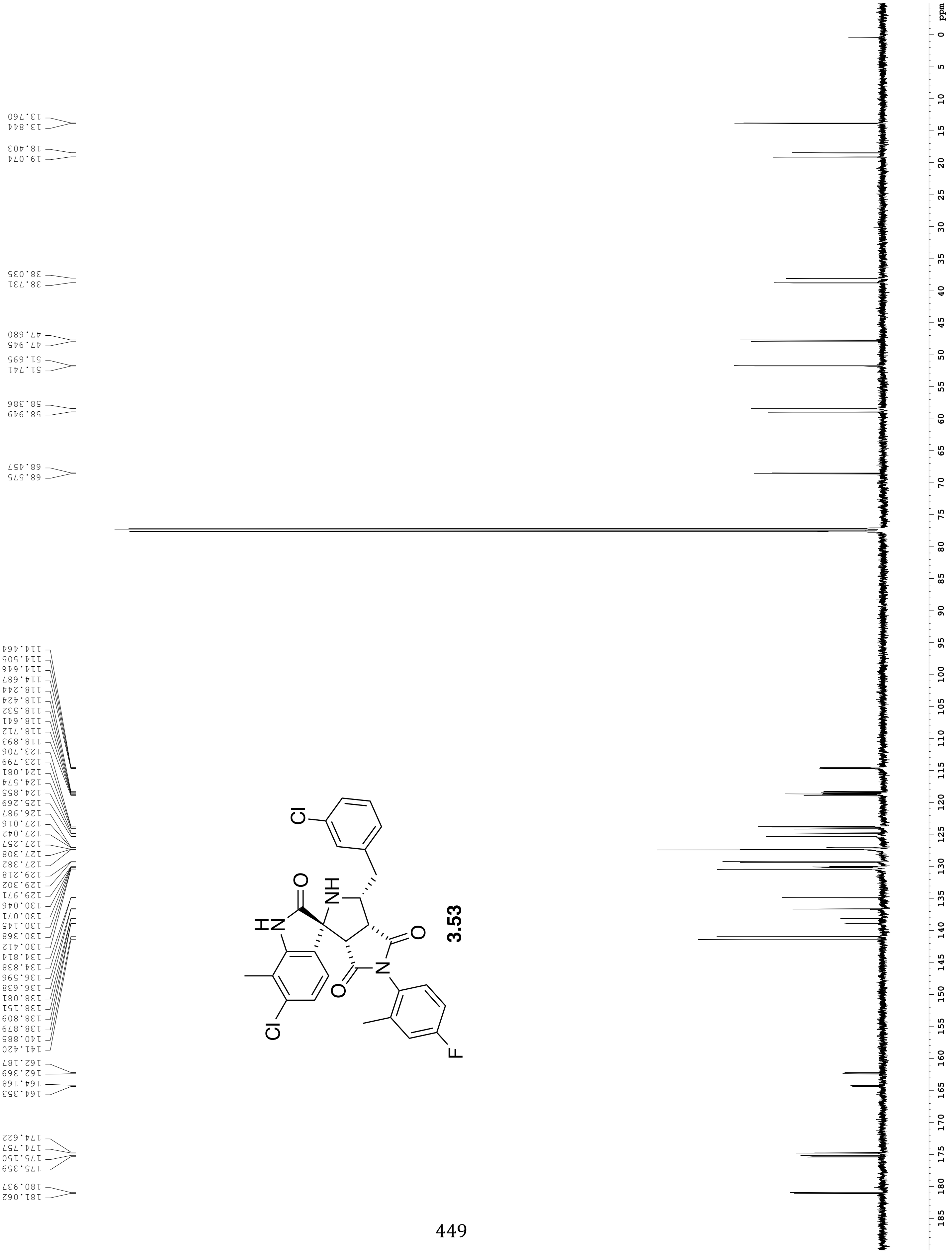
**3.52**


**3.52**

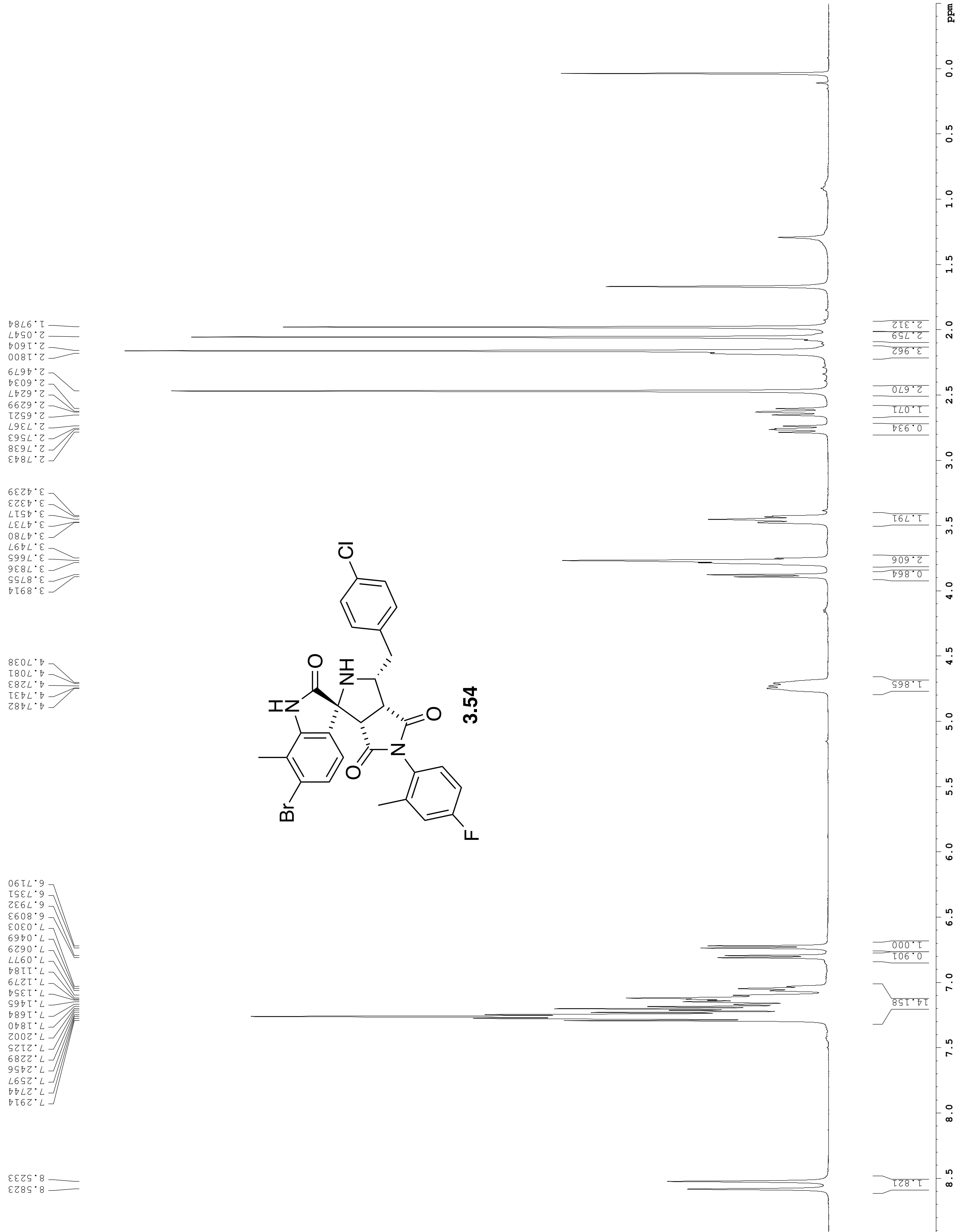
180.512
175.319
173.712
162.779
160.838
142.272
140.101
134.071
133.857
133.773
130.675
130.604
128.939
128.186
125.942
125.929
124.635
123.433
123.410
121.489
116.901
115.527
115.362
114.522
114.332
68.713
59.999
52.849
49.300
36.319
13.812
Cl
H
N
O
NH
O
N
O
F
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
ppm


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
1.9574
2.0234
2.1320
2.1687
2.4406
2.5632
2.5842
2.5907
2.6118
2.6919
2.7119
2.7196
2.7396
3.4179
3.4255
3.4413
3.4458
3.4537
3.4673
3.4736
3.7014
3.7174
3.7451
3.7521
3.7605
3.7679
3.7753
3.7837
3.8115
3.8274
4.6739
4.6835
4.6877
4.6952
4.7008
4.7138
4.7221
4.7289
4.7378
4.7433
4.7516
4.7589
6.7670
6.7833
6.8379
6.8541
6.9931
7.0095
7.0373
7.0535
7.0645
7.0827
7.0880
7.0977
7.1064
7.1147
7.1227
7.1334
7.1510
7.1679
7.1841
7.1907
7.2054
7.2153
7.2322
7.2426
7.2598
8.5084
8.5510
2.222
2.678
4.082
2.710
1.076
0.918
1.789
0.969
1.730
0.842
1.862
1.000
0.885
14.584
1.770
Cl
Cl
NH
H
N
O
O
O
N
F

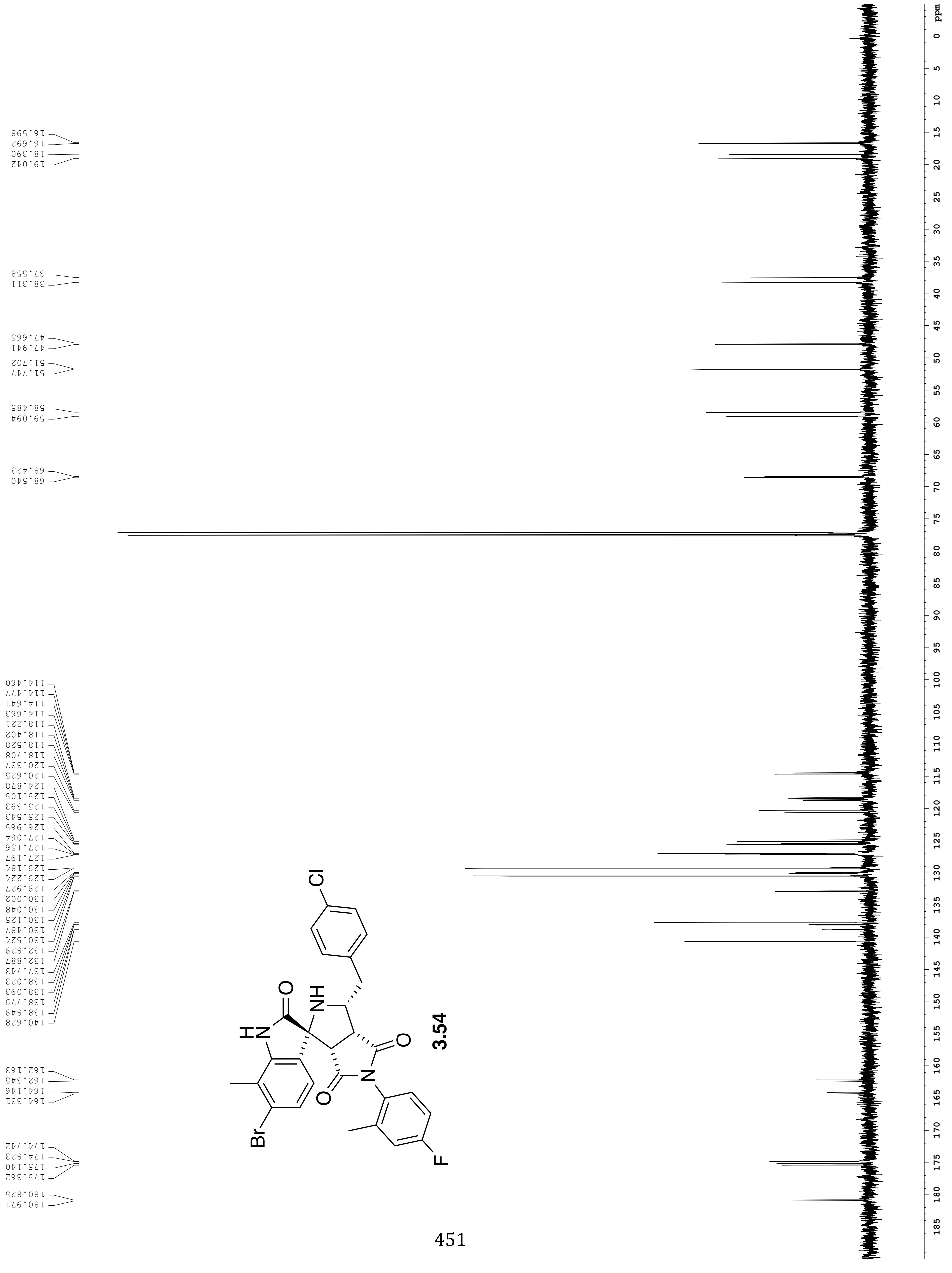
**3.53**


13.760
13.844
18.403
19.074
38.035
38.731
47.680
47.945
51.695
51.741
58.386
58.949
68.457
68.575
114.464
114.505
114.646
114.687
118.244
118.424
118.532
118.641
118.712
118.893
123.706
123.799
124.081
124.574
124.855
125.269
126.987
127.016
127.042
127.257
127.308
127.382
129.218
129.302
129.971
130.046
130.071
130.145
130.368
130.412
134.814
134.838
136.596
136.638
138.081
138.151
138.809
138.879
140.885
141.420
162.187
162.369
164.168
164.353
174.622
174.757
175.150
175.359
180.937
181.062
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
Cl
NH
H
N
O
O
N
O
Cl
F

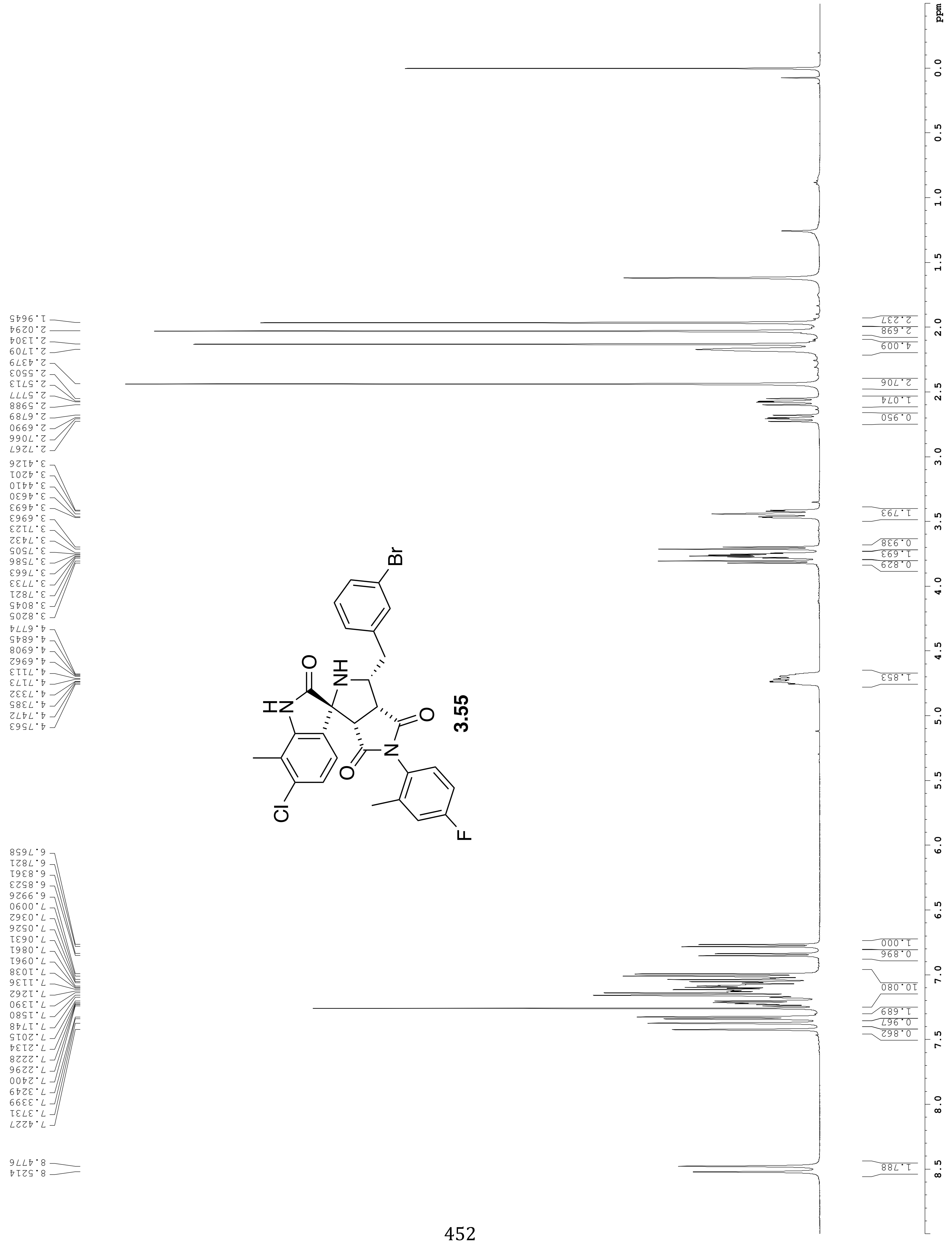
**3.53**


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
1.9784
2.0547
2.1604
2.1800
2.4679
2.6034
2.6247
2.6299
2.6521
2.7367
2.7563
2.7638
2.7843
3.4239
3.4323
3.4517
3.4737
3.4780
3.4797
3.7665
3.7836
3.8755
3.8914
4.7038
4.7081
4.7283
4.7431
4.7482
6.7190
6.7351
6.7932
6.8093
7.0303
7.0469
7.0629
7.0977
7.1184
7.1279
7.1354
7.1465
7.1684
7.1840
7.2002
7.2125
7.2289
7.2456
7.2597
7.2744
7.2914
8.5233
8.5823
2.312
2.759
3.962
2.670
1.071
0.934
1.791
2.606
0.864
1.865
1.000
0.901
14.158
1.821
Cl
NH
HN
O
O
O
N
Br
F

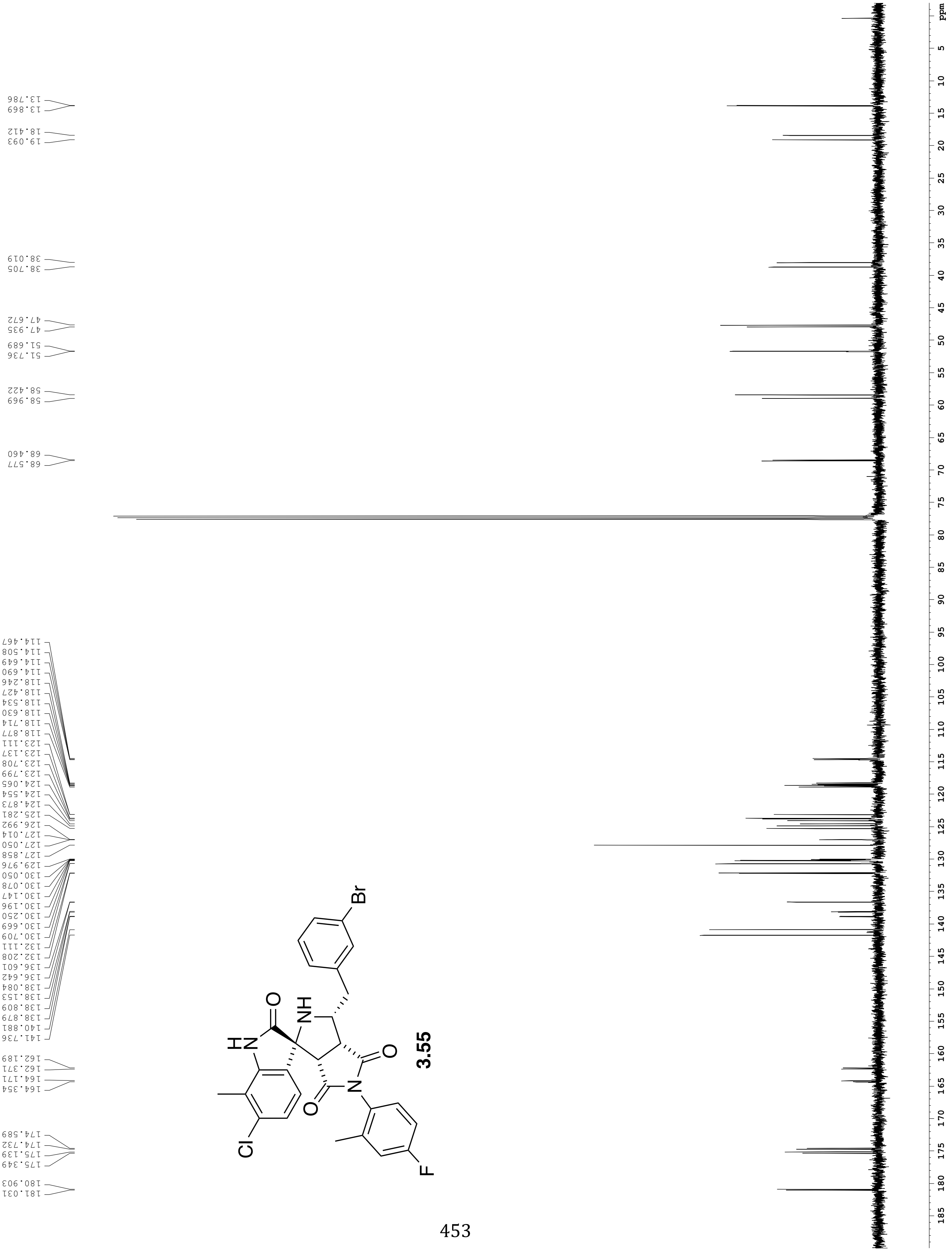
**3.54**


16.598
16.692
18.390
19.042
37.558
38.311
47.665
47.941
51.702
51.747
58.485
59.094
68.423
68.540
114.460
114.477
114.641
114.663
118.221
118.402
118.528
118.708
120.337
120.625
124.878
125.105
125.393
125.543
126.965
127.064
127.156
127.197
129.184
129.224
129.927
130.002
130.048
130.125
130.487
130.524
132.829
132.887
137.743
138.023
138.093
138.779
138.849
140.628
162.163
162.345
164.146
164.331
174.742
174.823
175.140
175.362
180.825
180.971
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
Cl
NH
O
H
N
Br
O
N
O
F

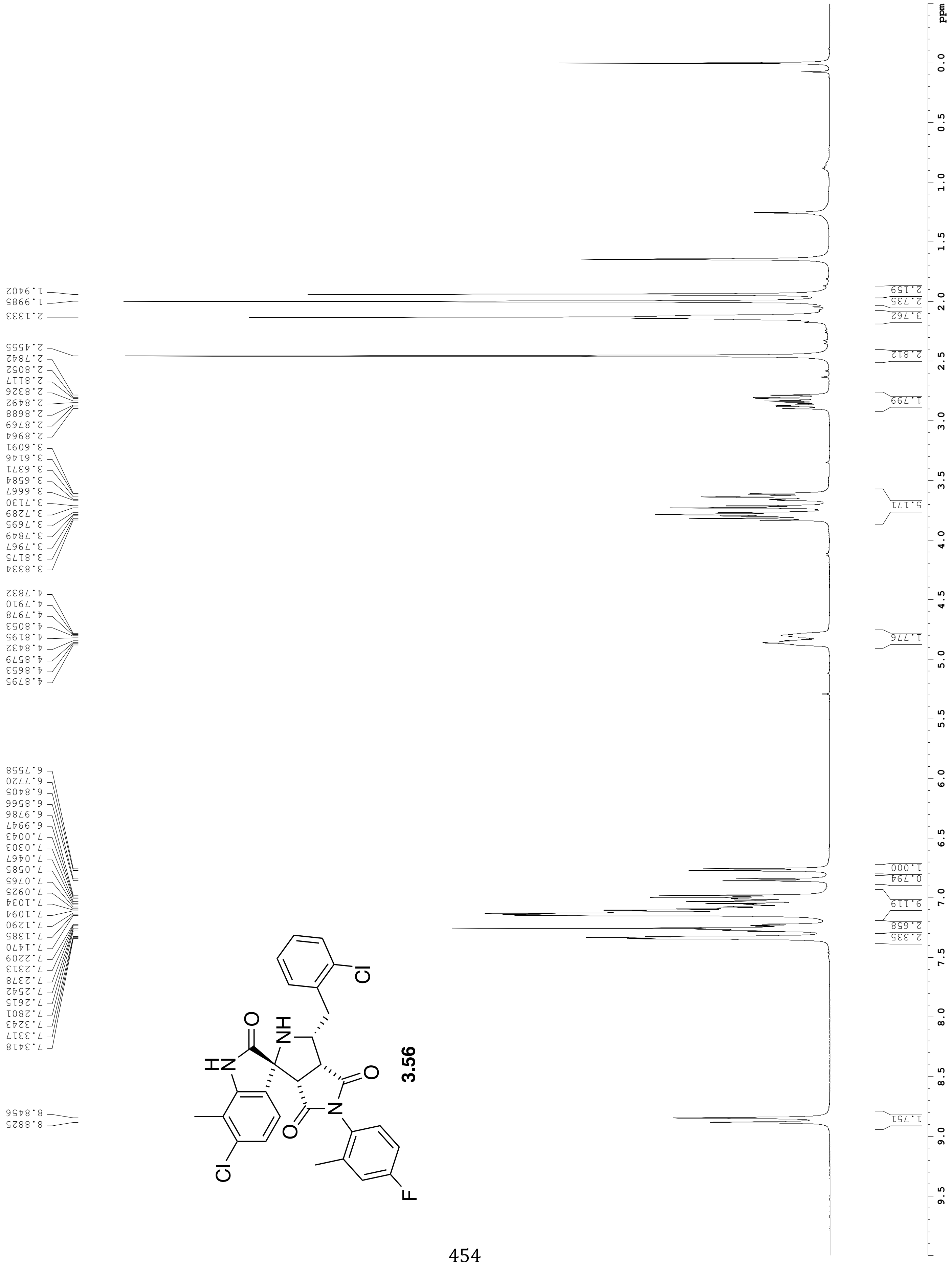
**3.54**


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
1.9645
2.0294
2.1304
2.1709
2.4379
2.5503
2.5713
2.5777
2.5988
2.6789
2.6990
2.7066
2.7267
3.4126
3.4201
3.4410
3.4630
3.4693
3.6963
3.7123
3.7432
3.7505
3.7586
3.7663
3.7733
3.7821
3.8045
3.8205
4.6774
4.6845
4.6908
4.6962
4.7113
4.7173
4.7332
4.7385
4.7472
4.7563
6.7658
6.7821
6.8361
6.8523
6.9926
7.0090
7.0362
7.0526
7.0631
7.0861
7.0961
7.1038
7.1136
7.1262
7.1390
7.1580
7.1748
7.2015
7.2134
7.2228
7.2296
7.2400
7.3249
7.3399
7.3731
7.4227
8.4776
8.5214
2.237
2.698
4.009
2.706
1.074
0.950
1.793
0.938
1.693
0.829
1.853
1.000
0.896
10.080
1.689
0.967
0.862
1.788
Br
O
NH
H
N
O
O
N
Cl
F

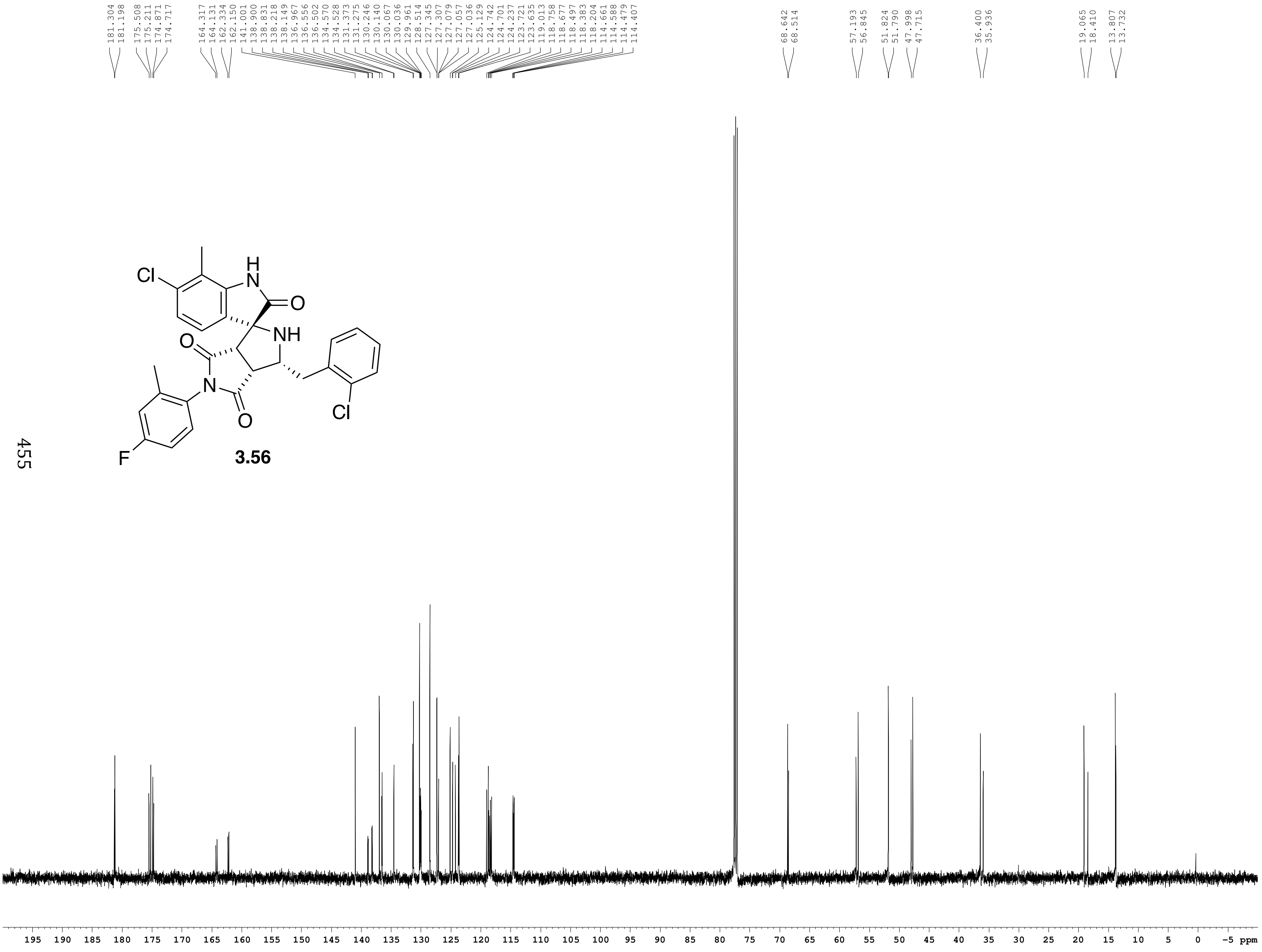
**3.55**


13.786
13.869
18.412
19.093
38.019
38.705
47.672
47.935
51.689
51.736
58.422
58.969
68.460
68.577
114.467
114.508
114.649
114.690
118.246
118.427
118.534
118.630
118.714
118.877
123.111
123.137
123.708
123.799
124.065
124.554
124.873
125.281
126.992
127.014
127.050
127.858
129.976
130.050
130.078
130.147
130.196
130.250
130.669
130.709
132.111
132.208
136.601
136.642
138.084
138.153
138.809
138.879
140.881
141.736
162.189
162.371
164.171
164.354
174.589
174.732
175.139
175.349
180.903
181.031
Br
NH
H
N
O
O
O
N
Cl
F
ppm
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185

**3.55**

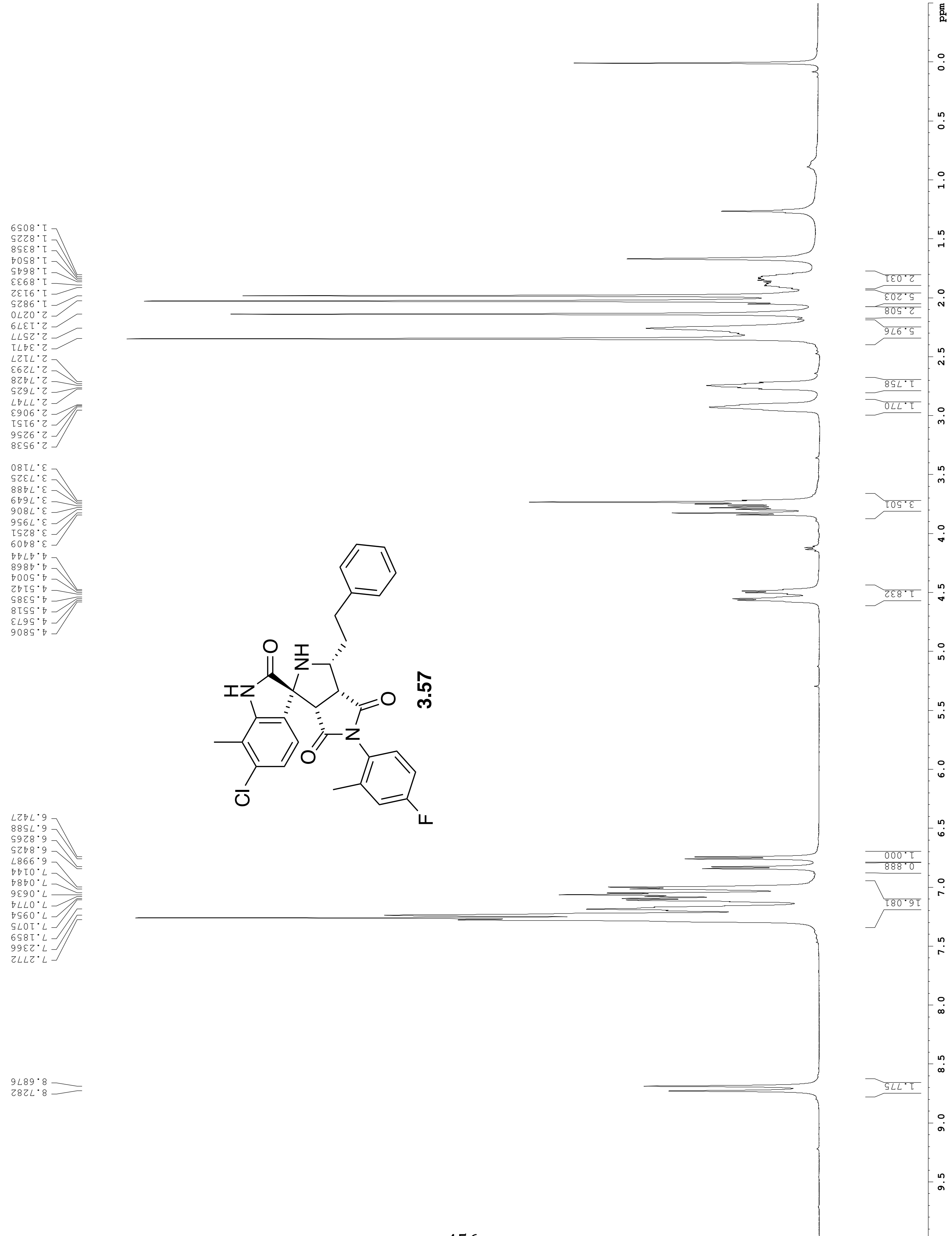

1.9402
1.9985
2.1333
2.4555
2.7842
2.8052
2.8117
2.8326
2.8492
2.8688
2.8769
2.8964
3.6091
3.6146
3.6371
3.6584
3.6667
3.7130
3.7289
3.7695
3.7849
3.7967
3.8175
3.8334
4.7832
4.7910
4.7978
4.8053
4.8195
4.8432
4.8579
4.8653
4.8795
6.7558
6.7720
6.8405
6.8566
6.9786
6.9947
7.0043
7.0303
7.0467
7.0585
7.0765
7.0925
7.1034
7.1094
7.1290
7.1385
7.1470
7.2209
7.2313
7.2378
7.2542
7.2615
7.2801
7.3243
7.3317
7.3418
8.8456
8.8825
2.159
2.735
3.762
2.812
1.799
5.171
1.776
1.000
0.794
9.119
2.658
2.335
1.751
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
Cl
O
NH
H
N
O
O
N
Cl
F

**3.56**

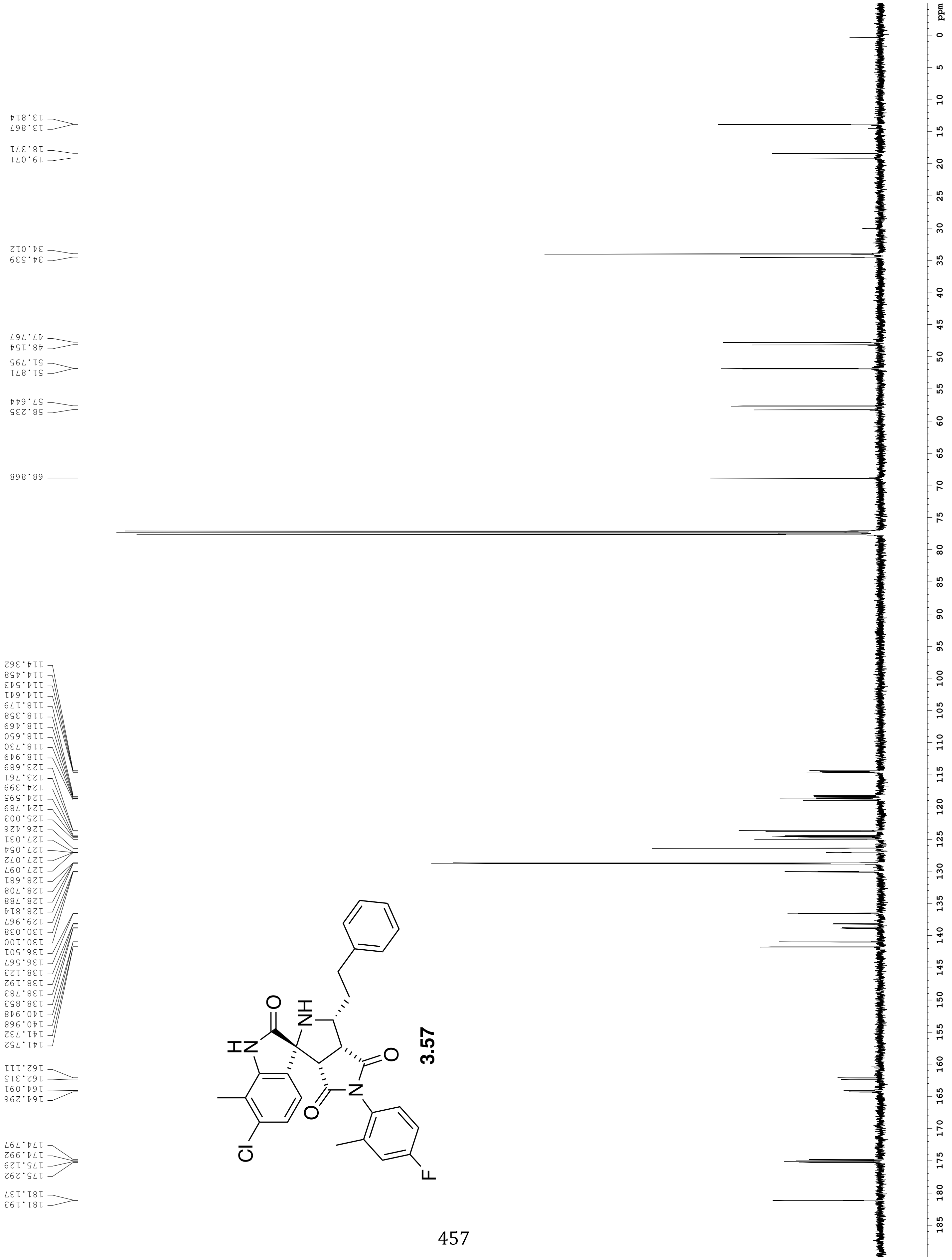


**3.56**

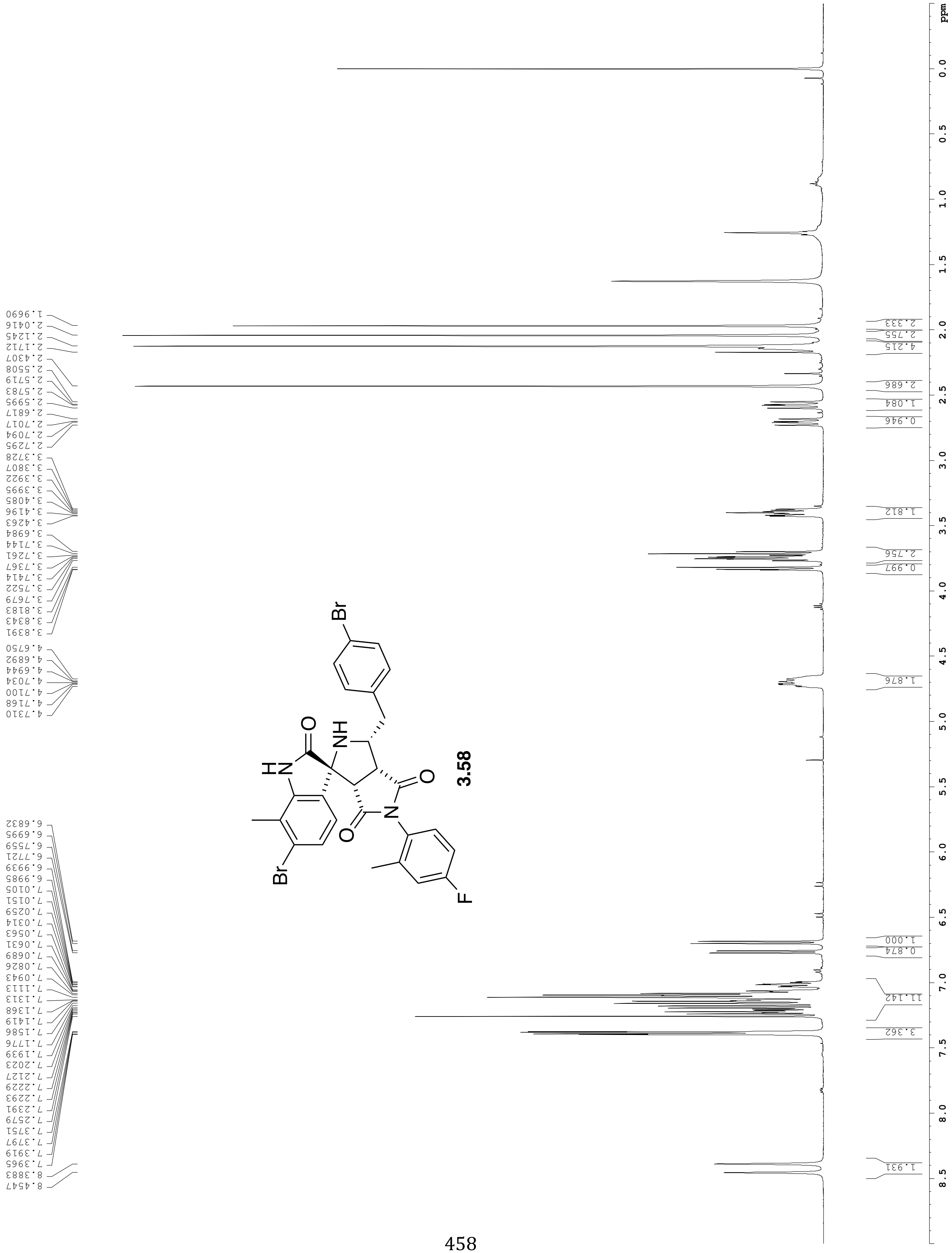
181.304
181.198
175.508
175.211
174.871
174.717
164.317
164.131
162.334
162.150
141.001
138.900
138.831
138.218
138.149
136.967
136.556
136.502
134.570
134.528
131.373
131.275
130.246
130.140
130.067
130.036
129.961
128.514
127.345
127.307
127.079
127.057
127.036
125.129
124.742
124.701
124.237
123.721
123.635
119.013
118.758
118.677
118.497
118.383
118.204
114.661
114.588
114.479
114.407
68.642
68.514
57.193
56.845
51.824
51.790
47.998
47.715
36.400
35.936
19.065
18.410
13.807
13.732
Cl
H
N
O
NH
O
N
O
Cl
F
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5 ppm


1.8059
1.8225
1.8358
1.8504
1.8645
1.8933
1.9132
1.9825
2.0270
2.1379
2.2577
2.3471
2.7127
2.7293
2.7428
2.7625
2.7747
2.9063
2.9151
2.9256
2.9538
3.7180
3.7325
3.7488
3.7649
3.7806
3.7956
3.8251
3.8409
4.4744
4.4868
4.5004
4.5142
4.5385
4.5518
4.5673
4.5806
6.7427
6.7588
6.8265
6.8425
6.9987
7.0144
7.0484
7.0636
7.0774
7.0954
7.1075
7.1859
7.2366
7.2772
8.6876
8.7282
2.031
5.203
2.508
5.976
1.758
1.770
3.501
1.832
1.000
0.888
16.081
1.775
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
Cl
H
N
O
NH
O
N
O
F

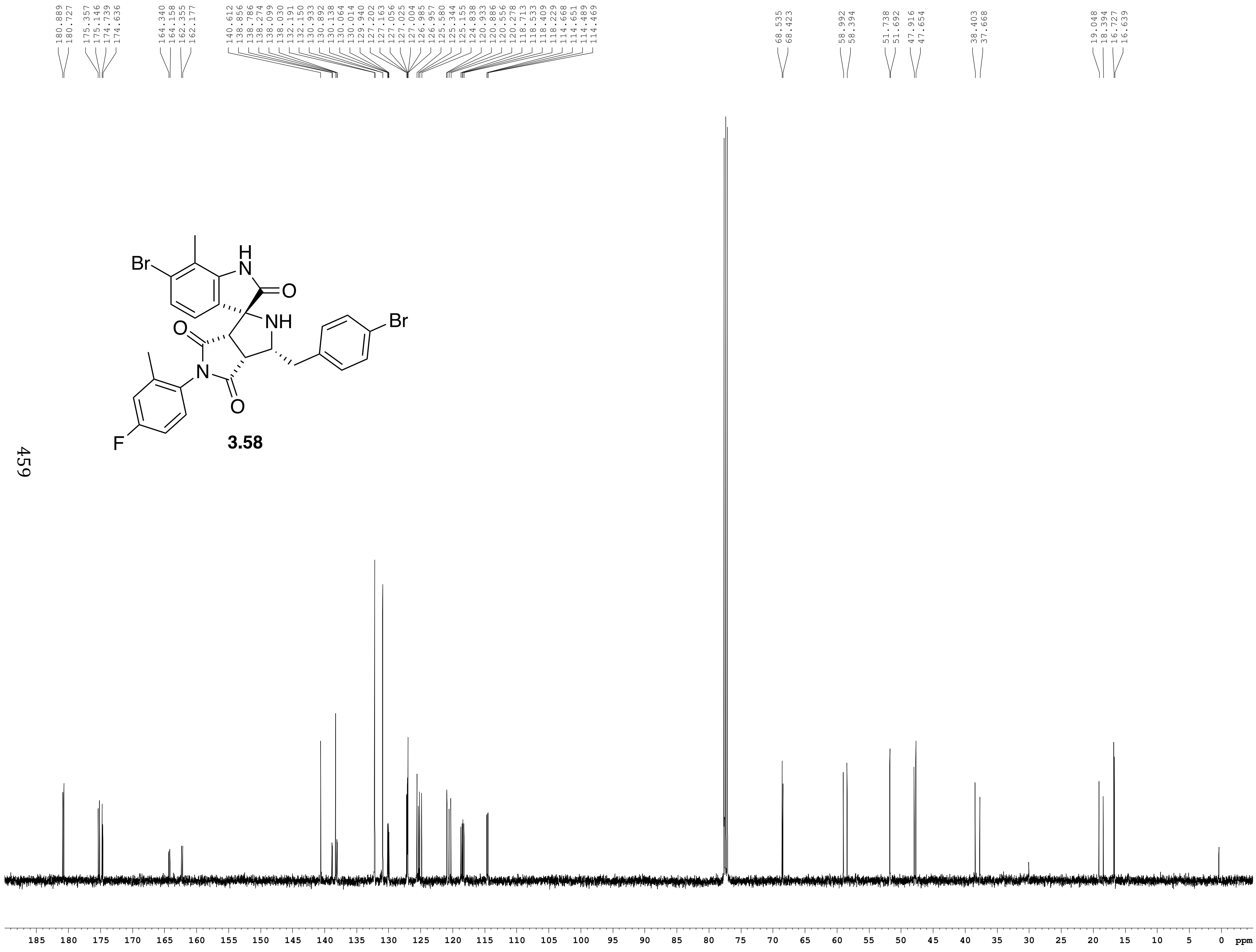
**3.57**


13.814
13.867
18.371
19.071
34.012
34.539
47.767
48.154
51.795
51.871
57.644
58.235
68.868
114.362
114.458
114.543
114.641
118.179
118.358
118.469
118.650
118.730
118.949
123.689
123.761
124.399
124.595
124.789
125.003
126.426
127.031
127.054
127.072
127.097
128.681
128.708
128.788
128.814
129.967
130.038
130.100
136.501
136.567
138.123
138.192
138.783
138.853
140.948
140.968
141.732
141.752
162.111
162.315
164.091
164.296
174.797
174.992
175.129
175.292
181.137
181.193
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
O
NH
H
N
O
N
O
Cl
F

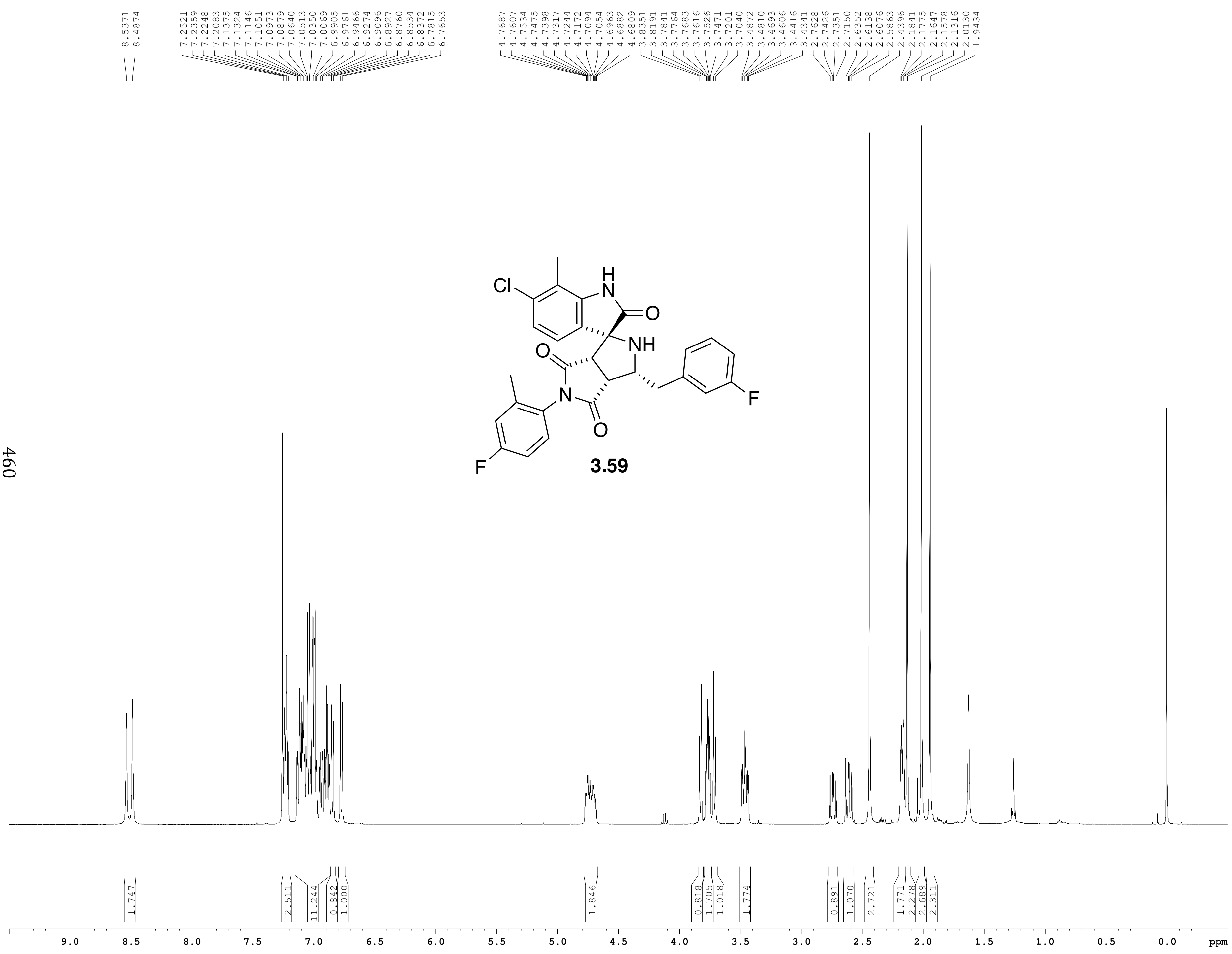
**3.57**


1.9690
2.0416
2.1245
2.1712
2.4307
2.5508
2.5719
2.5783
2.5995
2.6817
2.7017
2.7094
2.7295
3.3728
3.3807
3.3922
3.3995
3.4085
3.4196
3.4263
3.6984
3.7144
3.7261
3.7367
3.7414
3.7522
3.7679
3.8183
3.8343
3.8391
4.6750
4.6892
4.6944
4.7034
4.7100
4.7168
4.7310
6.6832
6.6995
6.7559
6.7721
6.9939
6.9985
7.0105
7.0151
7.0259
7.0314
7.0563
7.0631
7.0689
7.0826
7.0943
7.1113
7.1313
7.1368
7.1419
7.1586
7.1776
7.1939
7.2023
7.2127
7.2229
7.2293
7.2391
7.2579
7.3751
7.3797
7.3919
7.3965
8.3883
8.4547
2.333
2.755
4.215
2.686
1.084
0.946
1.812
2.756
0.997
1.876
1.000
0.874
11.142
3.362
1.931
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Br
O
NH
H
N
O
N
O
Br
F

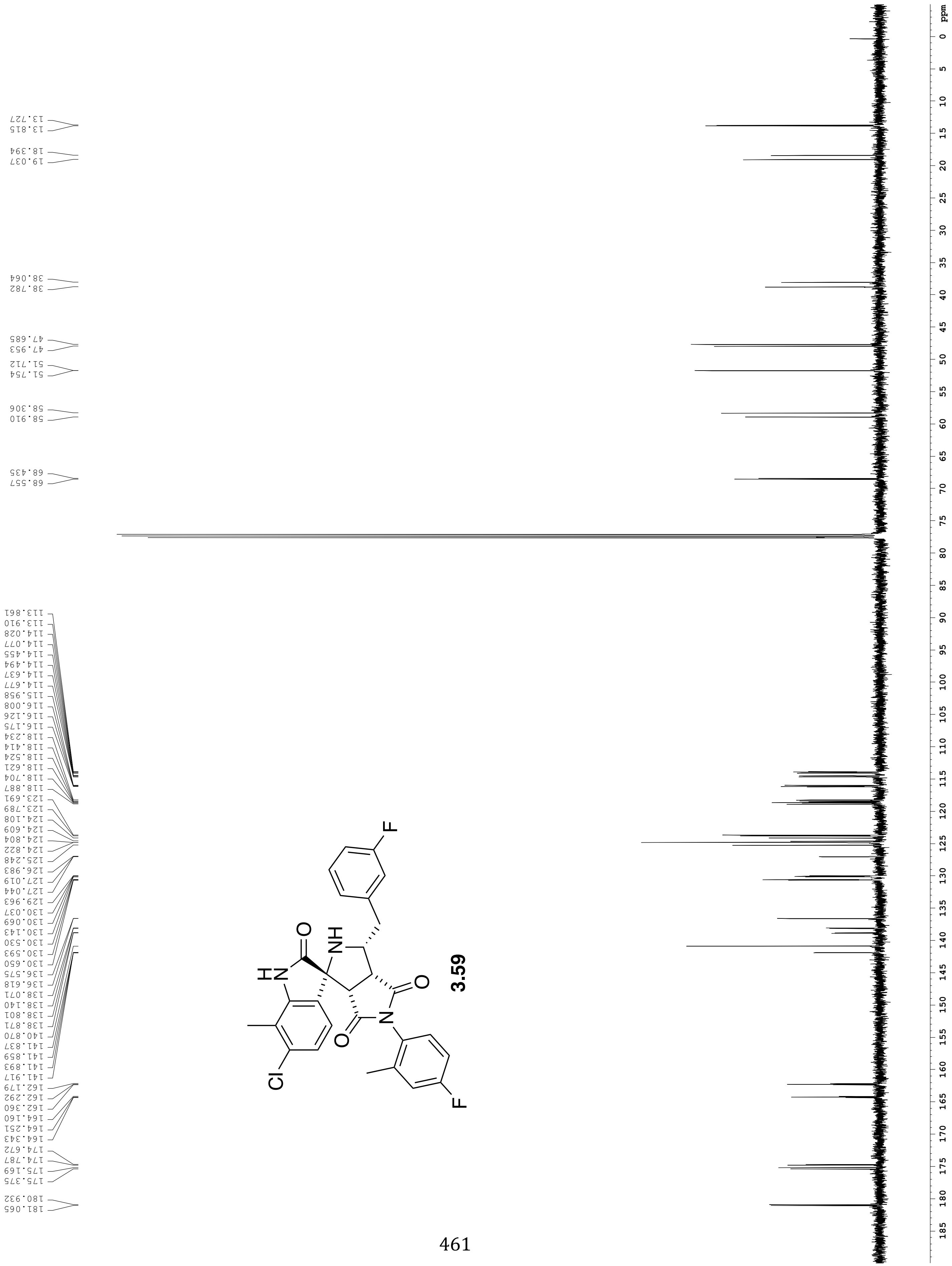
**3.58**


180.889
180.727
175.357
175.146
174.739
174.636
164.340
164.158
162.355
162.177
140.612
138.856
138.786
138.274
138.099
138.030
132.191
132.150
130.933
130.892
130.138
130.064
130.014
129.940
127.202
127.163
127.056
127.025
127.004
126.985
126.957
125.580
125.344
125.155
124.838
120.933
120.886
120.556
120.278
118.713
118.533
118.409
118.229
114.668
114.651
114.489
114.469
68.535
68.423
58.992
58.394
51.738
51.692
47.916
47.654
38.403
37.668
19.048
18.394
16.727
16.639
Br
H
N
O
NH
Br
O
N
O
F
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
ppm

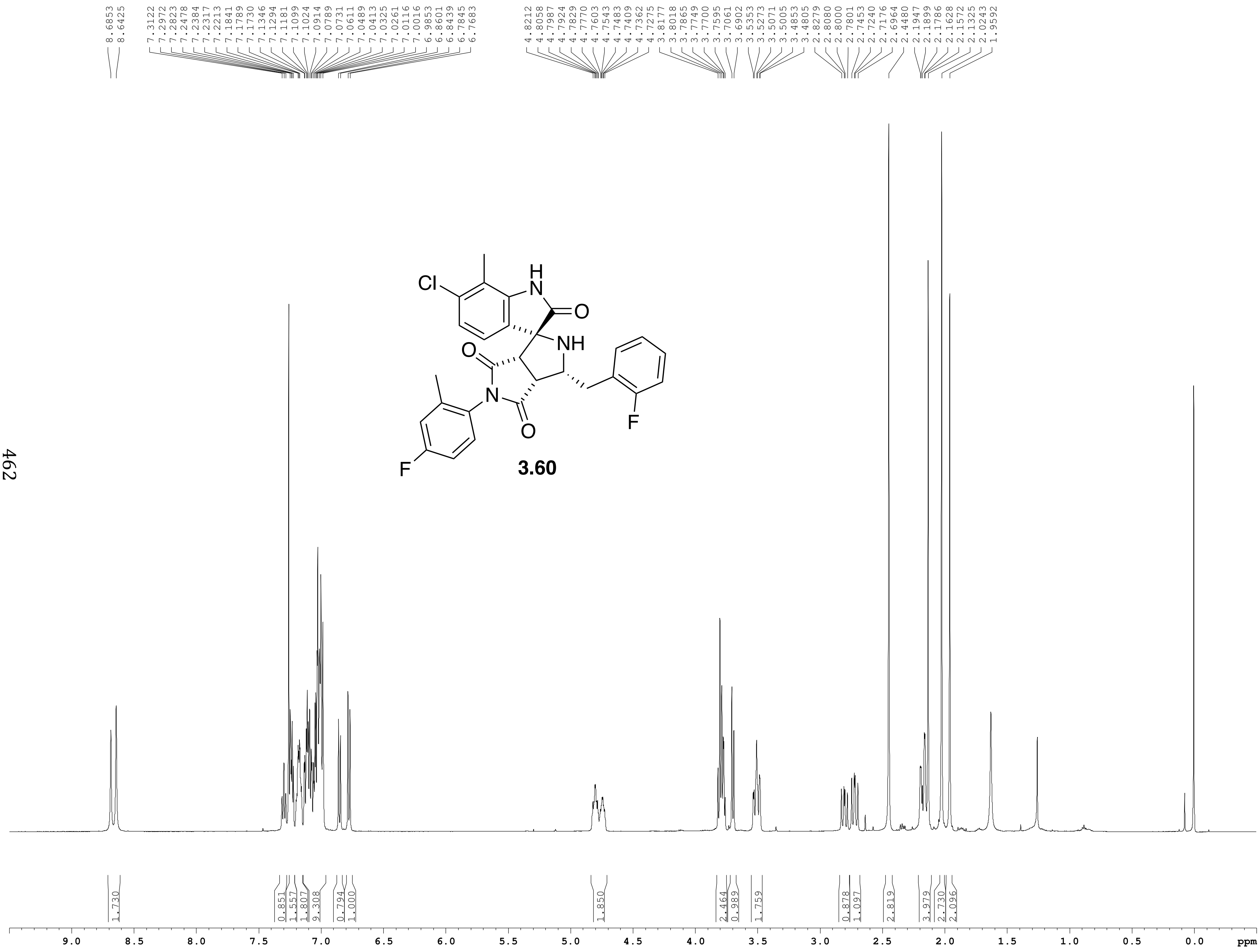
**3.58**

8.5371
8.4874
7.2521
7.2359
7.2248
7.2083
7.1375
7.1324
7.1146
7.1051
7.0973
7.0879
7.0640
7.0513
7.0350
7.0069
6.9905
6.9761
6.9466
6.9274
6.9096
6.8927
6.8760
6.8534
6.8372
6.7815
6.7653
4.7687
4.7607
4.7534
4.7475
4.7398
4.7317
4.7244
4.7172
4.7094
4.7054
4.6963
4.6882
4.6809
3.8351
3.8191
3.7841
3.7764
3.7683
3.7616
3.7526
3.7471
3.7201
3.7040
3.4872
3.4810
3.4693
3.4606
3.4416
3.4341
2.7628
2.7426
2.7351
2.7150
2.6352
2.6138
2.6076
2.5863
2.4396
2.1841
2.1775
2.1647
2.1578
2.1316
2.0130
1.9434
Cl
H
N
O
NH
O
N
O
F
F
1.747
2.511
11.244
0.842
1.000
1.846
0.818
1.705
1.018
1.774
0.891
1.070
2.721
1.771
2.278
2.689
2.311
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

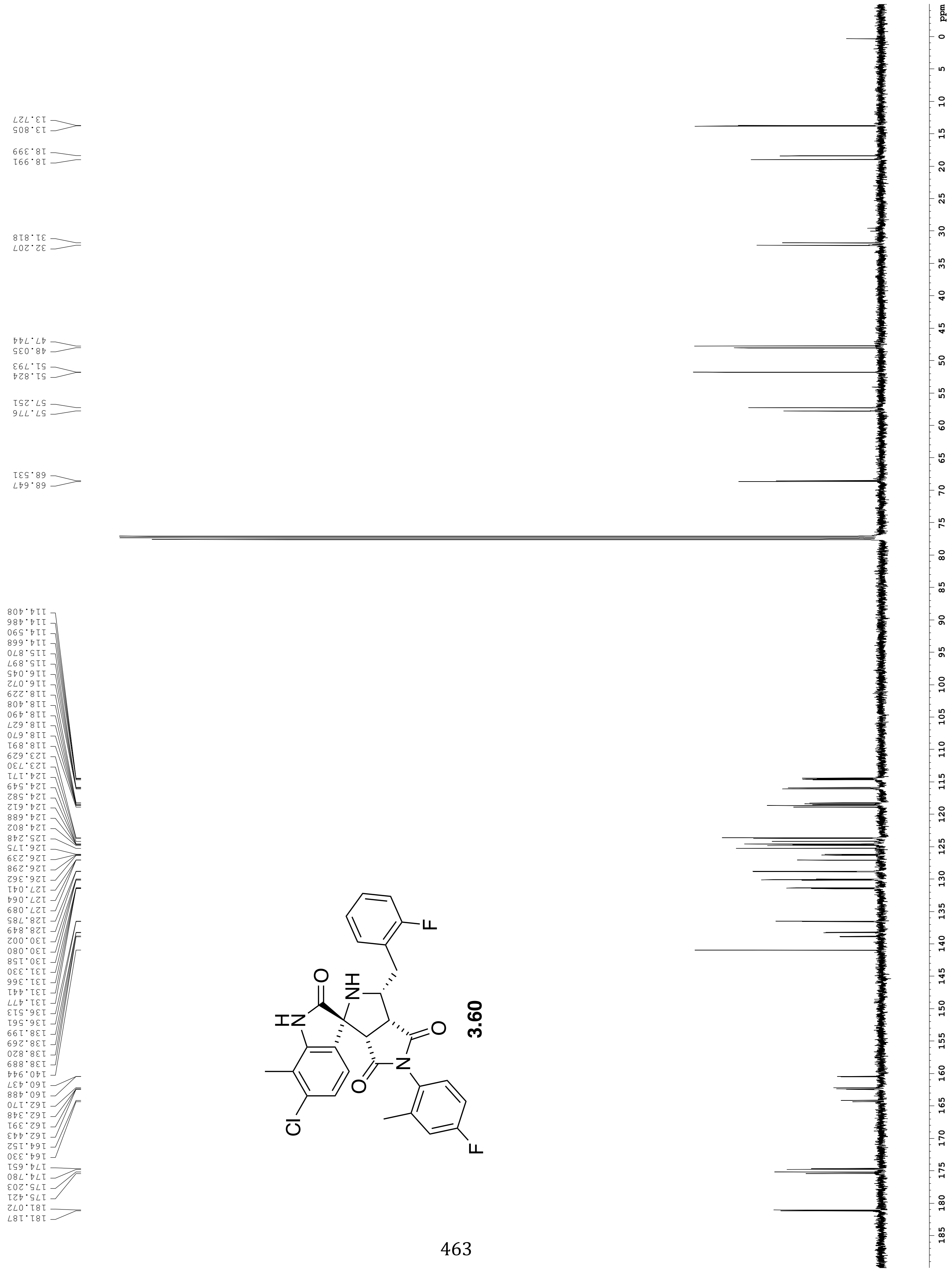
**3.59**


13.727
13.815
18.394
19.037
38.064
38.782
47.685
47.953
51.712
51.754
58.306
58.910
68.435
68.557
113.861
113.910
114.028
114.077
114.455
114.494
114.637
114.677
115.958
116.008
116.126
116.175
118.234
118.414
118.524
118.621
118.704
118.887
123.691
123.789
124.108
124.609
124.804
124.822
125.248
126.983
127.019
127.044
129.963
130.037
130.069
130.143
130.530
130.593
130.650
136.575
136.618
138.071
138.140
138.801
138.871
140.870
141.837
141.859
141.893
141.917
162.179
162.292
162.360
164.160
164.251
164.343
174.672
174.787
175.169
175.375
180.932
181.065
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
F
O
NH
H
N
O
O
N
Cl
F

**3.59**

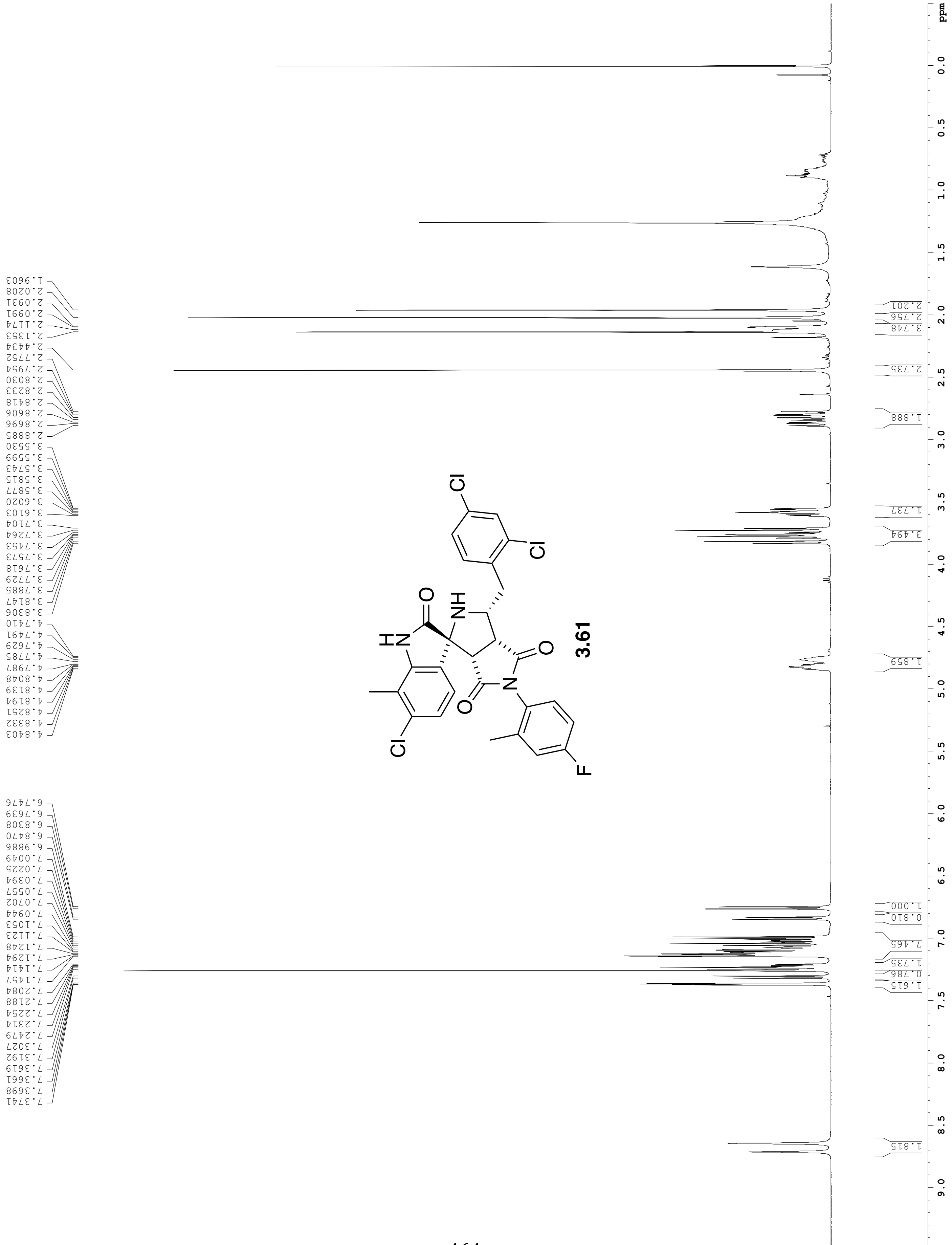

8.6853
8.6425
7.3122
7.2972
7.2823
7.2478
7.2384
7.2317
7.2213
7.1841
7.1789
7.1730
7.1346
7.1294
7.1181
7.1099
7.1024
7.0914
7.0789
7.0731
7.0611
7.0489
7.0413
7.0325
7.0261
7.0116
7.0016
6.9853
6.8601
6.8439
6.7845
6.7683
4.8212
4.8058
4.7987
4.7924
4.7829
4.7770
4.7603
4.7543
4.7483
4.7409
4.7362
4.7275
3.8177
3.8018
3.7865
3.7749
3.7700
3.7595
3.7061
3.6902
3.5353
3.5273
3.5071
3.5005
3.4853
3.4805
2.8279
2.8080
2.8000
2.7801
2.7453
2.7240
2.7176
2.6964
2.4480
2.1947
2.1899
2.1786
2.1628
2.1572
2.1325
2.0243
1.9592
Cl
H
N
O
NH
O
N
O
F
F
1.730
0.851
1.557
1.807
9.308
0.794
1.000
1.850
2.464
0.989
1.759
0.878
1.097
2.819
3.979
2.730
2.096
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

**3.60**

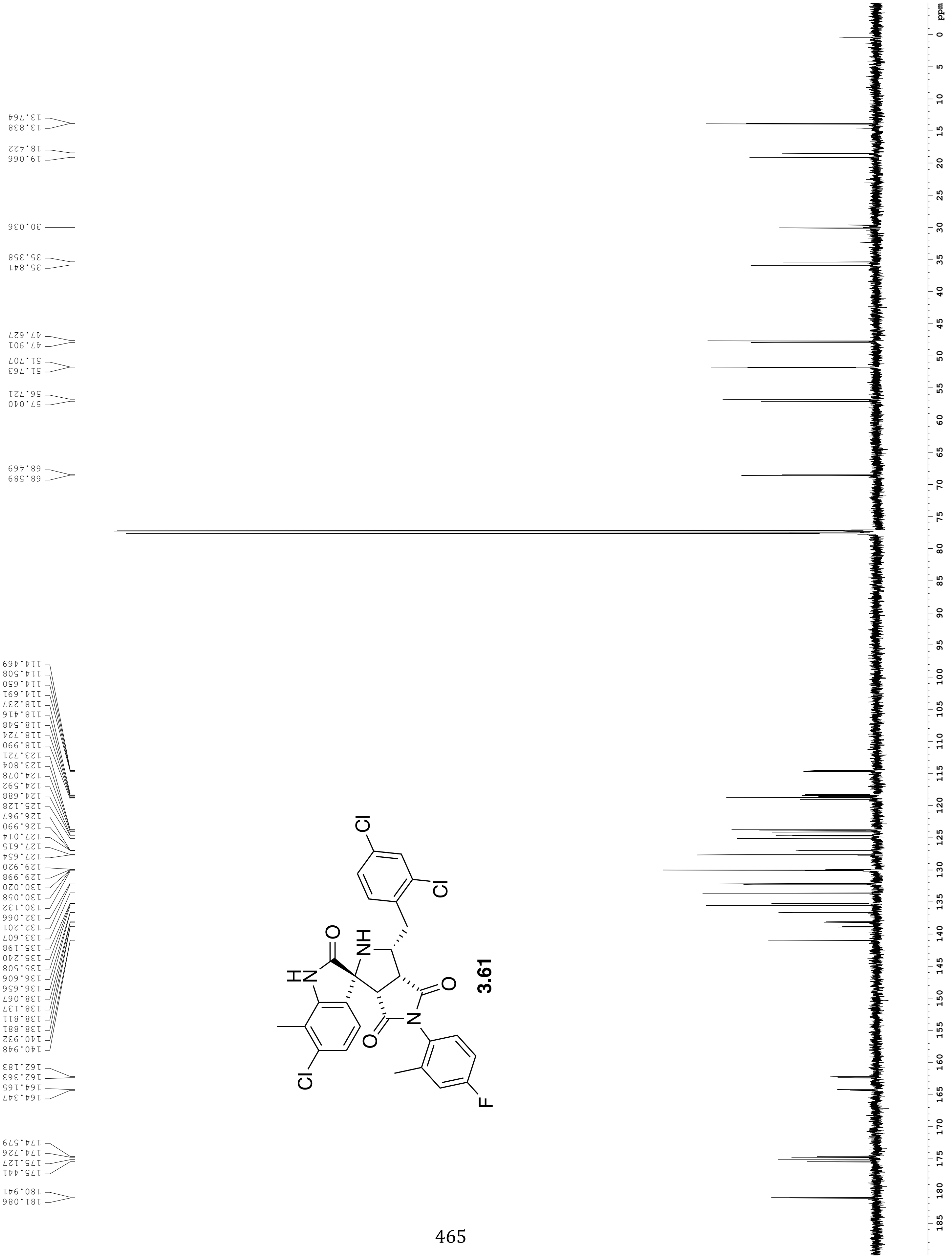


ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
13.727
13.805
18.399
18.991
31.818
32.207
47.744
48.035
51.793
51.824
57.251
57.776
68.531
68.647
114.408
114.486
114.590
114.668
115.870
115.897
116.045
116.072
118.229
118.408
118.490
118.627
118.670
118.891
123.629
123.730
124.171
124.549
124.582
124.612
124.688
124.802
125.248
126.175
126.239
126.298
126.362
127.041
127.064
127.089
128.785
128.849
130.002
130.080
130.158
131.330
131.366
131.441
131.477
136.513
136.561
138.199
138.269
138.820
138.889
140.944
160.437
160.488
162.170
162.348
162.391
162.443
164.152
164.330
174.651
174.780
175.203
175.421
181.072
181.187
F
NH
O
O
N
H
N
O
Cl
F

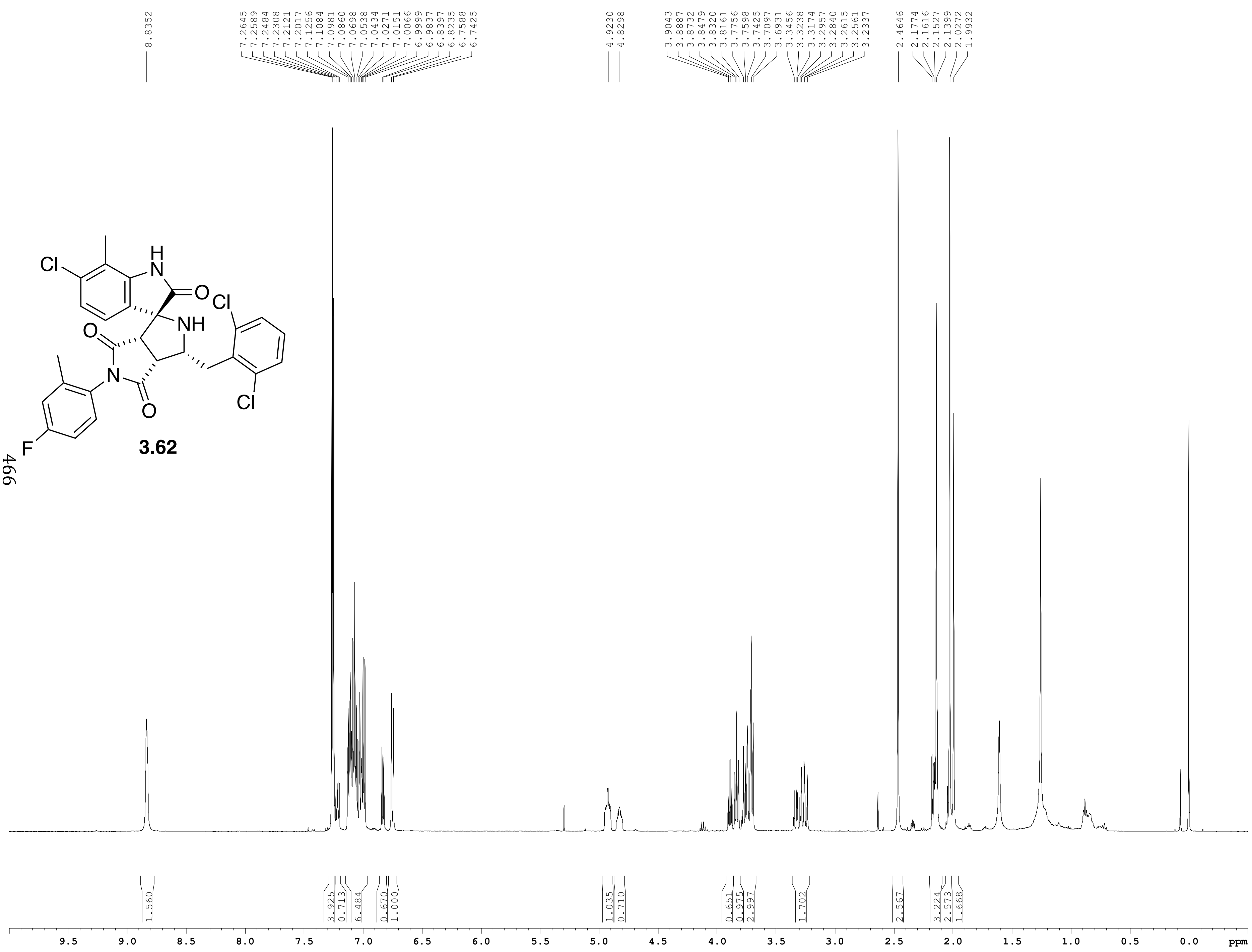
**3.60**


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
1.9603
2.0208
2.0931
2.0991
2.1174
2.1353
2.4434
2.7752
2.7954
2.8030
2.8233
2.8418
2.8606
2.8696
2.8885
3.5530
3.5599
3.5743
3.5815
3.5877
3.6020
3.6103
3.7104
3.7264
3.7453
3.7573
3.7618
3.7729
3.7885
3.8147
3.8306
4.7410
4.7491
4.7629
4.7785
4.7987
4.8048
4.8139
4.8194
4.8251
4.8332
4.8403
6.7476
6.7639
6.8308
6.8470
6.9886
7.0049
7.0225
7.0394
7.0557
7.0702
7.0944
7.1053
7.1123
7.1248
7.1294
7.1414
7.1457
7.2084
7.2188
7.2254
7.2314
7.2479
7.3027
7.3192
7.3619
7.3661
7.3698
7.3741
2.201
2.756
3.748
2.735
1.888
1.737
3.494
1.859
1.000
0.810
7.465
1.735
0.786
1.615
1.815
Cl
Cl
NH
O
H
N
O
O
N
Cl
F

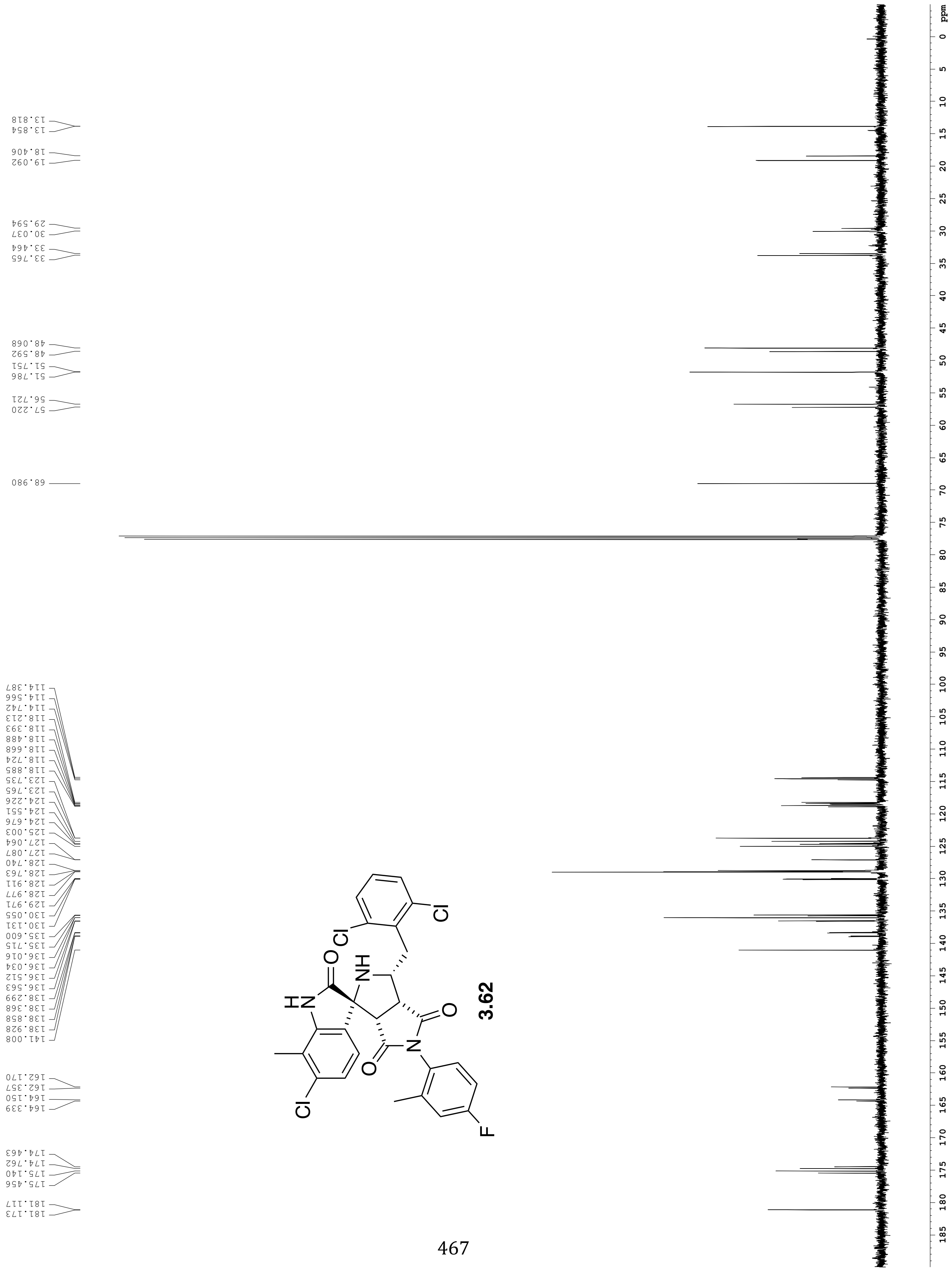
**3.61**


13.764
13.838
18.422
19.066
30.036
35.358
35.841
47.627
47.901
51.707
51.763
56.721
57.040
68.469
68.589
114.469
114.508
114.650
114.691
118.237
118.416
118.548
118.724
118.990
123.721
123.804
124.078
124.592
124.688
125.128
126.967
126.990
127.014
127.615
127.654
129.920
129.998
130.020
130.058
130.132
132.066
132.201
133.607
135.198
135.240
135.508
136.606
136.656
138.067
138.137
138.811
138.881
140.932
140.948
162.183
162.363
164.165
164.347
174.579
174.726
175.127
175.441
180.941
181.086
Cl
Cl
NH
O
H
N
O
O
N
Cl
F
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185

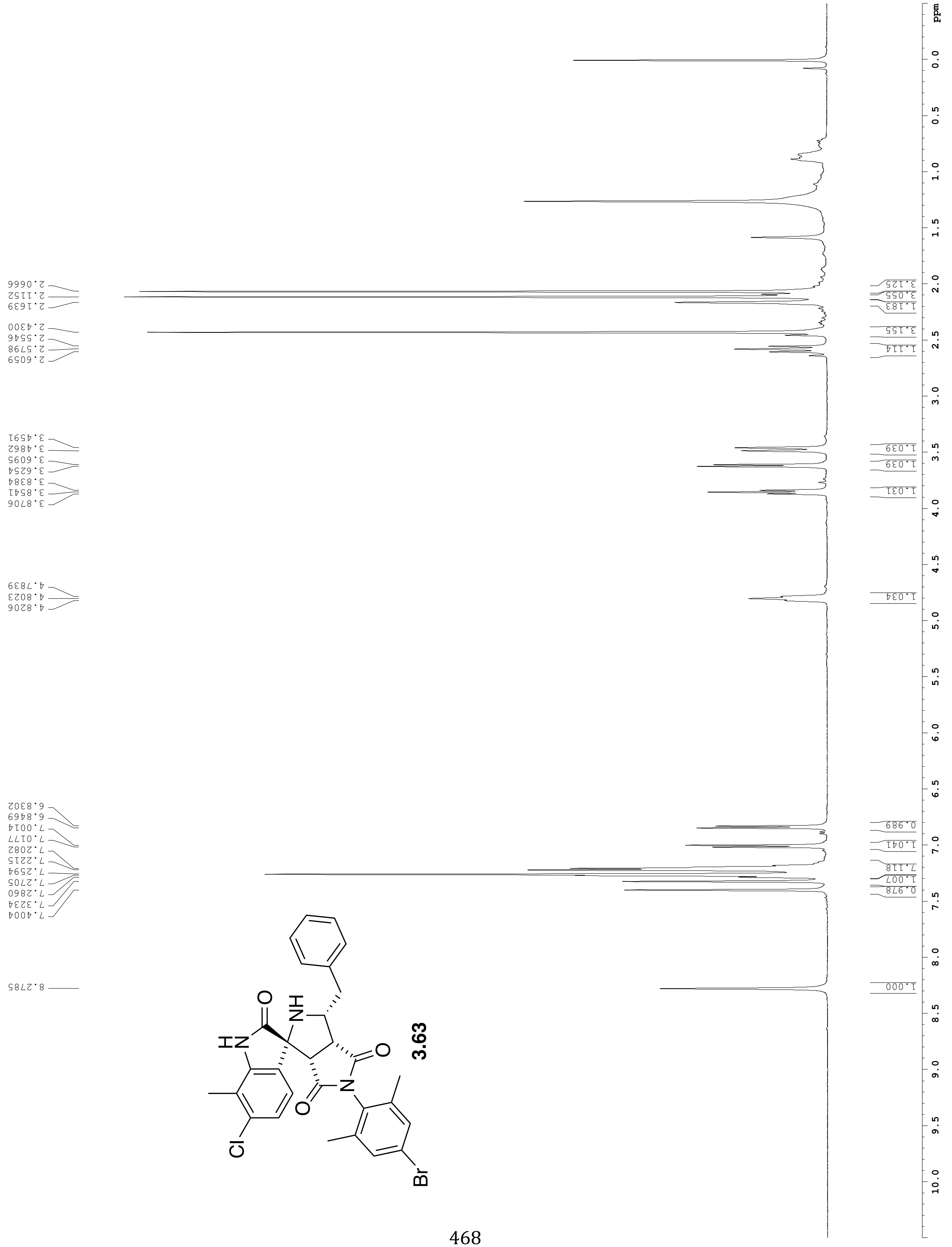
**3.61**


8.8352
7.2645
7.2589
7.2484
7.2308
7.2121
7.2017
7.1256
7.1084
7.0981
7.0860
7.0698
7.0538
7.0434
7.0271
7.0151
7.0066
6.9999
6.9837
6.8397
6.8235
6.7588
6.7425
4.9230
4.8298
3.9043
3.8887
3.8732
3.8479
3.8320
3.8161
3.7756
3.7598
3.7425
3.7097
3.6931
3.3456
3.3238
3.3174
3.2957
3.2840
3.2615
3.2561
3.2337
2.4646
2.1774
2.1616
2.1527
2.1399
2.0272
1.9932
Cl
H
N
O
Cl
NH
O
N
O
Cl
F
1.560
3.925
0.713
6.484
0.670
1.000
1.035
0.710
0.651
0.975
2.997
1.702
2.567
3.224
2.573
1.668
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

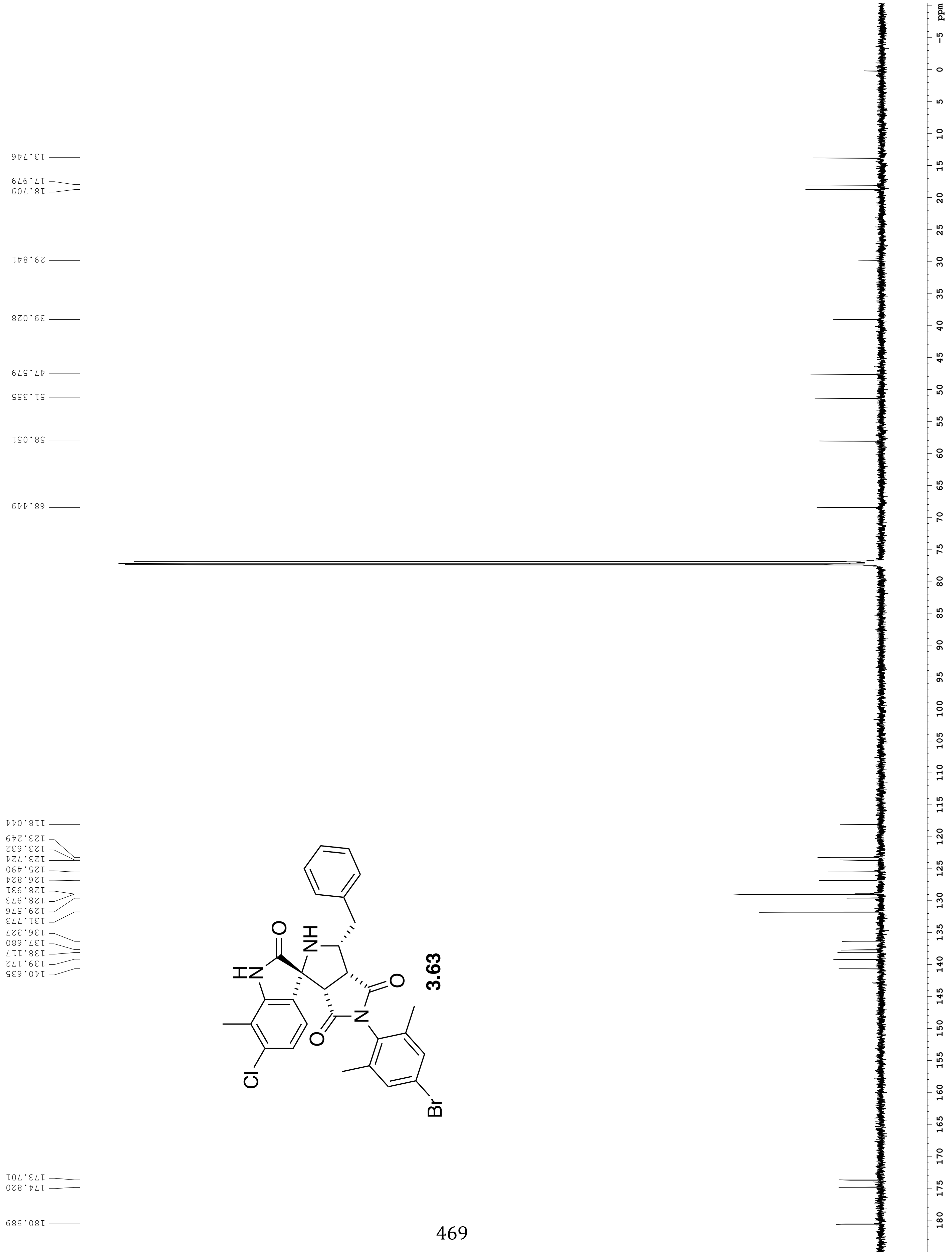
**3.62**


13.818
13.854
18.406
19.092
29.594
30.037
33.464
33.765
48.068
48.592
51.751
51.786
56.721
57.220
68.980
114.387
114.566
114.742
118.213
118.393
118.488
118.668
118.724
118.885
123.735
123.765
124.226
124.551
124.676
125.003
127.064
127.087
128.740
128.763
128.911
128.977
129.971
130.055
130.131
135.600
135.715
136.016
136.034
136.512
136.563
138.299
138.368
138.858
138.928
141.008
162.170
162.357
164.150
164.339
174.463
174.762
175.140
175.456
181.117
181.173
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
Cl
Cl
O
NH
HN
O
N
O
Cl
F

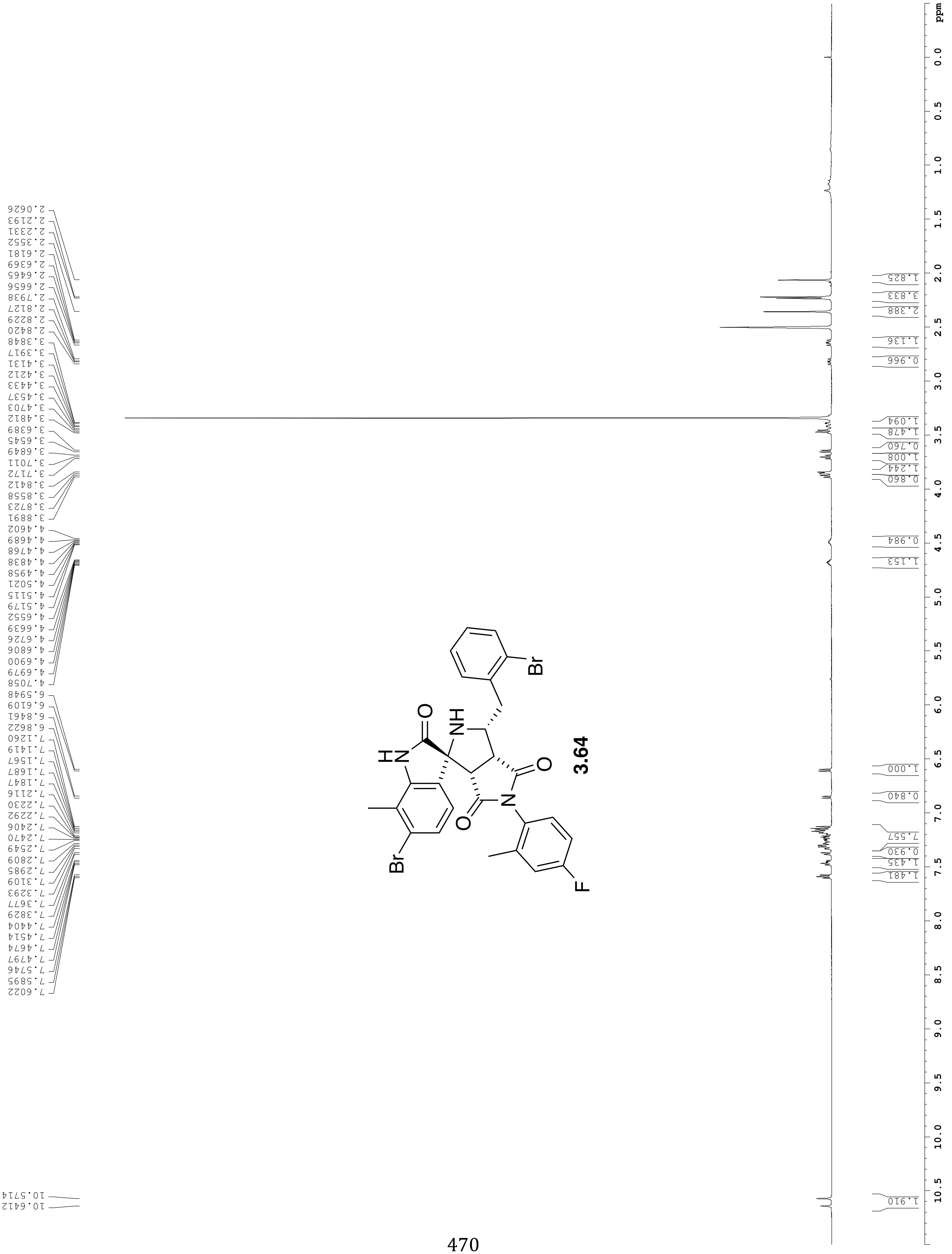
**3.62**


2.0666
2.1152
2.1639
2.4300
2.5546
2.5798
2.6059
3.4591
3.4862
3.6095
3.6254
3.8384
3.8541
3.8706
4.7839
4.8023
4.8206
6.8302
6.8469
7.0014
7.0177
7.2082
7.2215
7.2594
7.2705
7.2860
7.3234
7.4004
8.2785
3.125
3.055
1.183
3.155
1.114
1.039
1.039
1.031
1.034
0.989
1.041
7.118
1.007
0.978
1.000
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
O
NH
H
N
Cl
O
N
O
Br

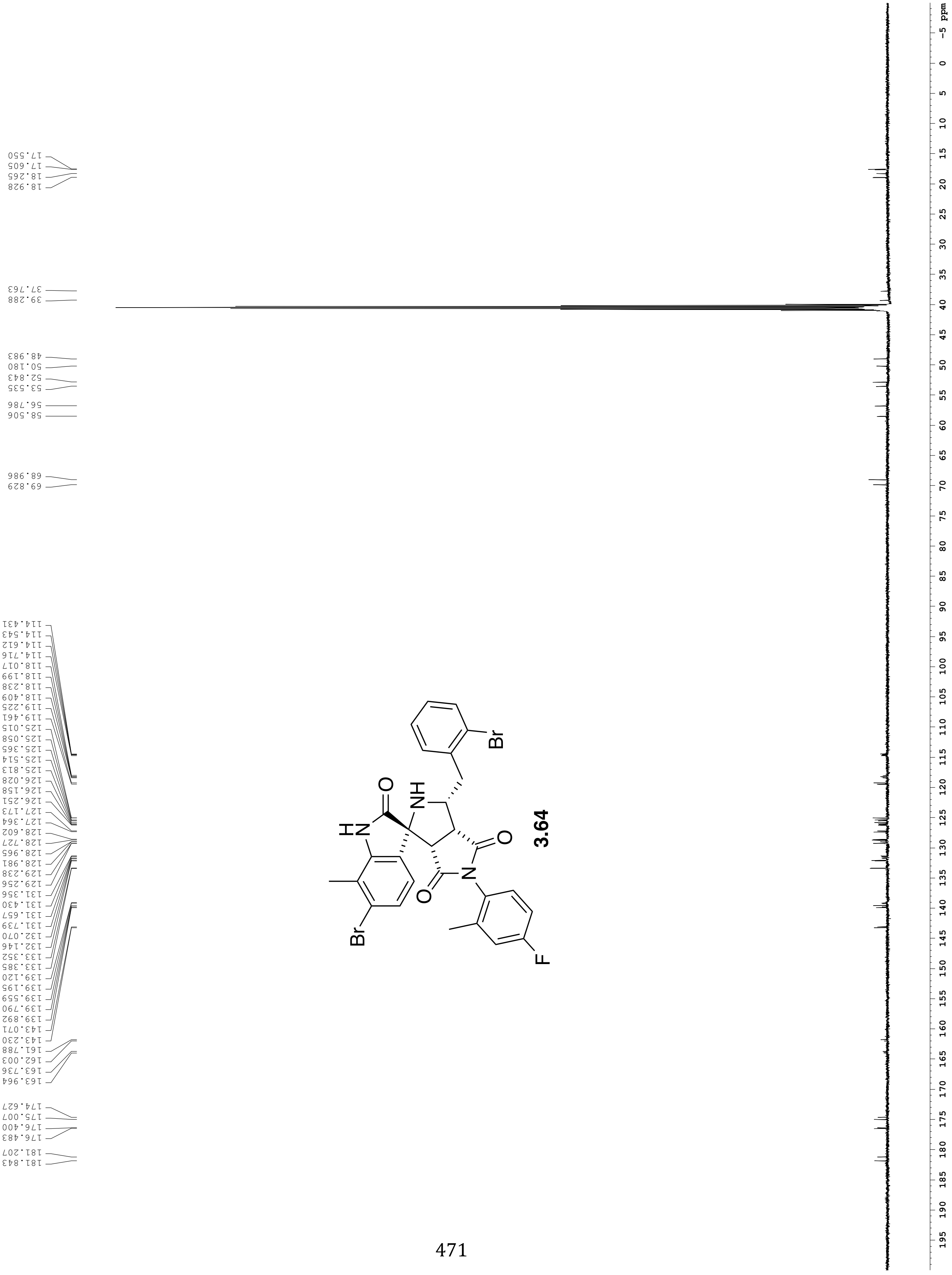
**3.63**

13.746
17.979
18.709
29.841
39.028
47.579
51.355
58.051
68.449
118.044
123.249
123.632
123.724
125.490
126.824
128.931
128.973
129.576
131.773
136.327
137.680
138.111
139.172
140.635
173.701
174.820
180.589
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
O
NH
HN
O
O
N
Cl
Br

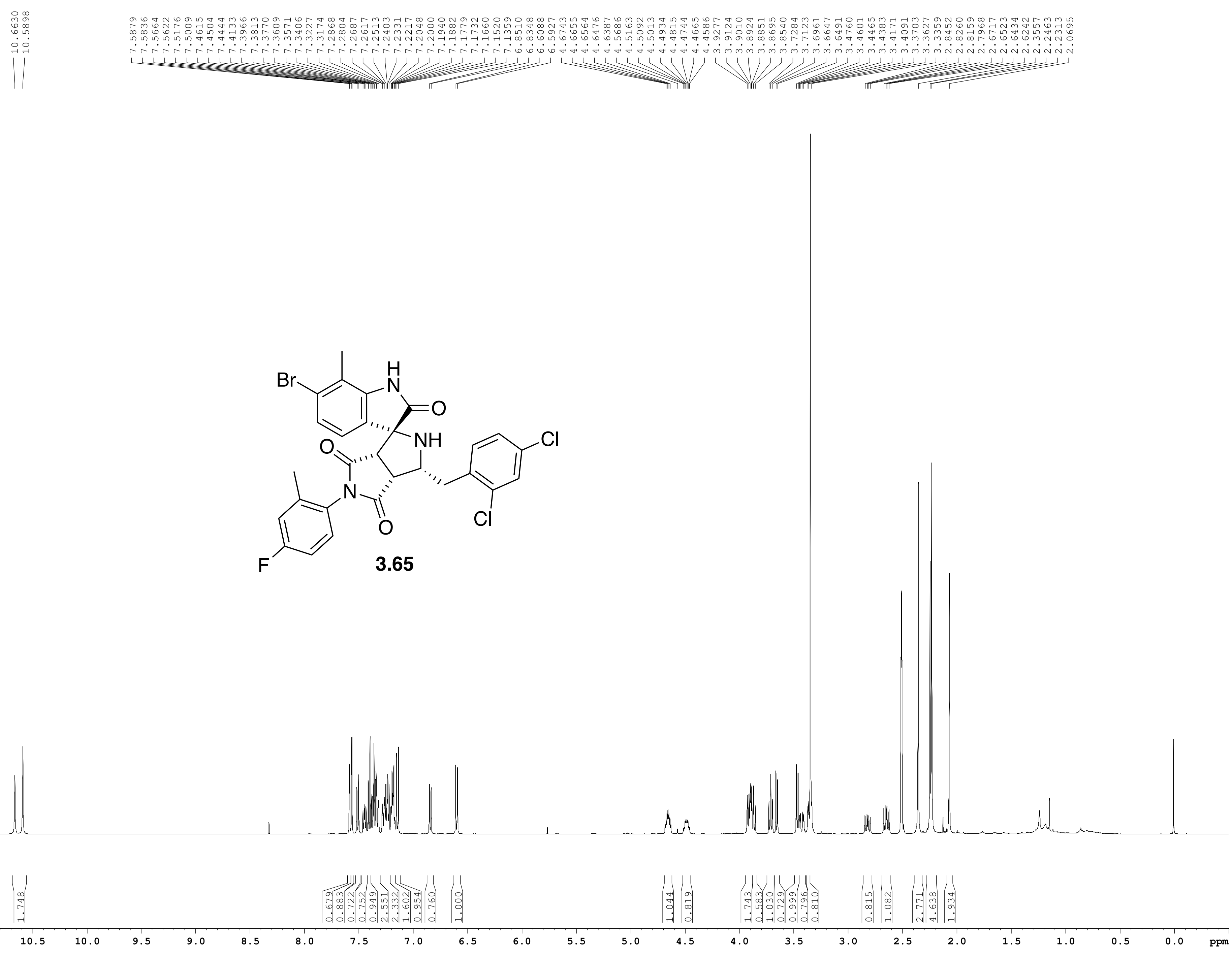
**3.63**


2.0626
2.2193
2.2331
2.3552
2.6181
2.6369
2.6465
2.6656
2.7938
2.8127
2.8229
2.8420
3.3848
3.3917
3.4131
3.4212
3.4433
3.4537
3.4703
3.4812
3.6389
3.6545
3.6849
3.7011
3.7172
3.8412
3.8558
3.8723
3.8881
4.4602
4.4689
4.4768
4.4838
4.4958
4.5021
4.5115
4.5179
4.6552
4.6639
4.6726
4.6806
4.6900
4.6979
4.7058
6.5948
6.6109
6.8461
6.8622
7.1260
7.1419
7.1567
7.1687
7.1847
7.2116
7.2230
7.2292
7.2406
7.2470
7.2549
7.2809
7.2985
7.3109
7.3293
7.3677
7.3829
7.4404
7.4514
7.4674
7.4797
7.5546
7.5895
7.6022
10.5714
10.6412
1.825
3.833
2.388
1.136
0.966
1.094
1.478
0.760
1.008
1.244
0.860
0.984
1.153
1.000
0.840
7.557
0.930
1.435
1.481
1.910
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
Br
NH
O
H
N
O
N
O
Br
F

**3.64**

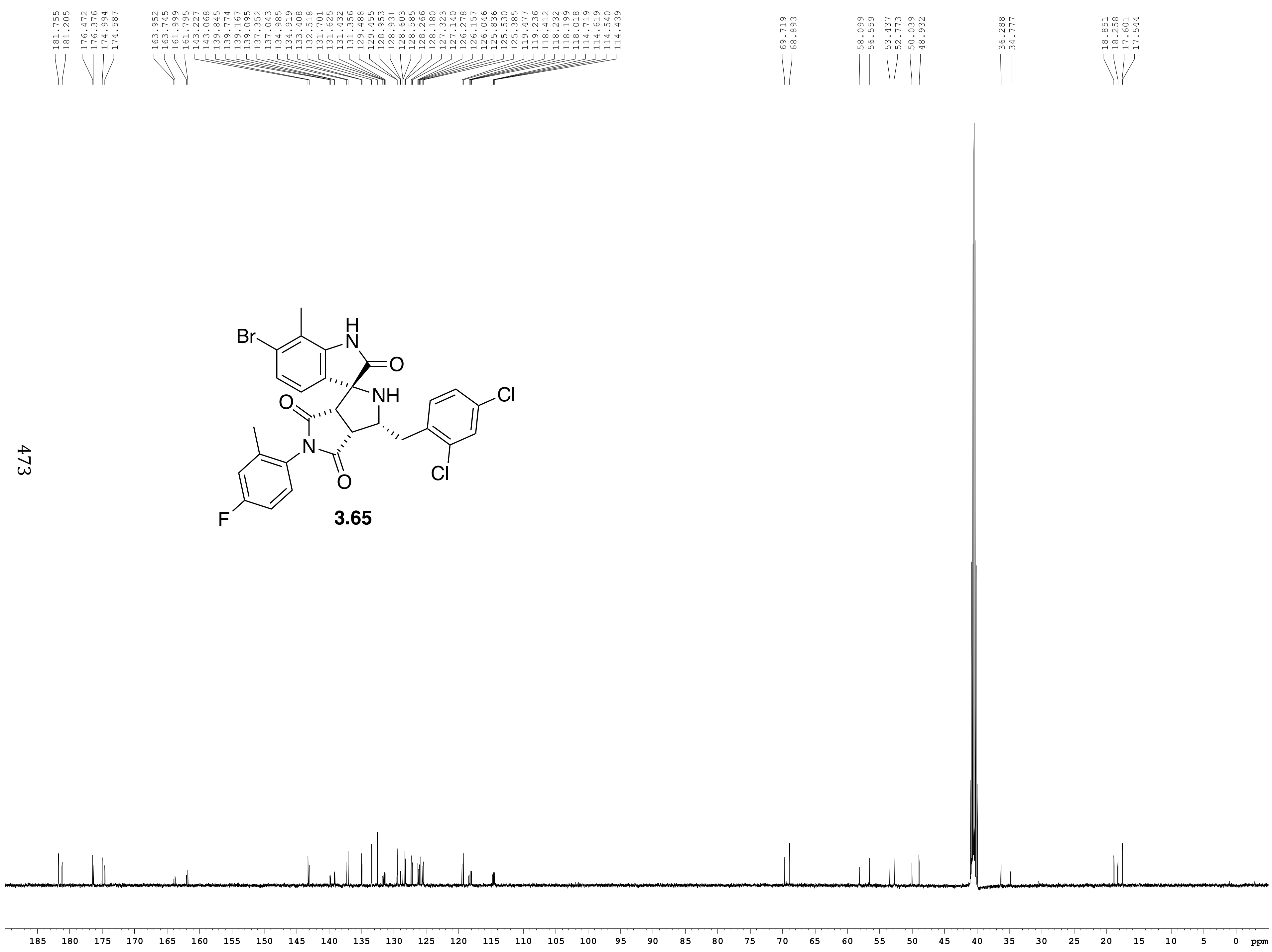

17.550
17.605
18.265
18.928
37.763
39.288
48.983
50.180
52.843
53.535
56.786
58.506
68.986
69.829
114.431
114.543
114.612
114.716
118.017
118.199
118.238
118.409
119.225
119.461
125.015
125.058
125.365
125.514
125.813
126.028
126.158
126.251
127.173
127.364
128.602
128.727
128.965
128.981
129.238
129.256
131.356
131.430
131.657
131.739
132.070
132.146
133.352
133.385
139.120
139.195
139.559
139.790
139.892
143.071
143.230
161.788
162.003
163.736
163.964
174.627
175.007
176.400
176.483
181.207
181.843
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
Br
NH
O
HN
O
O
N
Br
F

**3.64**



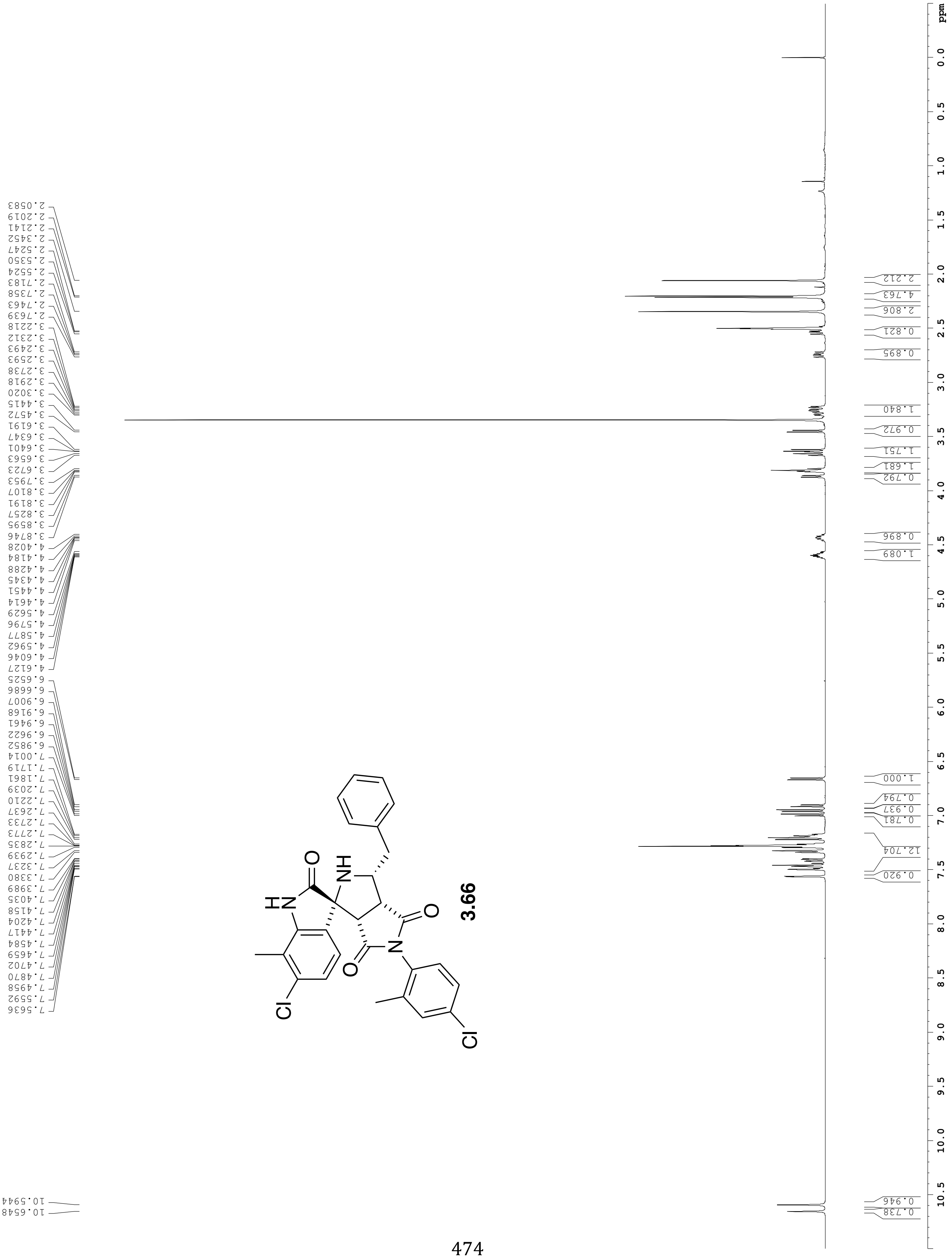
**3.65**

10.6630
10.5898
7.5879
7.5836
7.5664
7.5622
7.5176
7.5009
7.4615
7.4504
7.4444
7.4133
7.3966
7.3813
7.3770
7.3609
7.3571
7.3406
7.3227
7.3174
7.2868
7.2804
7.2687
7.2617
7.2513
7.2403
7.2331
7.2217
7.2048
7.2000
7.1940
7.1882
7.1779
7.1732
7.1660
7.1520
7.1359
6.8510
6.8348
6.6088
6.5927
4.6743
4.6655
4.6564
4.6476
4.6387
4.5686
4.5163
4.5092
4.5013
4.4934
4.4815
4.4744
4.4665
4.4586
3.9277
3.9124
3.9010
3.8924
3.8851
3.8695
3.8540
3.7284
3.7123
3.6961
3.6647
3.6491
3.4760
3.4601
3.4465
3.4383
3.4171
3.4091
3.3703
3.3627
3.3359
2.8452
2.8260
2.8159
2.7968
2.6717
2.6523
2.6434
2.6242
2.3557
2.2463
2.2313
2.0695
Br
H
N
O
O
NH
Cl
N
O
Cl
F
1.748
0.679
0.883
0.722
0.752
0.949
2.551
2.332
1.602
0.954
0.760
1.000
1.044
0.819
1.743
0.583
1.030
0.729
0.999
0.796
0.810
0.815
1.082
2.771
4.638
1.934
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

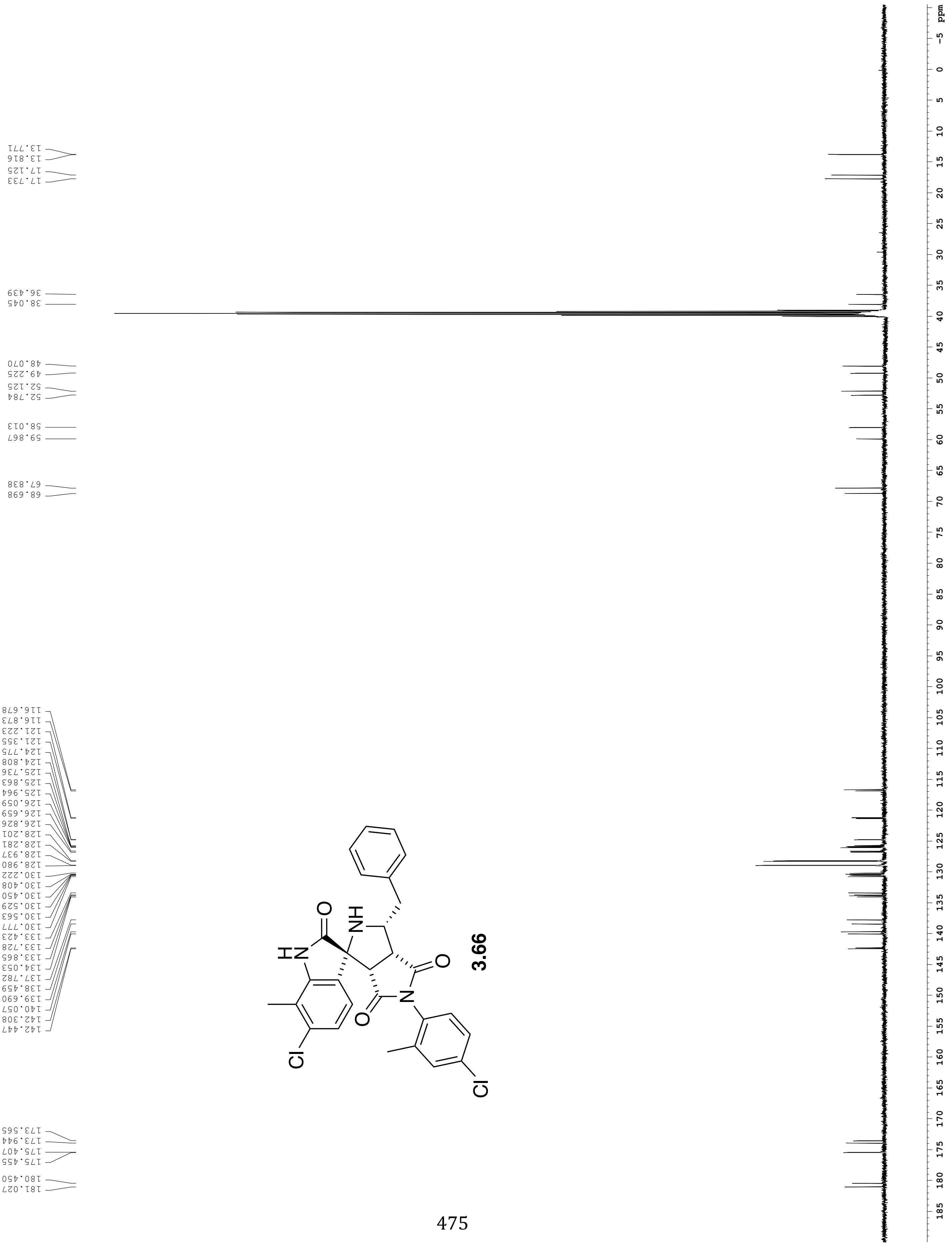


**3.65**

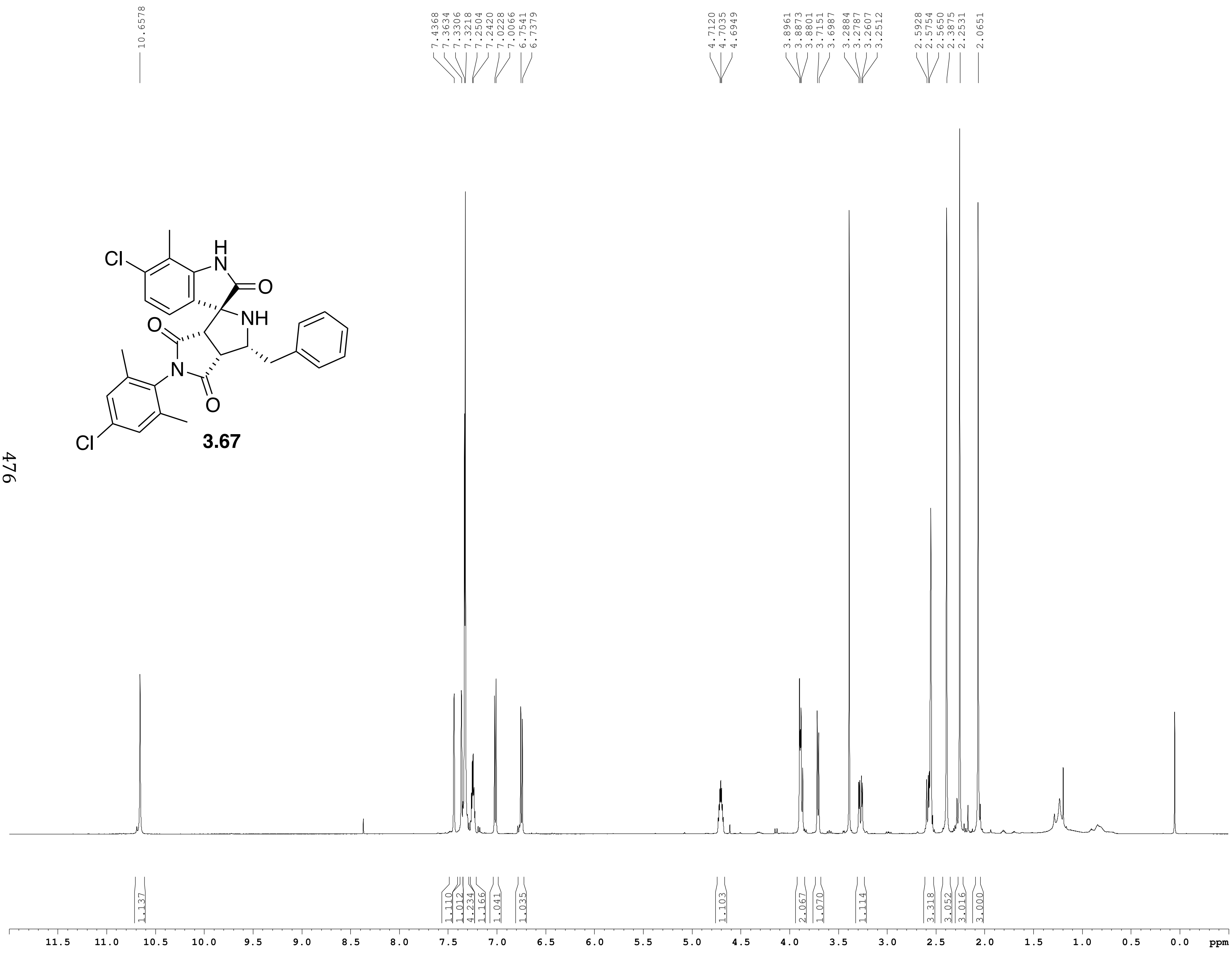
181.755
181.205
176.472
176.376
174.994
174.587
163.952
163.745
161.999
161.795
143.227
143.068
139.845
139.774
139.167
139.095
137.352
137.043
134.985
134.919
133.408
132.518
131.701
131.625
131.432
131.356
129.488
129.455
128.953
128.931
128.603
128.585
128.266
128.180
127.323
127.140
126.278
126.157
126.046
125.836
125.530
125.385
119.477
119.236
118.412
118.232
118.199
118.018
114.719
114.619
114.540
114.439
69.719
68.893
58.099
56.559
53.437
52.773
50.039
48.932
36.288
34.777
18.851
18.258
17.601
17.544
Br
H
N
O
NH
Cl
O
N
O
Cl
F
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
ppm


2.0583
2.2019
2.2141
2.3452
2.5247
2.5350
2.5524
2.7183
2.7358
2.7463
2.7639
3.2218
3.2312
3.2493
3.2593
3.2738
3.2918
3.3020
3.3415
3.4572
3.6191
3.6347
3.6401
3.6563
3.6723
3.7953
3.8107
3.8191
3.8257
3.8595
3.8746
4.4028
4.4184
4.4288
4.4345
4.4451
4.4614
4.5629
4.5796
4.5877
4.5962
4.6046
4.6127
6.6525
6.6686
6.9007
6.9168
6.9461
6.9622
6.9852
7.0014
7.1719
7.1861
7.2039
7.2210
7.2637
7.2733
7.2773
7.2835
7.2937
7.3237
7.3380
7.3989
7.4035
7.4158
7.4204
7.4417
7.4584
7.4659
7.4702
7.4870
7.4958
7.5592
7.5636
10.5944
10.6548
2.212
4.763
2.806
0.821
0.895
1.840
0.972
1.751
1.681
0.792
0.896
1.089
1.000
0.794
0.937
0.781
12.704
0.920
0.946
0.738
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
O
NH
H
N
O
O
N
Cl
Cl

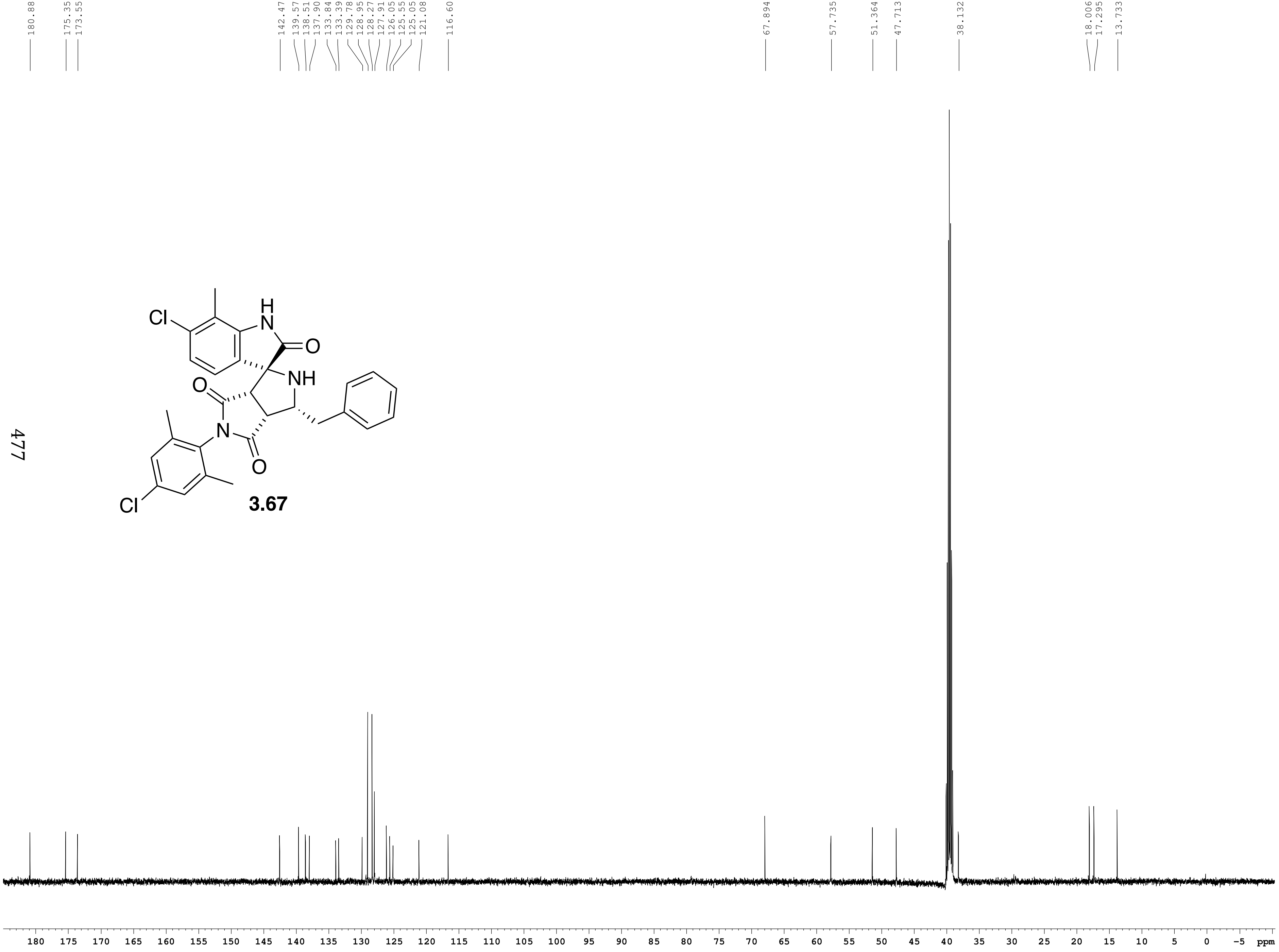
**3.66**


13.771
13.816
17.125
17.733
36.439
38.045
48.070
49.225
52.125
52.784
58.013
59.867
67.838
68.698
116.678
116.873
121.223
121.355
124.775
124.808
125.736
125.863
125.964
126.059
126.659
126.826
128.201
128.281
128.937
128.980
130.222
130.408
130.450
130.529
130.563
130.777
133.423
133.728
133.865
134.053
137.782
138.459
139.690
140.057
142.308
142.447
173.565
173.944
175.407
175.455
180.450
181.027
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
O
NH
HN
O
O
N
Cl
Cl

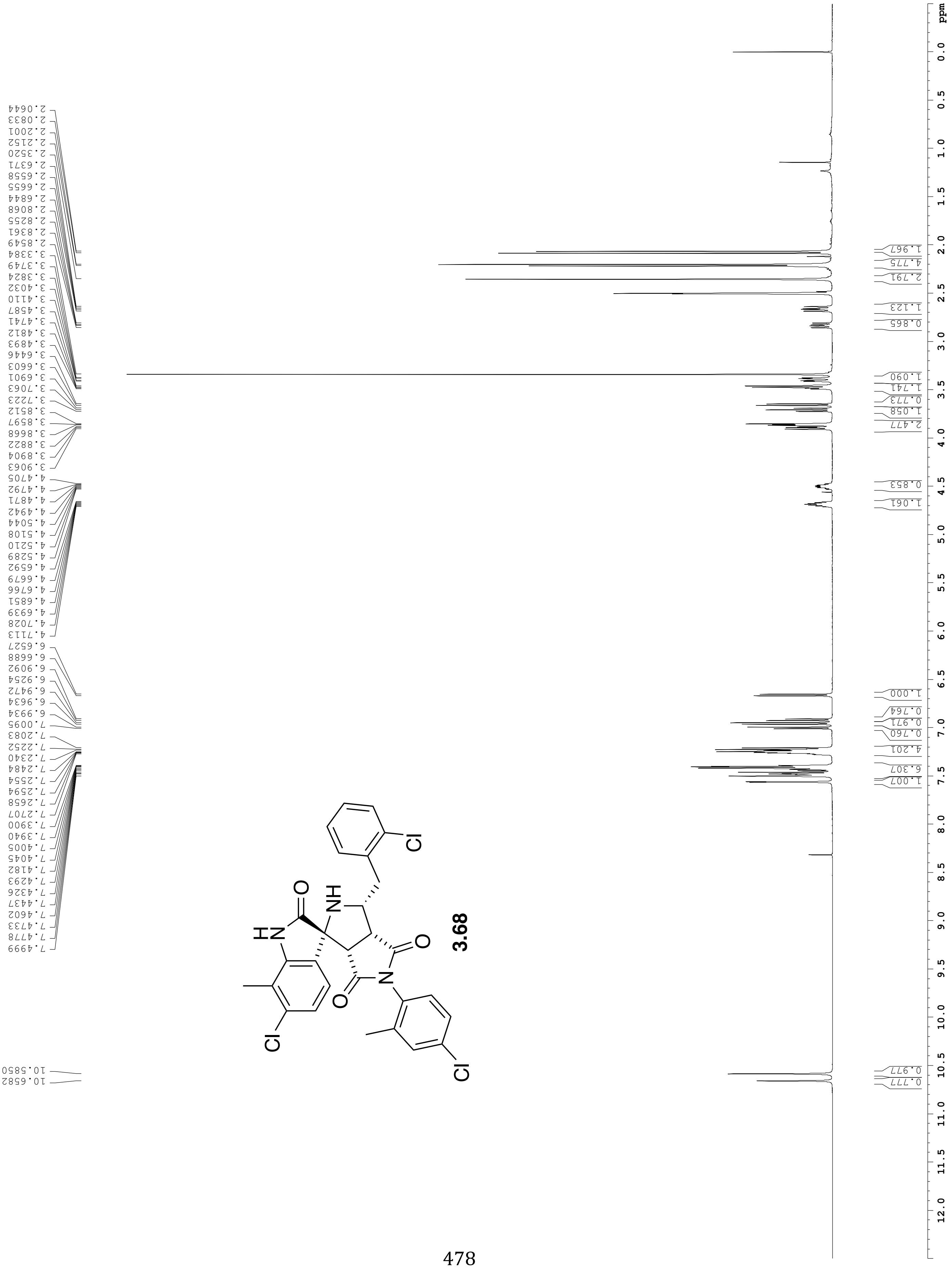
**3.66**


10.6578
7.4368
7.3634
7.3306
7.3218
7.2504
7.2420
7.0228
7.0066
6.7541
6.7379
4.7120
4.7035
4.6949
3.8961
3.8873
3.8801
3.7151
3.6987
3.2884
3.2787
3.2607
3.2512
2.5928
2.5754
2.5650
2.3875
2.2531
2.0651
Cl
H
N
O
NH
O
N
O
Cl
1.137
1.110
1.012
4.234
1.166
1.041
1.035
1.103
2.067
1.070
1.114
3.318
3.052
3.016
3.000
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

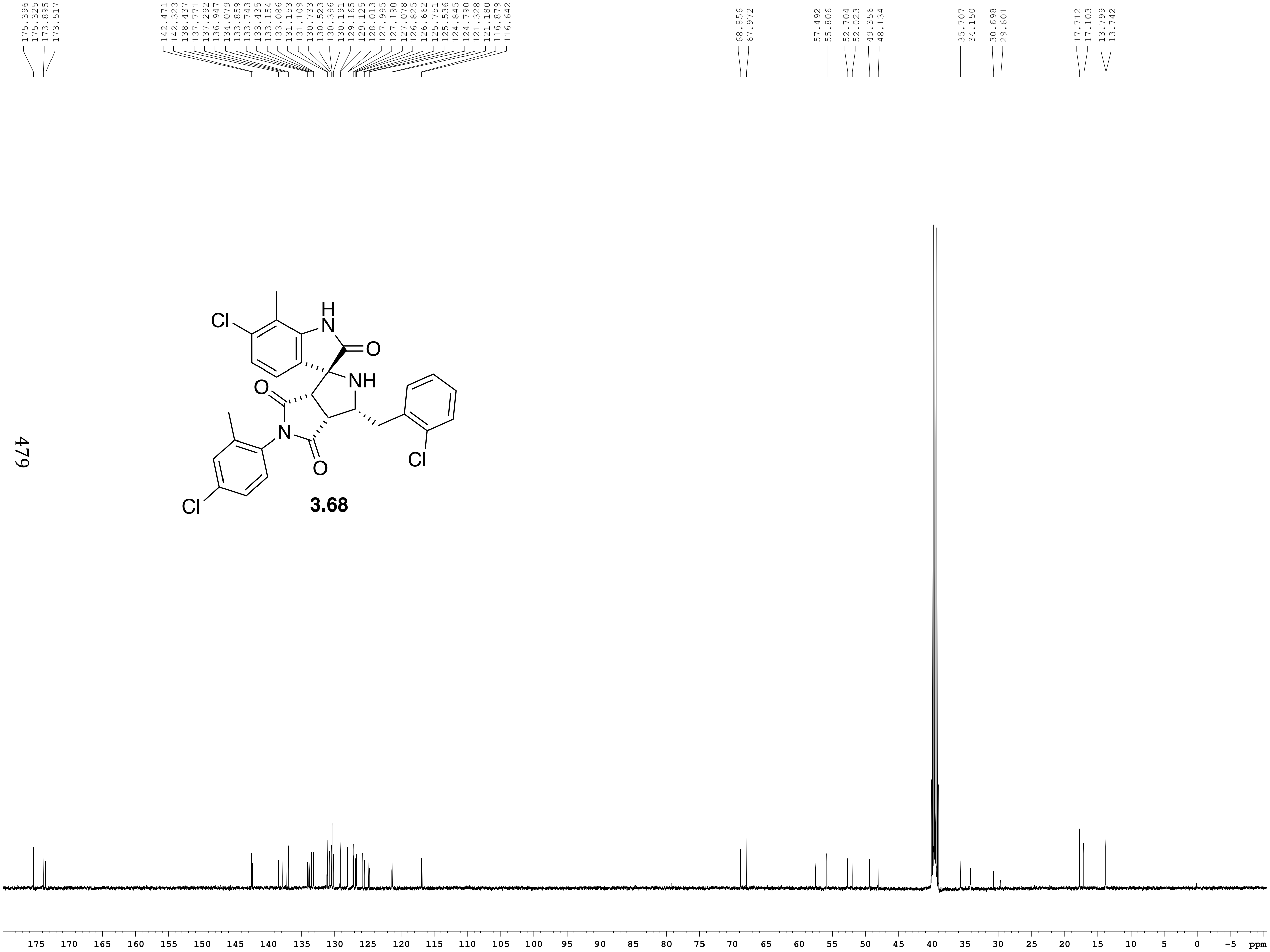
**3.67**


180.881
175.359
173.558
142.477
139.571
138.516
137.902
133.846
133.394
129.789
128.958
128.278
127.910
126.059
125.552
125.050
121.080
116.607
67.894
57.735
51.364
47.713
38.132
18.006
17.295
13.733
Cl
H
N
O
NH
O
N
O
Cl
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
ppm

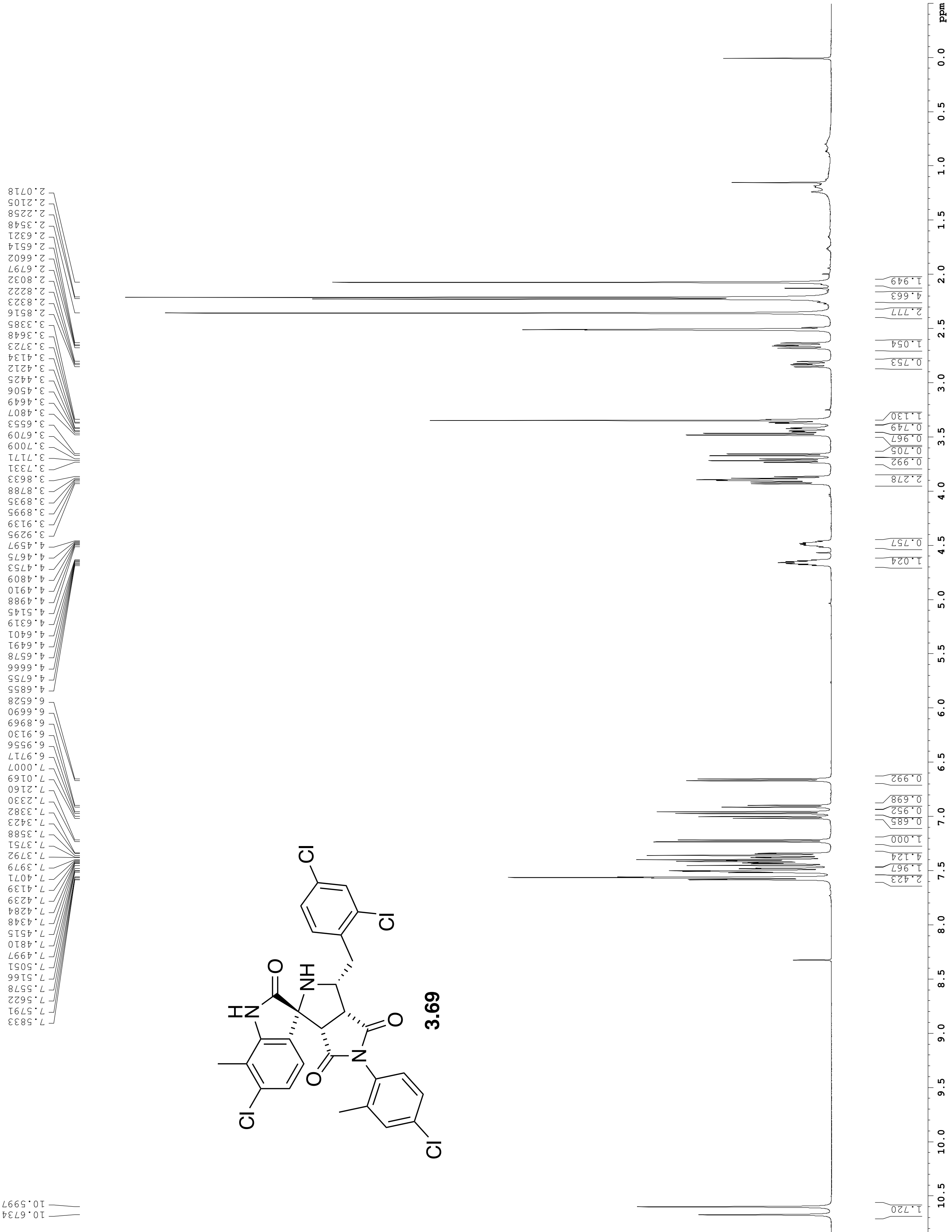
**3.67**


2.0644
2.0833
2.2001
2.2152
2.3520
2.6371
2.6558
2.6655
2.6844
2.8068
2.8255
2.8361
2.8549
3.3384
3.3749
3.3824
3.4032
3.4110
3.4587
3.4741
3.4812
3.4893
3.6446
3.6603
3.6901
3.7063
3.7223
3.8512
3.8597
3.8668
3.8822
3.8904
3.9063
4.4705
4.4792
4.4871
4.4942
4.5044
4.5108
4.5210
4.5289
4.6592
4.6679
4.6766
4.6851
4.6939
4.7028
4.7113
6.6527
6.6688
6.9092
6.9254
6.9472
6.9634
6.9934
7.0095
7.2083
7.2252
7.2340
7.2484
7.2554
7.2594
7.2658
7.2707
7.3900
7.3940
7.4005
7.4045
7.4182
7.4293
7.4326
7.4437
7.4602
7.4733
7.4778
7.4999
10.5850
10.6582
1.967
4.775
2.791
1.123
0.865
1.090
1.741
0.773
1.058
2.477
0.853
1.061
1.000
0.764
0.971
0.760
4.201
6.307
1.007
0.977
0.777
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
Cl
O
NH
H
N
O
N
O
Cl
Cl

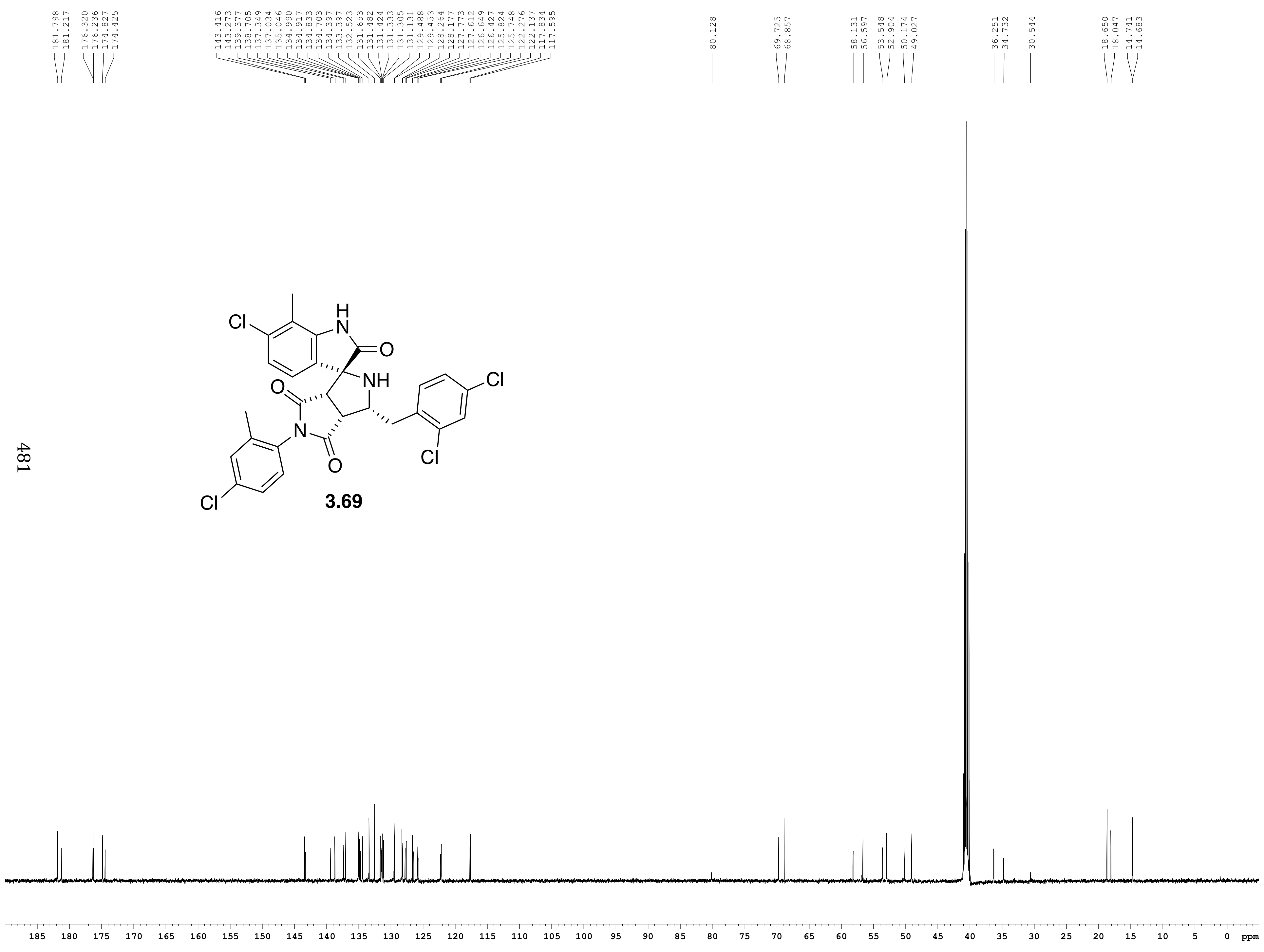
**3.68**


175.396
175.325
173.895
173.517
142.471
142.323
138.437
137.771
137.292
136.947
134.079
133.859
133.743
133.435
133.154
133.086
131.153
131.109
130.733
130.523
130.396
130.191
129.165
129.125
128.013
127.995
127.190
127.078
126.825
126.662
125.751
125.536
124.845
124.790
121.328
121.180
116.879
116.642
68.856
67.972
57.492
55.806
52.704
52.023
49.356
48.134
35.707
34.150
30.698
29.601
17.712
17.103
13.799
13.742
Cl
H
N
O
NH
O
N
O
Cl
Cl
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
ppm

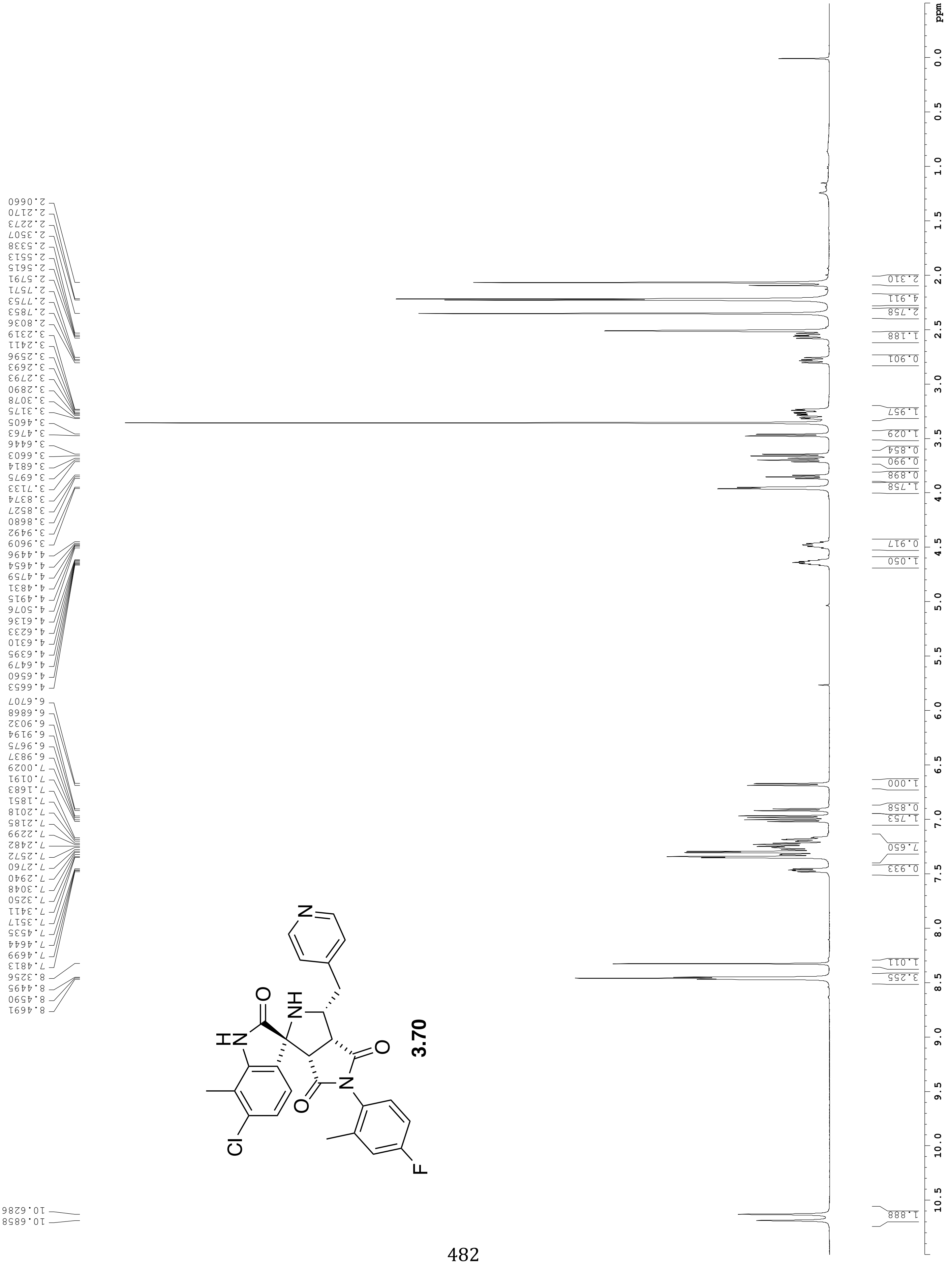
**3.68**


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
2.0718
2.2105
2.2258
2.3548
2.6321
2.6514
2.6602
2.6797
2.8032
2.8222
2.8323
2.8516
3.3385
3.3648
3.3723
3.4134
3.4212
3.4425
3.4506
3.4649
3.4807
3.6553
3.6709
3.7009
3.7171
3.7331
3.8633
3.8788
3.8935
3.8995
3.9139
3.9295
4.4597
4.4675
4.4753
4.4809
4.4910
4.4988
4.5145
4.6319
4.6401
4.6491
4.6578
4.6666
4.6755
4.6855
6.6528
6.6690
6.8969
6.9130
6.9556
6.9717
7.0007
7.0169
7.2160
7.2330
7.3382
7.3423
7.3588
7.3751
7.3792
7.3979
7.4071
7.4139
7.4239
7.4284
7.4348
7.4515
7.4810
7.4997
7.5051
7.5166
7.5578
7.5622
7.5791
7.5833
10.5997
10.6734
1.949
4.663
2.777
1.054
0.753
1.130
0.749
0.967
0.705
0.992
2.278
0.757
1.024
0.992
0.698
0.952
0.685
1.000
4.124
1.967
2.423
1.720
Cl
Cl
NH
O
H
N
O
O
N
Cl
Cl

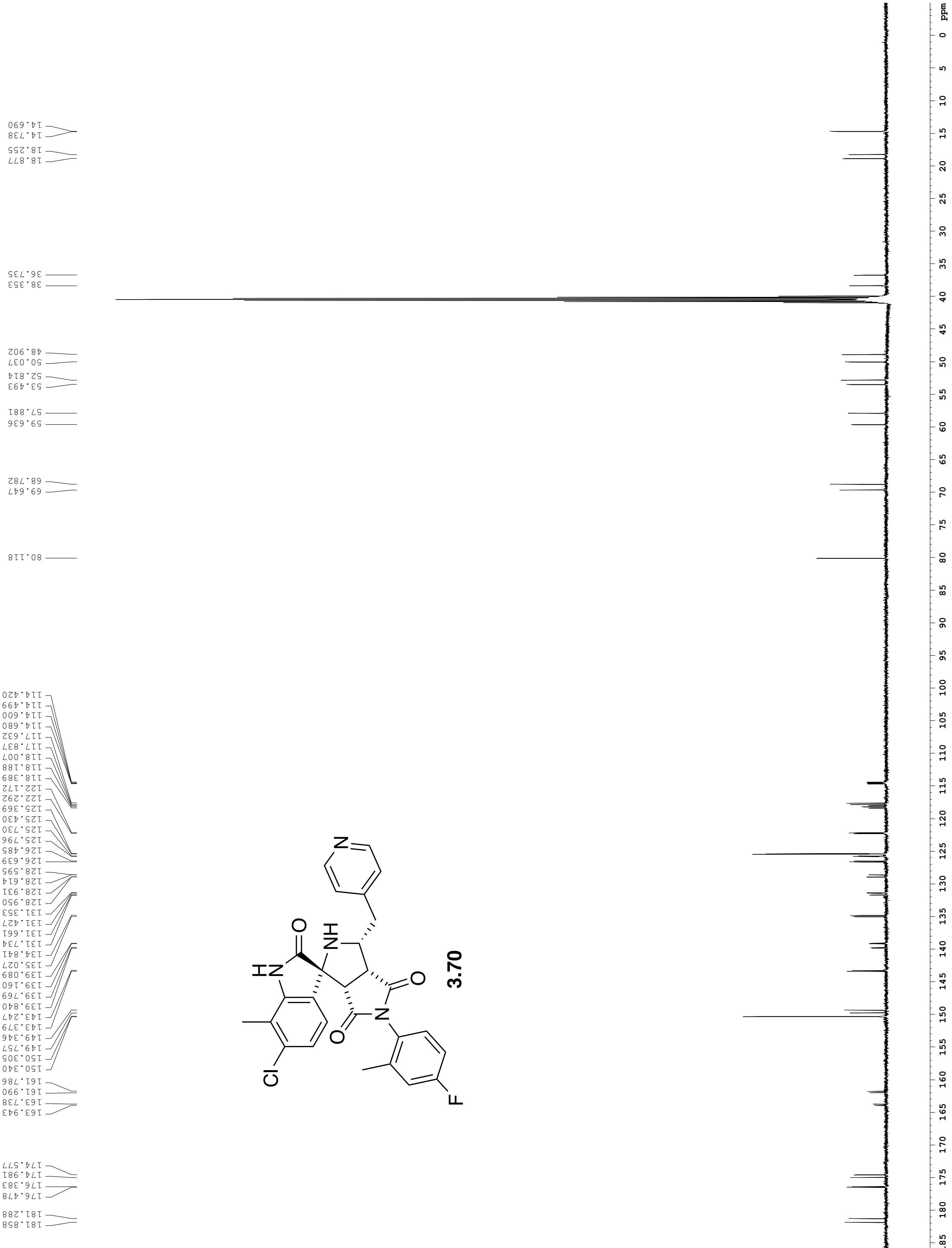
**3.69**


181.798
181.217
176.320
176.236
174.827
174.425
143.416
143.273
139.377
138.705
137.349
137.034
135.046
134.990
134.917
134.833
134.703
134.397
133.397
132.523
131.653
131.482
131.424
131.333
131.305
131.131
129.488
129.453
128.264
128.177
127.773
127.612
126.649
126.427
125.824
125.748
122.276
122.137
117.834
117.595
80.128
69.725
68.857
58.131
56.597
53.548
52.904
50.174
49.027
36.251
34.732
30.544
18.650
18.047
14.741
14.683
Cl
H
N
O
NH
Cl
O
N
O
Cl
Cl
185 180 175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 ppm

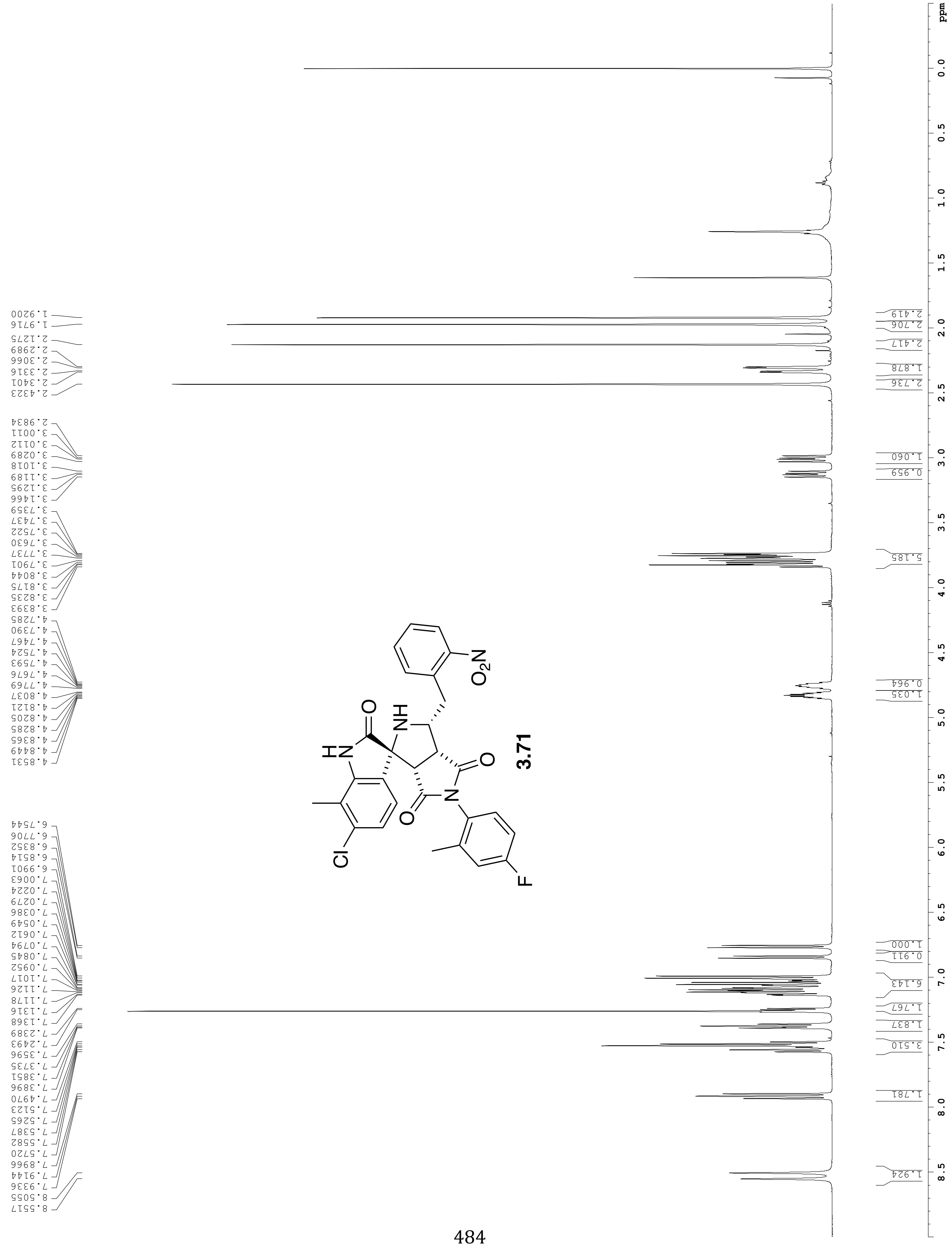
**3.69**


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
2.0660
2.2170
2.2273
2.3507
2.5338
2.5513
2.5615
2.5791
2.7571
2.7753
2.7853
2.8036
3.2319
3.2411
3.2596
3.2693
3.2793
3.2890
3.3078
3.3175
3.4605
3.4763
3.6446
3.6603
3.6814
3.6975
3.7133
3.8374
3.8527
3.8680
3.9492
3.9609
4.4496
4.4654
4.4759
4.4831
4.4915
4.5076
4.6136
4.6233
4.6310
4.6395
4.6479
4.6560
4.6653
6.6707
6.6868
6.9032
6.9194
6.9675
6.9837
7.0029
7.0191
7.1683
7.1851
7.2018
7.2185
7.2299
7.2482
7.2572
7.2760
7.2940
7.3048
7.3250
7.3411
7.3517
7.4535
7.4644
7.4699
7.4813
8.3256
8.4495
8.4590
8.4691
10.6286
10.6858
2.310
4.911
2.758
1.188
0.901
1.957
1.029
0.854
0.990
0.898
1.758
0.917
1.050
1.000
0.858
1.753
7.650
0.933
1.011
3.255
1.888
N
NH
O
H
N
O
N
O
Cl
F

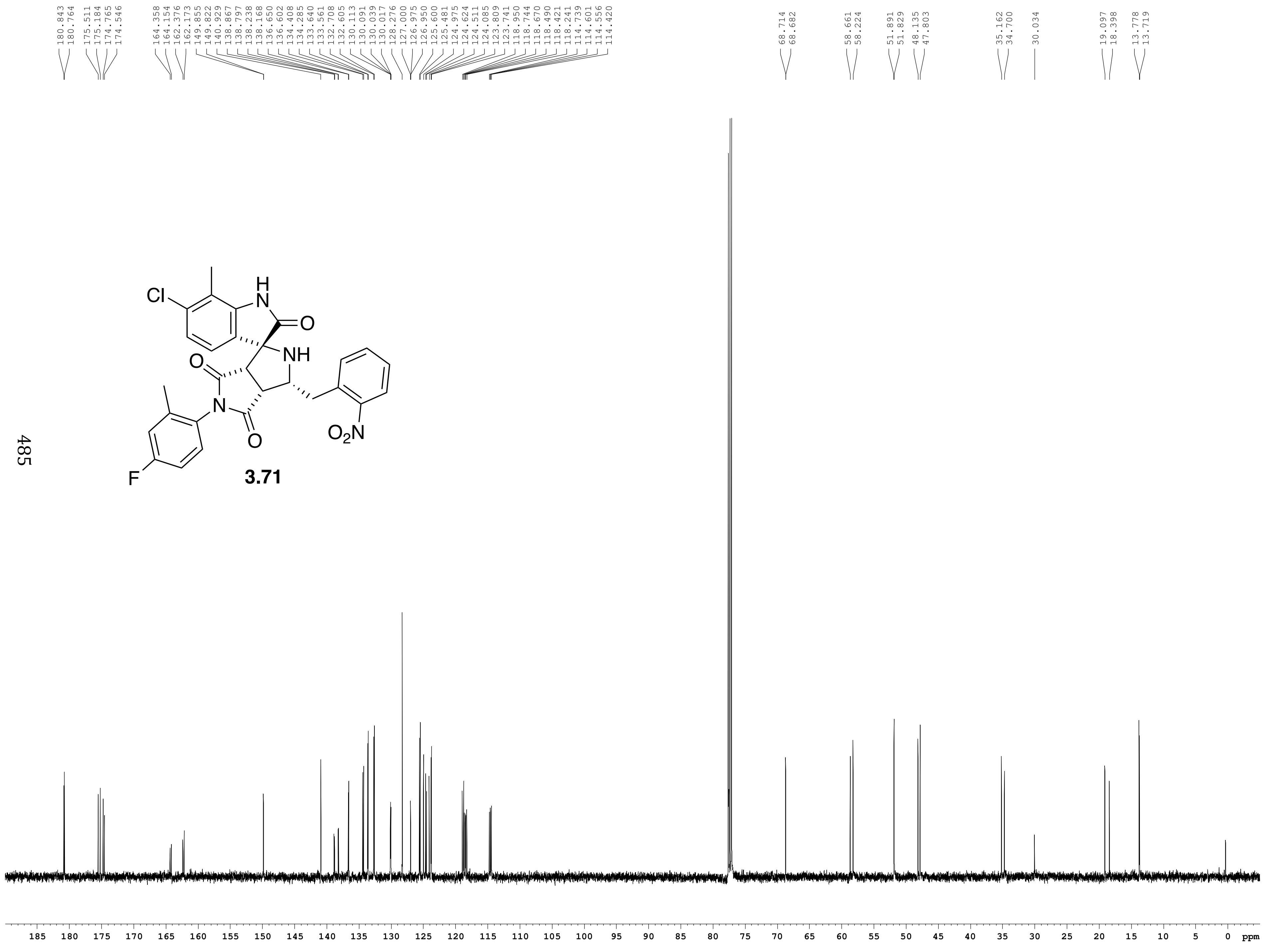
3.70

14.690
14.738
18.255
18.877
36.735
38.353
48.902
50.037
52.814
53.493
57.881
59.636
68.782
69.647
80.118
114.420
114.499
114.600
114.680
117.632
117.837
118.007
118.188
118.389
122.172
122.292
125.369
125.430
125.730
125.796
126.485
126.639
128.595
128.614
128.931
128.950
131.353
131.427
131.661
131.734
134.841
135.027
139.089
139.160
139.769
139.840
143.247
143.379
149.346
149.757
150.305
150.340
161.786
161.990
163.738
163.943
174.577
174.981
176.383
176.478
181.288
181.858
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
N
O
NH
H
N
O
N
O
Cl
F

**3.70**

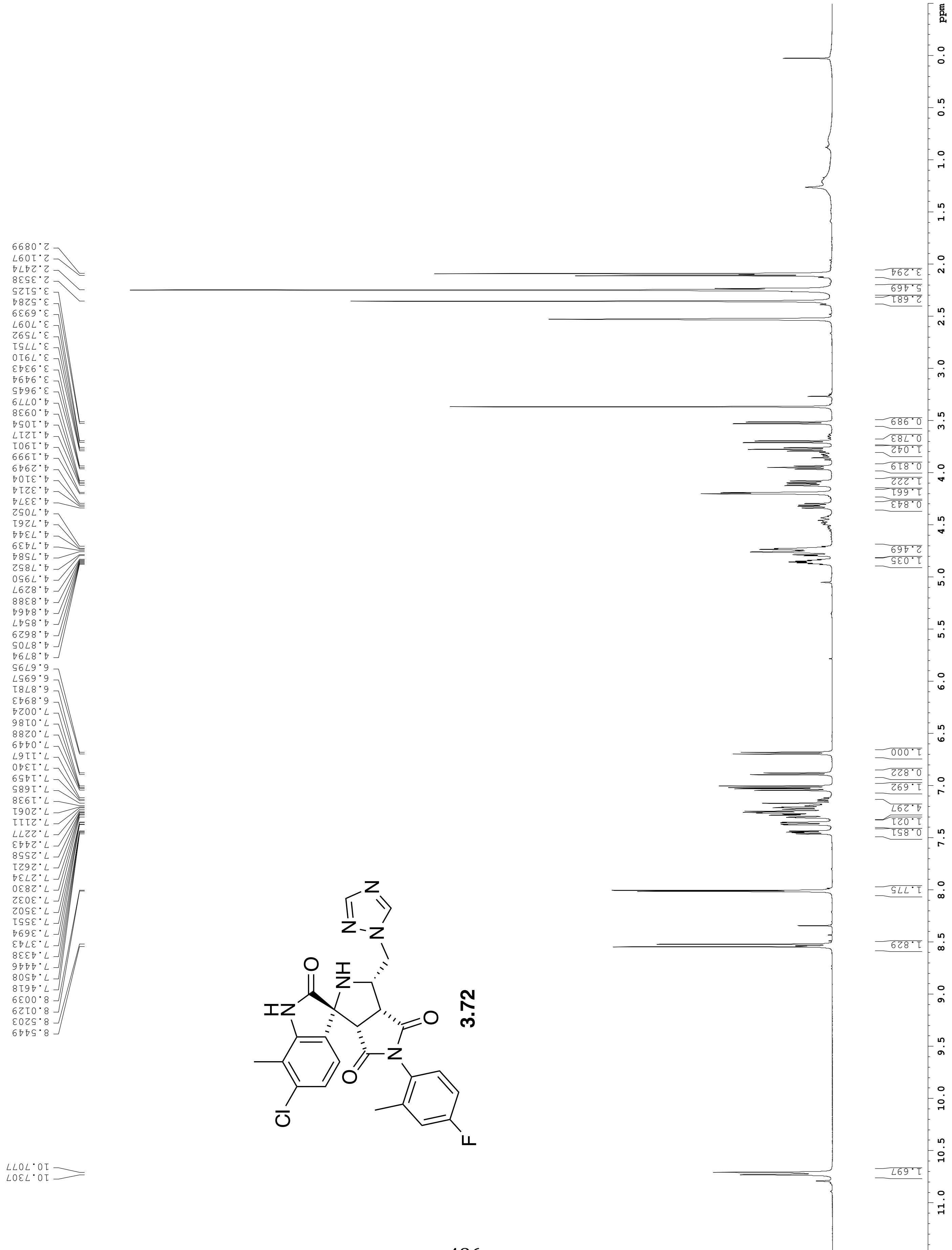

1.9200
1.9716
2.1275
2.2989
2.3066
2.3316
2.3401
2.4323
2.9834
3.0011
3.0112
3.0289
3.1018
3.1189
3.1295
3.1466
3.7359
3.7437
3.7522
3.7630
3.7737
3.7901
3.8044
3.8175
3.8235
3.8393
4.7285
4.7390
4.7467
4.7524
4.7593
4.7676
4.7769
4.8037
4.8121
4.8205
4.8285
4.8365
4.8449
4.8531
6.7544
6.7706
6.8352
6.8514
6.9901
7.0063
7.0224
7.0279
7.0386
7.0549
7.0612
7.0794
7.0845
7.0952
7.1017
7.1126
7.1178
7.1316
7.1368
7.2389
7.2493
7.3596
7.3735
7.3851
7.3896
7.4970
7.5123
7.5265
7.5387
7.5582
7.5720
7.8966
7.9144
7.9336
8.5055
8.5517
O
NH
H
N
Cl
$O_2N$
O
N
O
F
2.419
2.706
2.417
1.878
2.736
1.060
0.959
5.185
0.964
1.035
1.000
0.911
6.143
1.767
1.837
3.510
1.781
1.924
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5

**3.71**

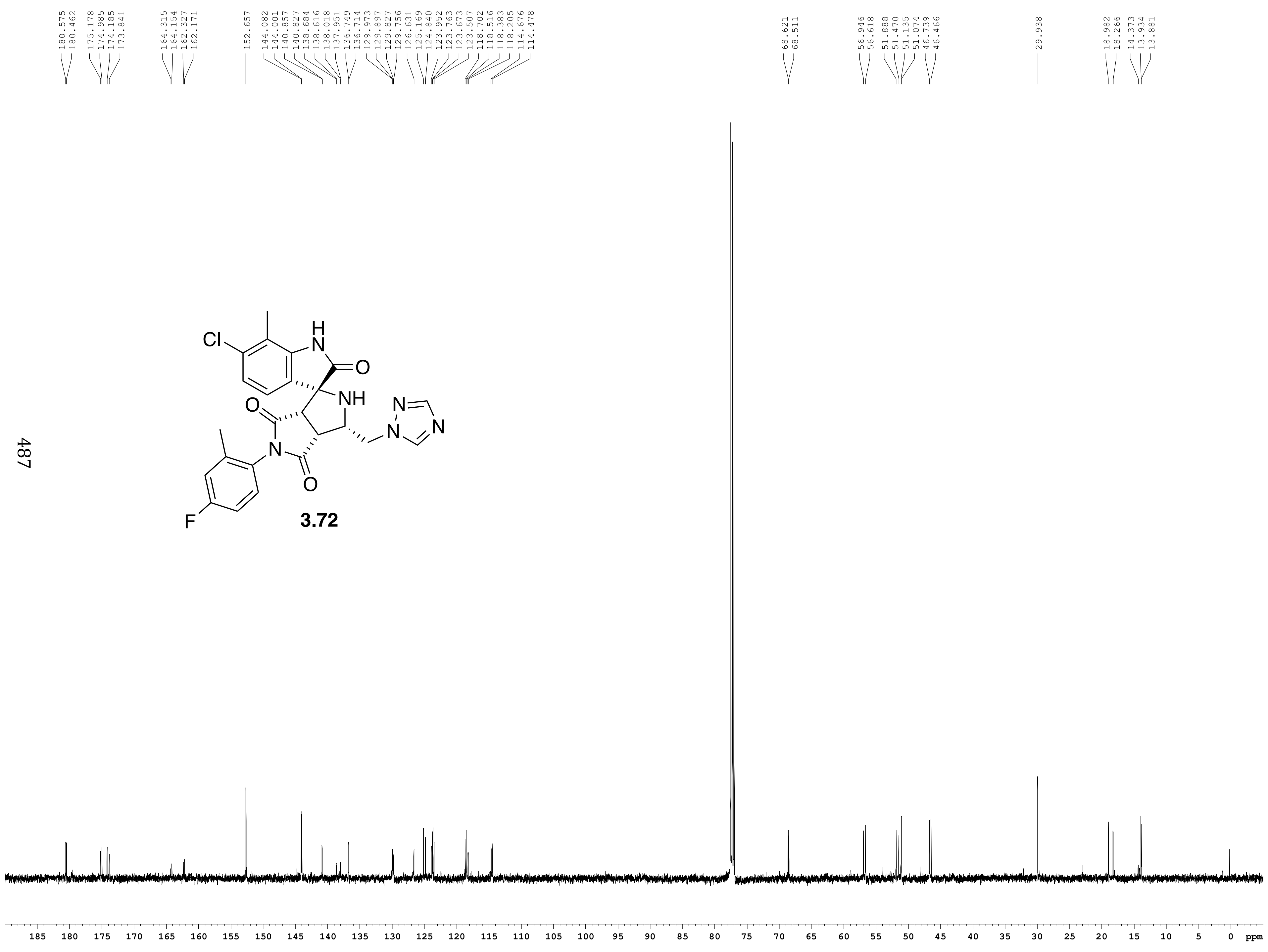


3.71

180.843
180.764
175.511
175.184
174.765
174.546
164.358
164.154
162.376
162.173
149.855
149.822
140.929
138.867
138.797
138.238
138.168
136.650
136.602
134.408
134.285
133.640
133.561
132.708
132.605
130.113
130.091
130.039
130.017
128.276
127.000
126.975
126.950
125.600
125.481
124.975
124.624
124.511
124.085
123.809
123.741
118.950
118.744
118.670
118.490
118.421
118.241
114.739
114.601
114.556
114.420
68.714
68.682
58.661
58.224
51.891
51.829
48.135
47.803
35.162
34.700
30.034
19.097
18.398
13.778
13.719
Cl
H
N
O
NH
O
N
O
O₂N
F
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
ppm

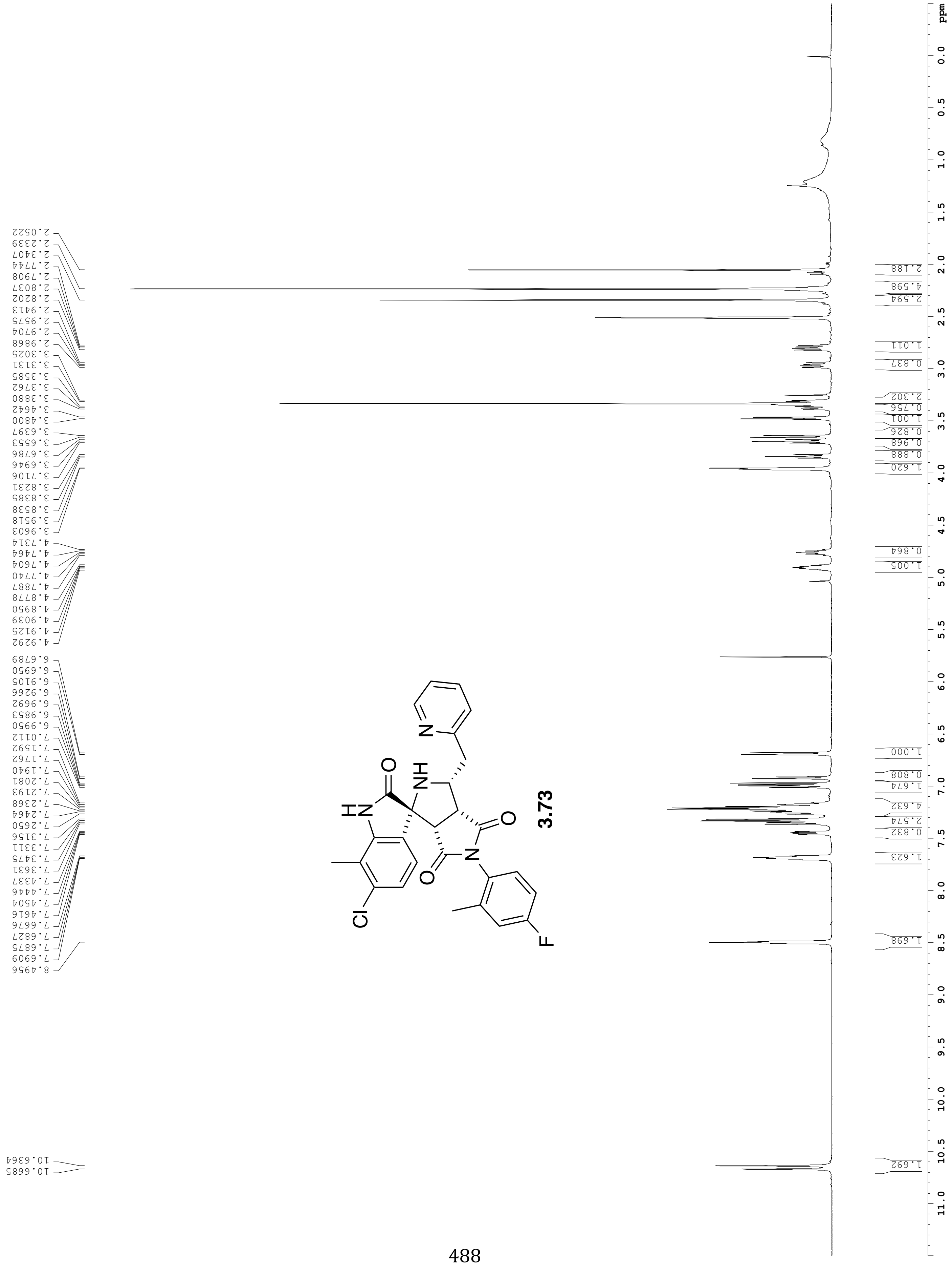
2.0899
2.1097
2.2474
2.3538
3.5125
3.5284
3.6939
3.7097
3.7592
3.7751
3.7910
3.9343
3.9494
3.9645
4.0779
4.0938
4.1054
4.1217
4.1901
4.1999
4.2949
4.3104
4.3214
4.3374
4.7052
4.7261
4.7344
4.7439
4.7584
4.7852
4.7950
4.8297
4.8388
4.8464
4.8547
4.8629
4.8705
4.8794
6.6795
6.6957
6.8781
6.8943
7.0024
7.0186
7.0288
7.0449
7.1167
7.1340
7.1459
7.1685
7.1938
7.2061
7.2111
7.2277
7.2443
7.2558
7.2621
7.2734
7.2830
7.3032
7.3502
7.3551
7.3694
7.3743
7.4338
7.4446
7.4508
7.4618
8.0039
8.0129
8.5203
8.5449
10.7077
10.7307
3.294
5.469
2.681
0.989
0.783
1.042
0.819
1.222
1.661
0.843
2.469
1.035
1.000
0.822
1.692
4.297
1.021
0.851
1.775
1.829
1.697
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
N
N
N
NH
O
H
N
O
O
N
O
Cl
F

**3.72**

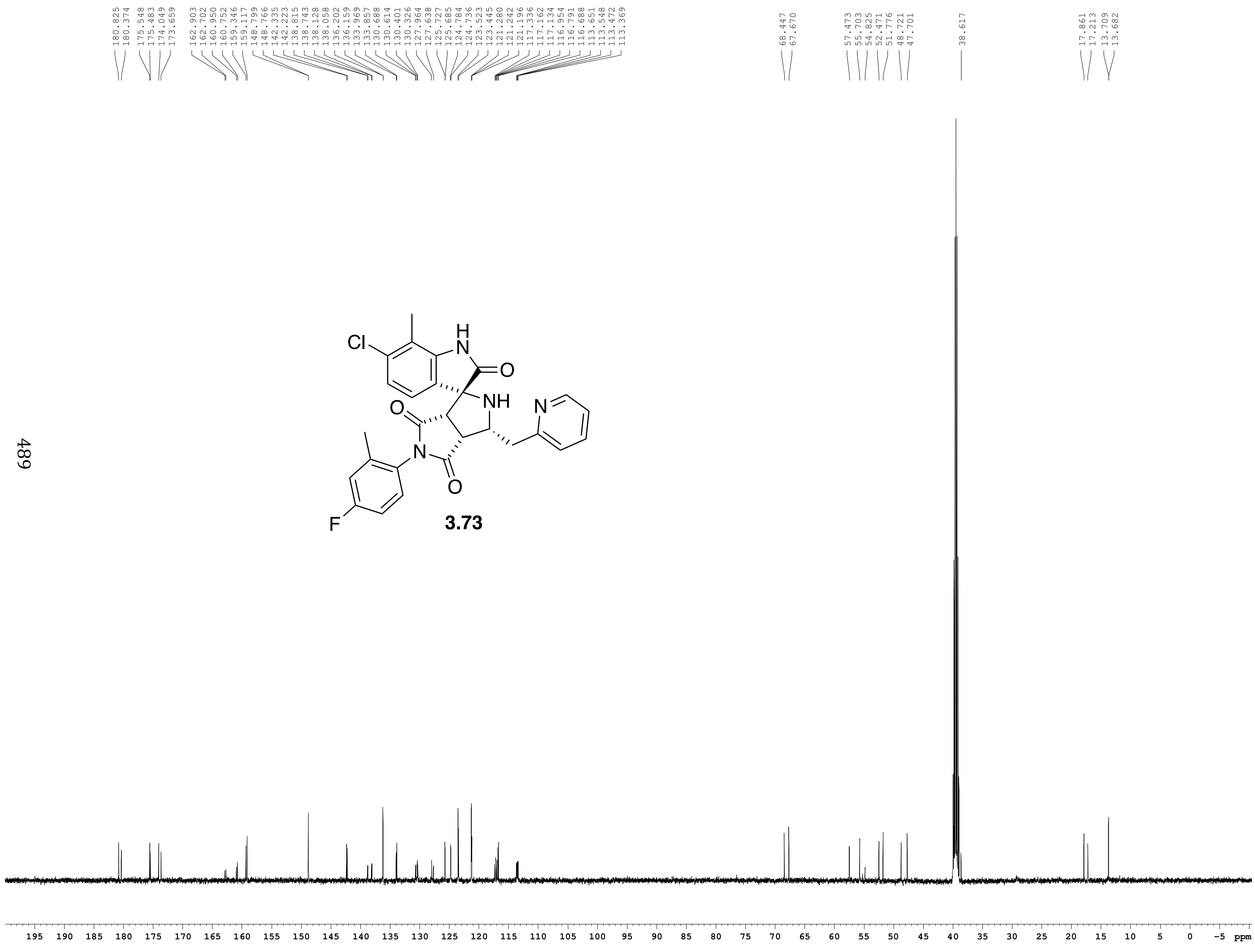


**3.72**

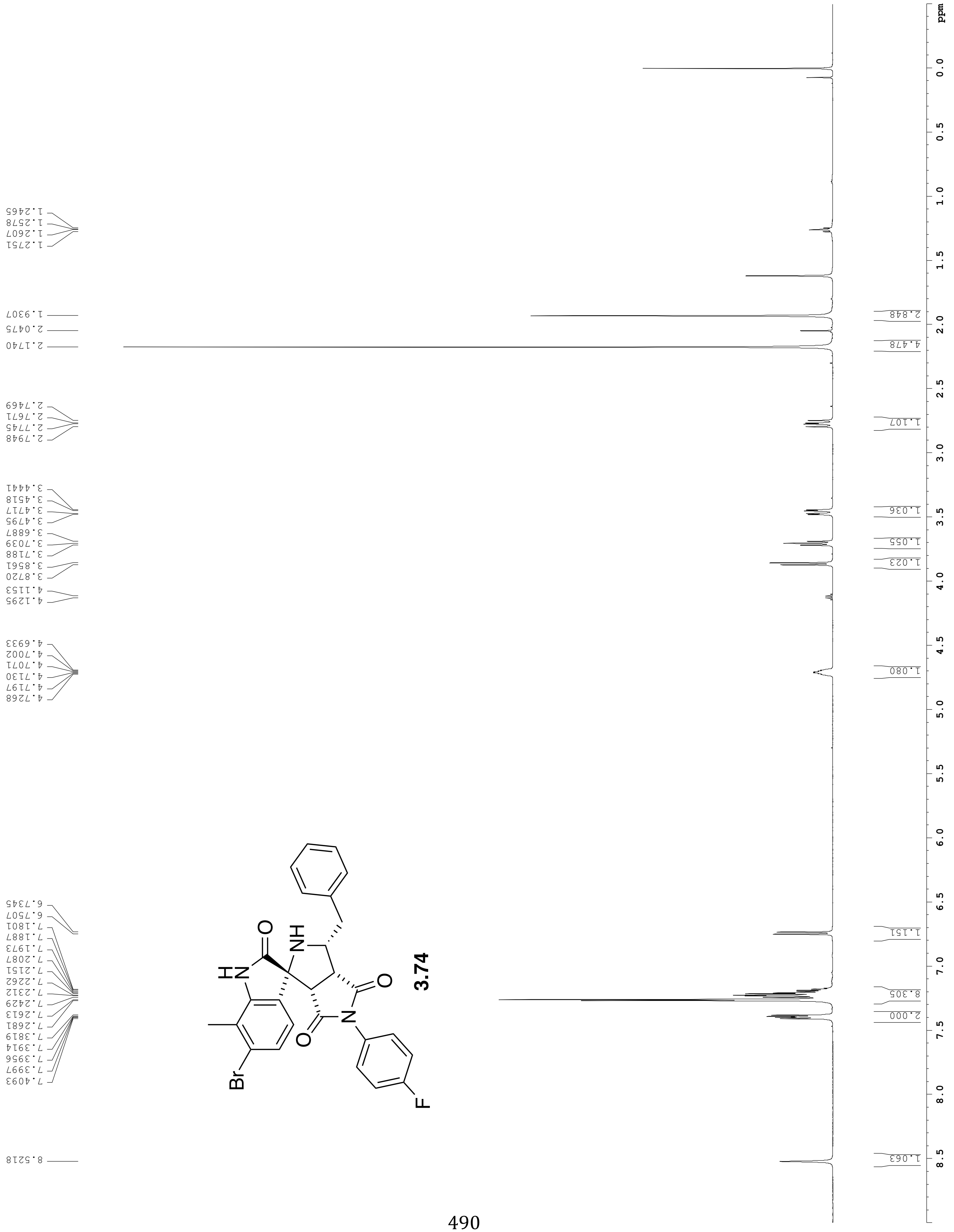
180.575
180.462
175.178
174.985
174.185
173.841
164.315
164.154
162.327
162.171
152.657
144.082
144.001
140.857
140.827
138.684
138.616
138.018
137.951
136.749
136.714
129.973
129.897
129.827
129.756
126.631
125.169
124.840
123.952
123.763
123.673
123.507
118.702
118.516
118.383
118.205
114.676
114.478
68.621
68.511
56.946
56.618
51.888
51.470
51.135
51.074
46.739
46.466
29.938
18.982
18.266
14.373
13.934
13.881
Cl
H
N
O
NH
N
N
N
O
N
O
F
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
ppm


2.0522
2.2339
2.3407
2.7744
2.7908
2.8037
2.8202
2.9413
2.9575
2.9704
2.9868
3.3025
3.3131
3.3585
3.3762
3.3880
3.4642
3.4800
3.6397
3.6553
3.6786
3.6946
3.7106
3.8231
3.8385
3.8538
3.9518
3.9603
4.7314
4.7464
4.7604
4.7740
4.7887
4.8778
4.8950
4.9039
4.9125
4.9292
6.6789
6.6950
6.9105
6.9266
6.9692
6.9853
6.9950
7.0112
7.1592
7.1762
7.1940
7.2081
7.2193
7.2368
7.2464
7.2650
7.3156
7.3311
7.3475
7.3631
7.4337
7.4446
7.4504
7.4616
7.6676
7.6827
7.6875
7.6909
8.4956
10.6364
10.6685
2.188
4.598
2.594
1.011
0.837
2.302
0.756
1.001
0.826
0.968
0.888
1.620
0.864
1.005
1.000
0.808
1.674
4.632
2.574
0.832
1.623
1.698
1.692
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
N
NH
O
HN
O
N
O
Cl
F

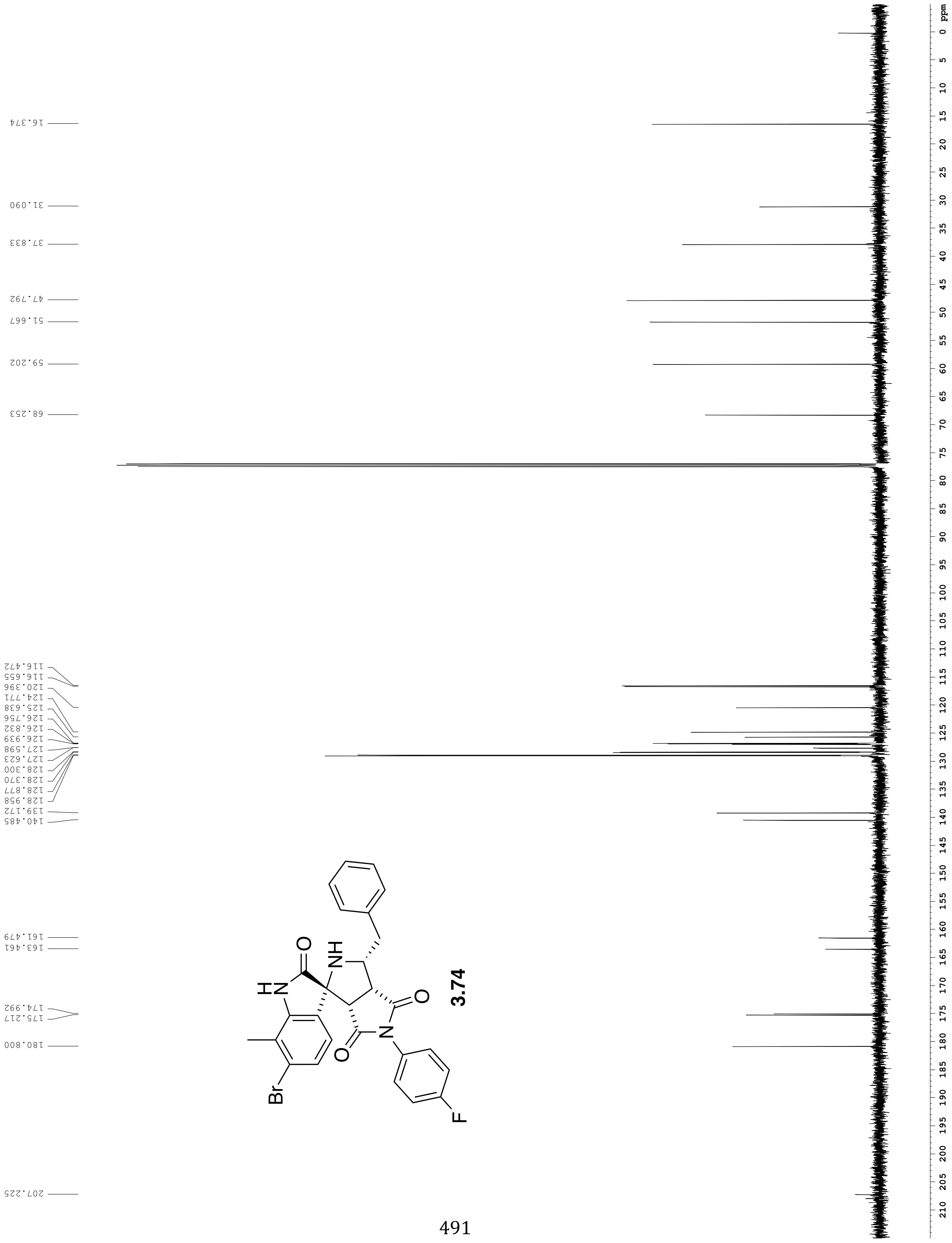
**3.73**


180.825
180.374
175.548
175.483
174.049
173.659
162.903
162.702
160.950
160.752
159.346
159.117
148.799
148.766
142.335
142.223
138.815
138.743
138.128
138.058
136.202
136.159
133.969
133.857
130.688
130.614
130.401
130.326
127.964
127.638
125.727
125.685
124.784
124.736
123.523
123.445
121.280
121.242
121.196
117.336
117.162
117.134
116.954
116.791
116.688
113.651
113.548
113.472
113.369
68.447
67.670
57.473
55.703
54.825
52.471
51.776
48.721
47.701
38.617
17.861
17.213
13.709
13.682
Cl
H
N
O
NH
N
O
N
O
F
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
ppm

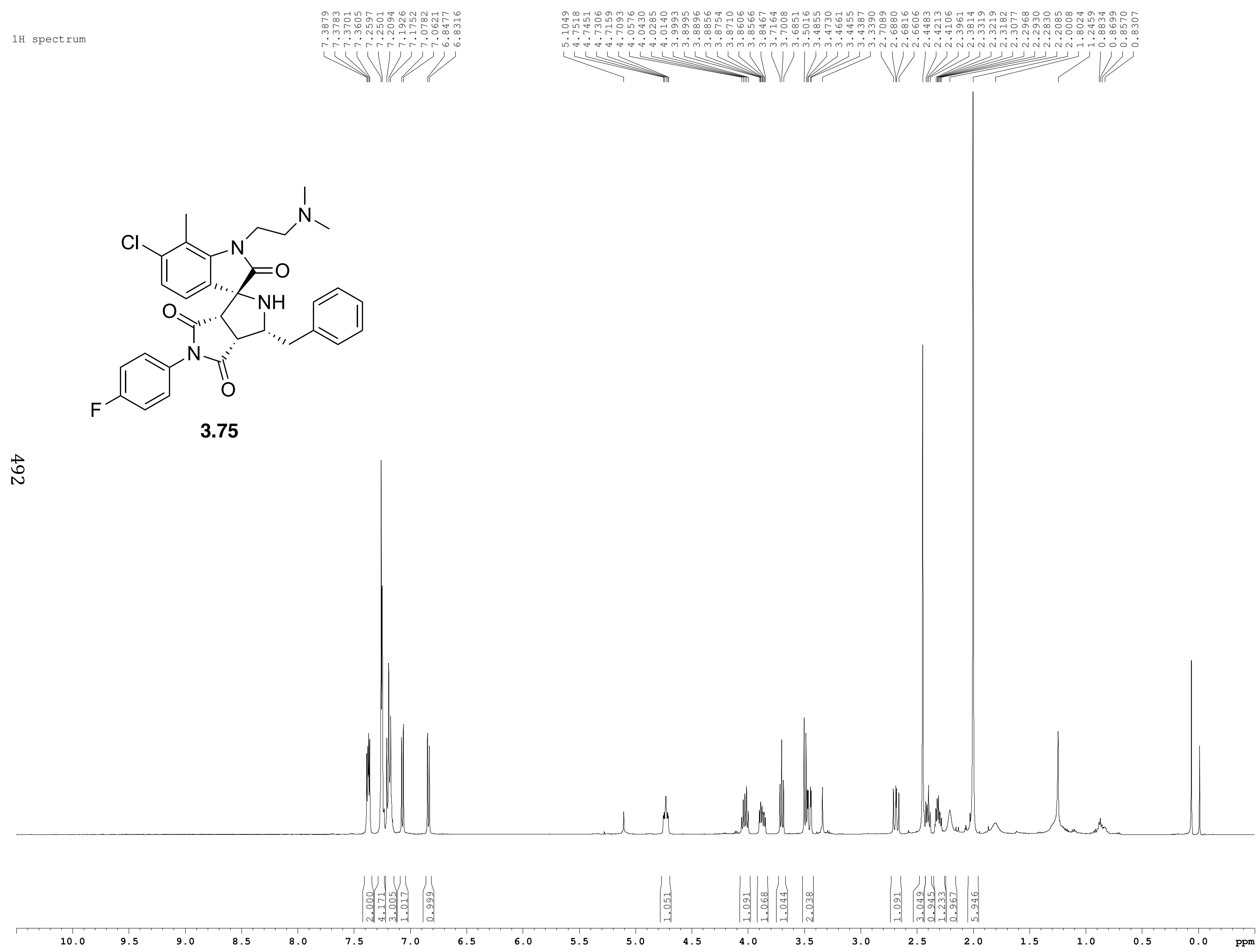
**3.73**


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
1.2465
1.2578
1.2607
1.2751
1.9307
2.0475
2.1740
2.7469
2.7671
2.7745
2.7948
3.4441
3.4518
3.4717
3.4795
3.6887
3.7039
3.7188
3.8561
3.8720
4.1153
4.1295
4.6933
4.7002
4.7071
4.7130
4.7197
4.7268
6.7345
6.7507
7.1801
7.1887
7.1973
7.2087
7.2151
7.2262
7.2312
7.2429
7.2613
7.2681
7.3819
7.3914
7.3956
7.3997
7.4093
8.5218
2.848
4.478
1.107
1.036
1.055
1.023
1.080
1.151
8.305
2.000
1.063
O
NH
H
N
O
O
N
Br
F

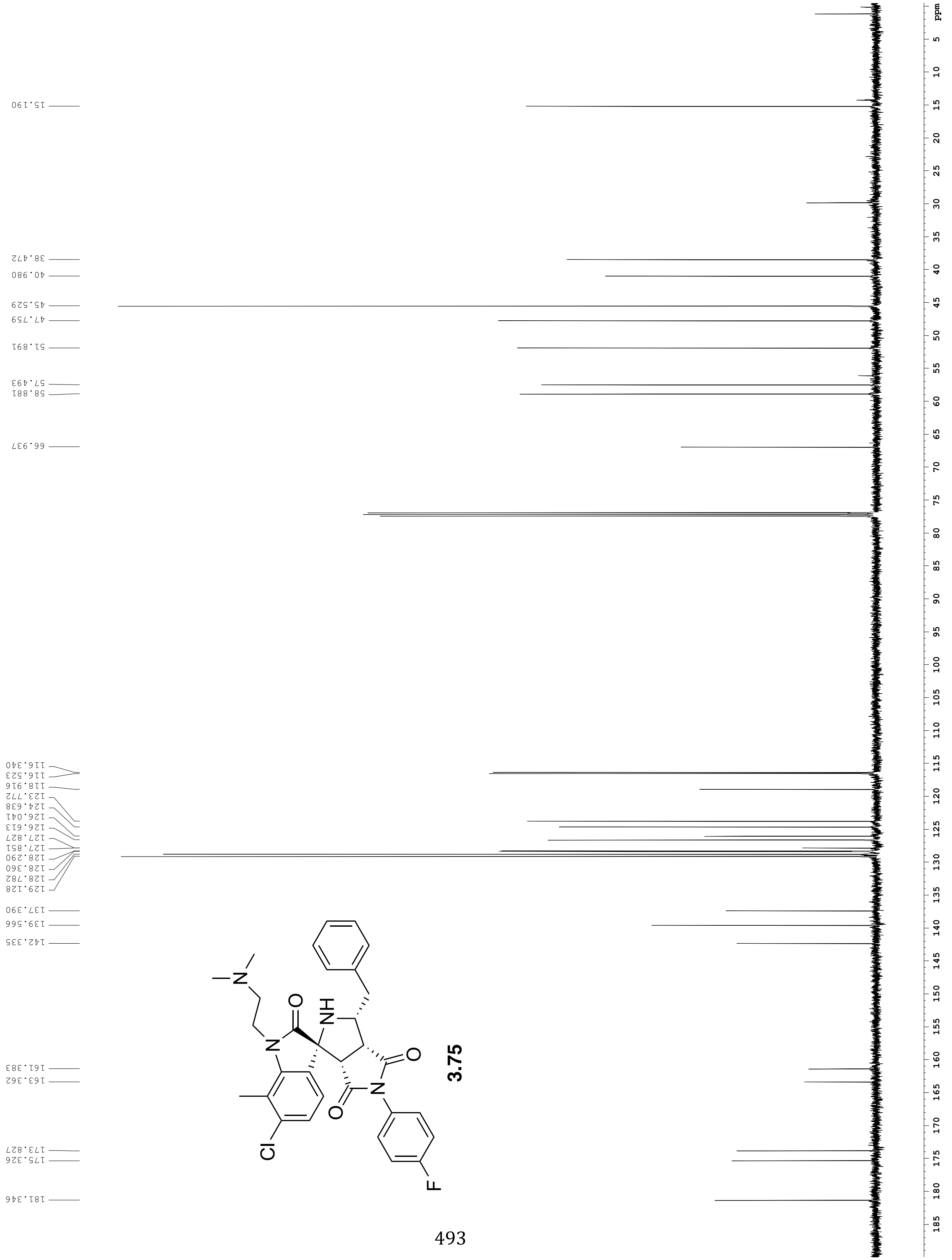
**3.74**


16.374
31.090
37.833
47.792
51.667
59.202
68.253
116.472
116.655
120.396
124.771
125.638
126.756
126.832
126.939
127.598
127.623
128.300
128.370
128.877
128.958
139.172
140.485
161.479
163.461
174.992
175.217
180.800
207.225
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
NH
O
H
N
O
N
O
Br
F

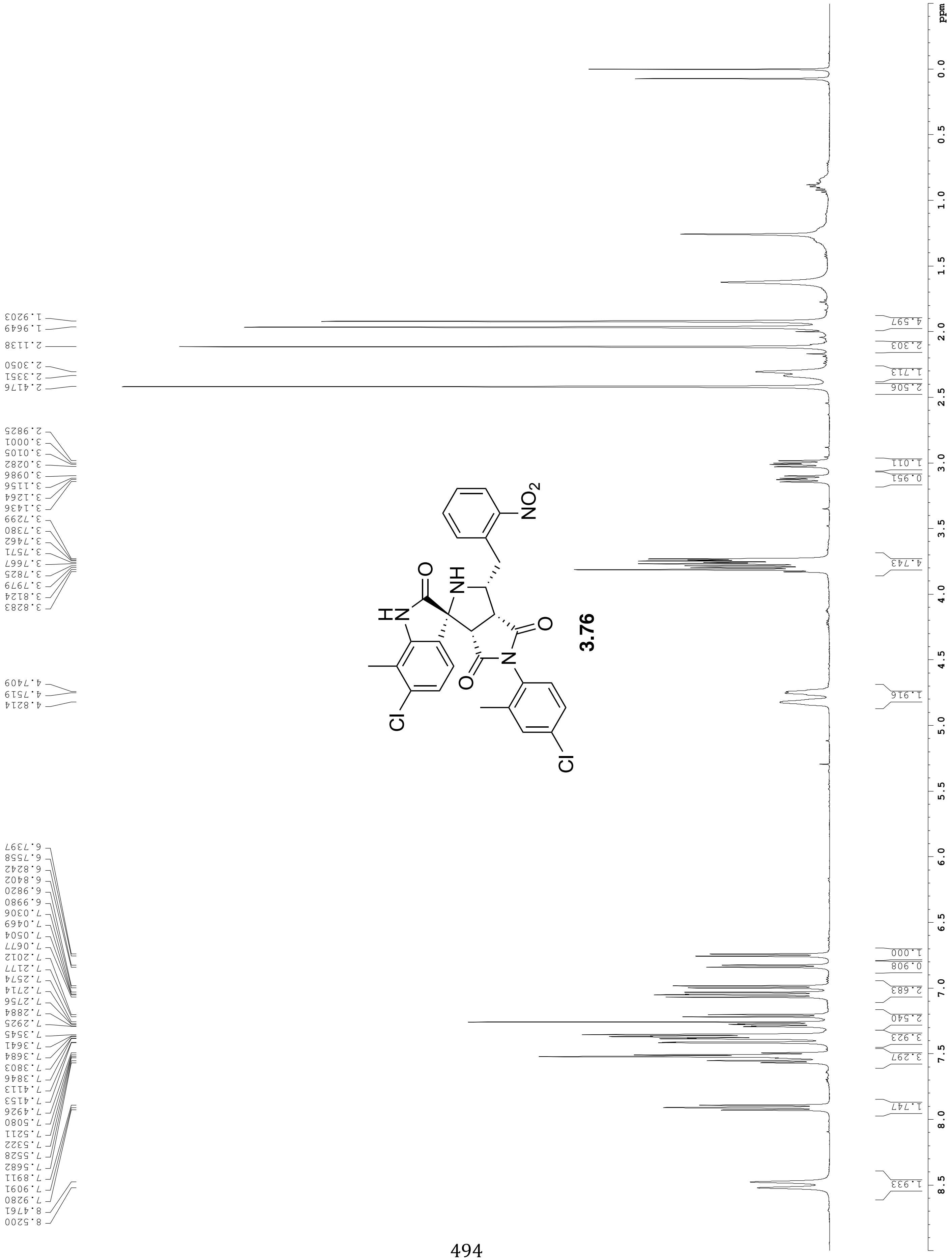
**3.74**


1H spectrum
7.3879
7.3783
7.3701
7.3605
7.2597
7.2501
7.2094
7.1926
7.1752
7.0782
7.0621
6.8477
6.8316
5.1049
4.7518
4.7451
4.7306
4.7159
4.7093
4.0576
4.0430
4.0285
4.0140
3.9993
3.8995
3.8896
3.8856
3.8754
3.8710
3.8606
3.8566
3.8467
3.7164
3.7008
3.6851
3.5016
3.4855
3.4730
3.4661
3.4455
3.4387
3.3390
2.7089
2.6880
2.6816
2.6606
2.4483
2.4213
2.4106
2.3961
2.3814
2.3319
2.3219
2.3182
2.3077
2.2968
2.2930
2.2830
2.2085
2.0008
1.8024
1.2459
0.8834
0.8699
0.8570
0.8307
Cl
N
N
O
NH
O
N
O
F
2.000
4.171
3.005
1.017
0.999
1.051
1.091
1.068
1.044
2.038
1.091
3.049
0.945
1.233
0.967
5.946
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

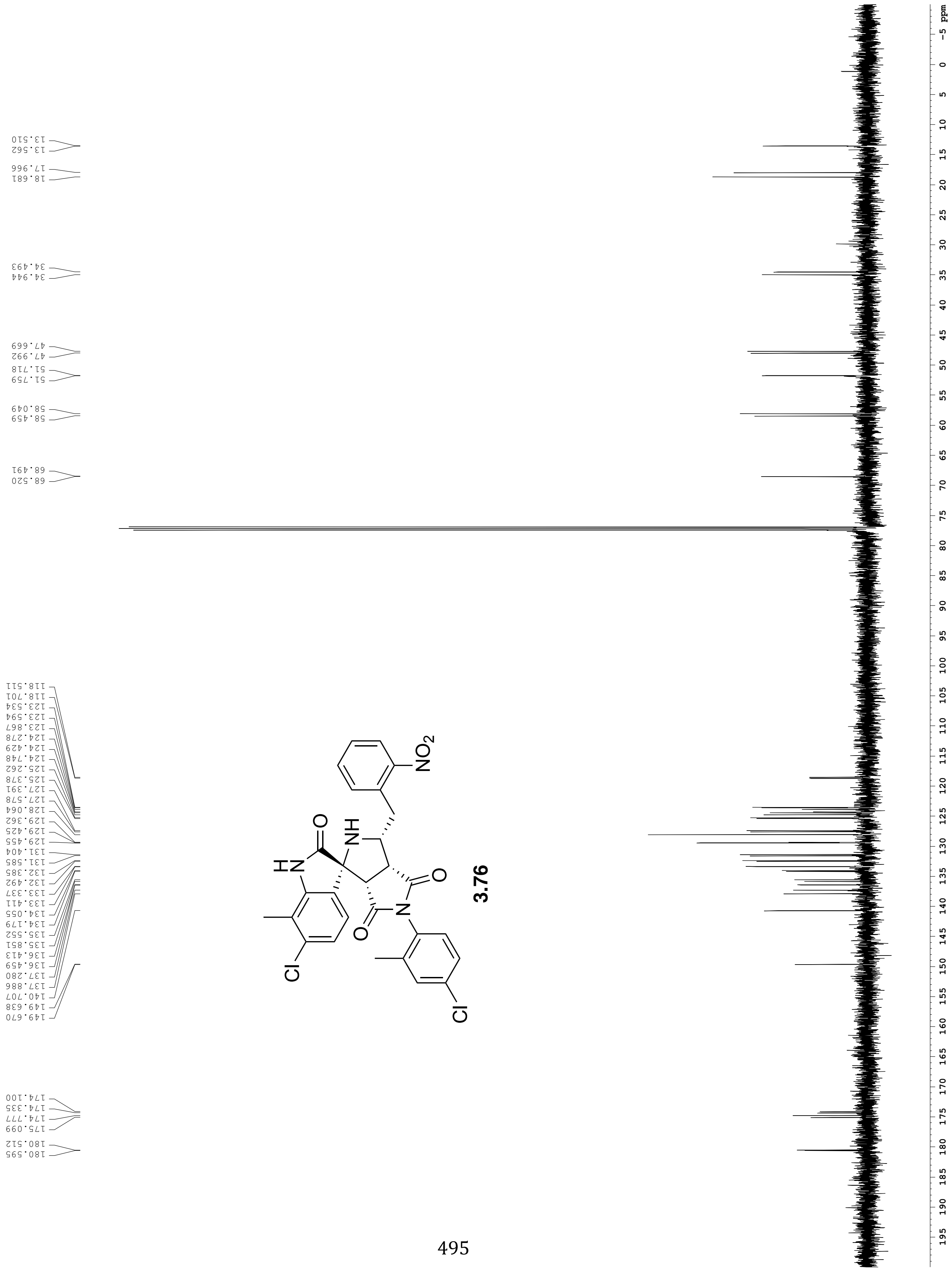
**3.75**


15.190
38.472
40.980
45.529
47.759
51.891
57.493
58.881
66.937
116.340
116.523
118.916
123.772
124.638
126.041
126.613
127.827
127.851
128.290
128.360
128.782
129.128
137.390
139.566
142.335
161.383
163.362
173.827
175.326
181.346
ppm
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
N
O
NH
O
N
O
Cl
F

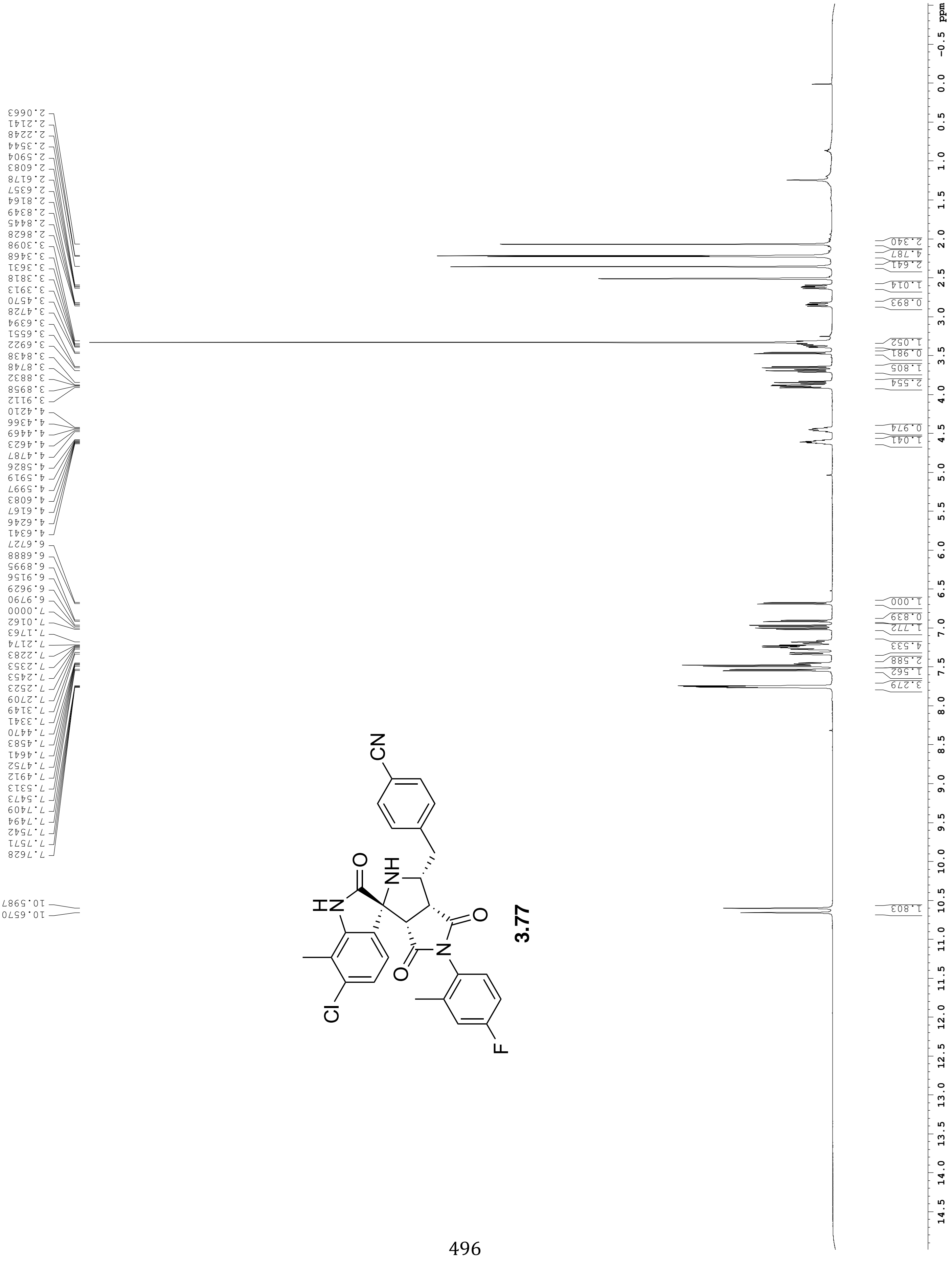
**3.75**


1.9203
1.9649
2.1138
2.3050
2.3351
2.4176
2.9825
3.0001
3.0105
3.0282
3.0986
3.1156
3.1264
3.1436
3.7299
3.7380
3.7462
3.7571
3.7667
3.7825
3.7916
3.8124
3.8283
4.7409
4.7519
4.8214
6.7397
6.7558
6.8242
6.8402
6.9820
6.9980
7.0306
7.0469
7.0504
7.0677
7.2012
7.2177
7.2574
7.2714
7.2756
7.2884
7.2925
7.3545
7.3641
7.3684
7.3803
7.3846
7.4113
7.4153
7.4926
7.5080
7.5211
7.5322
7.5528
7.5682
7.8811
7.9091
7.9280
8.4761
8.5200
4.597
2.303
1.713
2.506
1.011
0.951
4.743
1.916
1.000
0.908
2.683
2.540
3.923
3.297
1.747
1.933
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
NO2
NH
O
HN
O
N
O
Cl
Cl

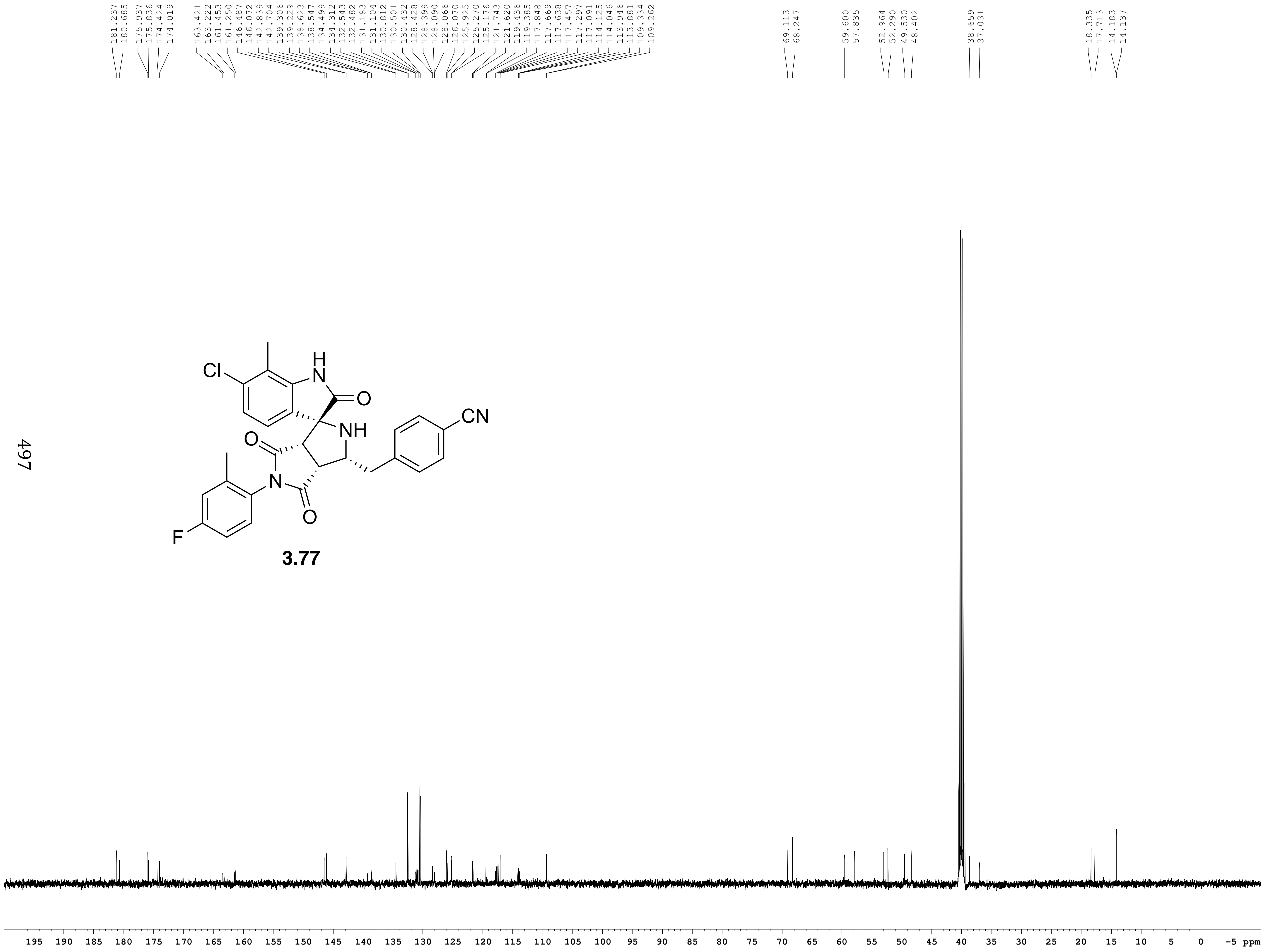
**3.76**


13.510
13.562
17.966
18.681
34.493
34.944
47.669
47.992
51.718
51.759
58.049
58.459
68.491
68.520
118.511
118.701
123.534
123.594
123.867
124.278
124.429
124.748
125.262
125.378
127.391
127.578
128.064
129.362
129.425
129.455
131.404
131.585
132.385
132.492
133.337
133.411
134.055
134.179
135.552
135.851
136.413
136.459
137.280
137.886
140.707
149.638
149.670
174.100
174.335
174.777
175.099
180.512
180.595
NO2
NH
O
HN
O
N
O
Cl
Cl
-5 ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195

**3.76**

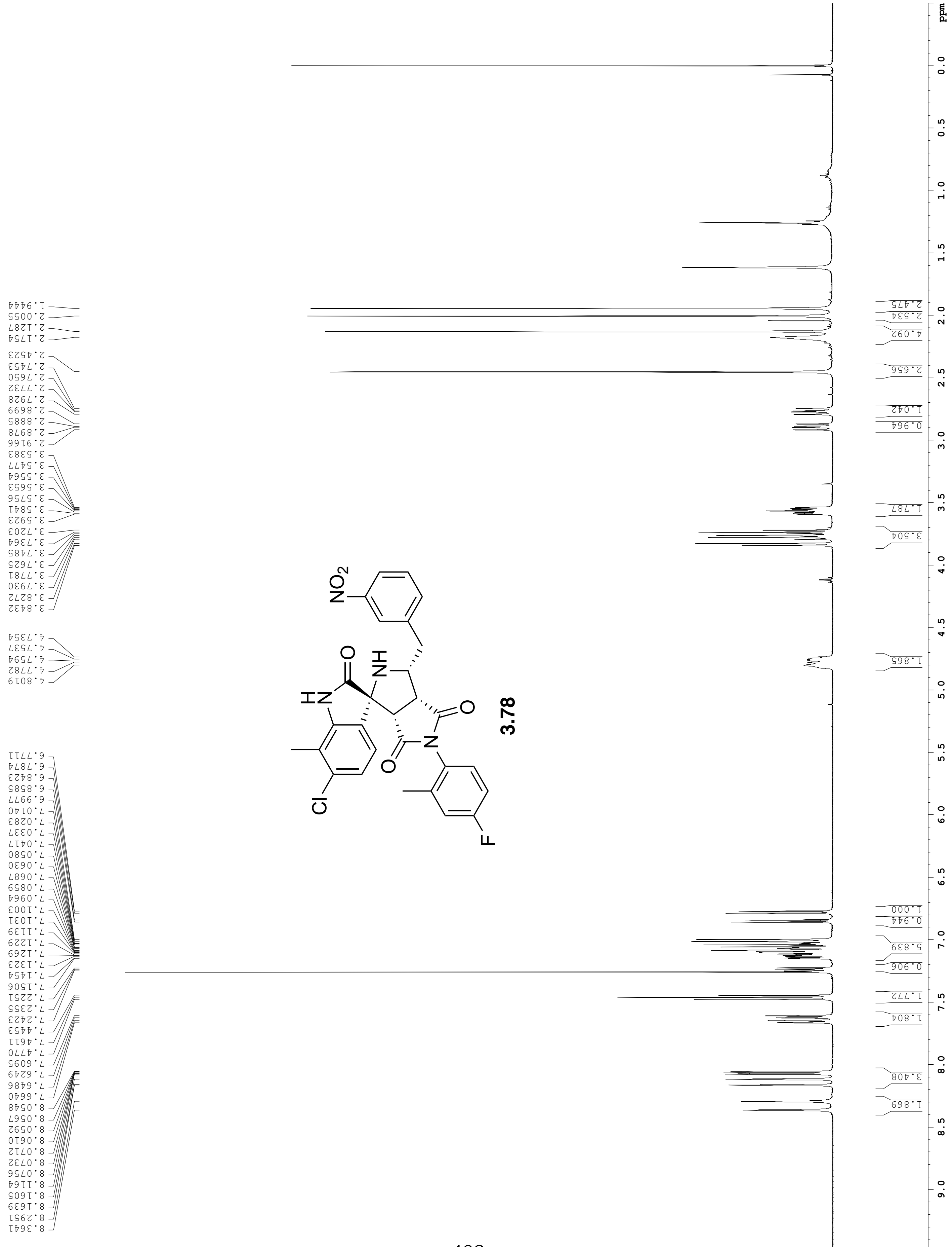

2.0663
2.2141
2.2248
2.3544
2.5904
2.6083
2.6178
2.6357
2.8164
2.8349
2.8445
2.8628
3.3098
3.3468
3.3631
3.3818
3.3913
3.4570
3.4728
3.6394
3.6551
3.6922
3.8438
3.8748
3.8832
3.8958
3.9112
4.4210
4.4366
4.4469
4.4623
4.4787
4.5826
4.5919
4.5997
4.6083
4.6167
4.6246
4.6341
6.6727
6.6888
6.8995
6.9156
6.9629
6.9790
7.0000
7.0162
7.1763
7.2174
7.2283
7.2353
7.2453
7.2523
7.2709
7.3149
7.3341
7.4470
7.4583
7.4641
7.4752
7.4912
7.5313
7.5473
7.7409
7.7494
7.7542
7.7571
7.7628
10.5987
10.6570
2.340
4.787
2.641
1.014
0.893
1.052
0.981
1.805
2.554
0.974
1.041
1.000
0.839
1.772
4.533
2.588
1.562
3.279
1.803
ppm
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
CN
NH
O
H
N
O
N
O
Cl
F

**3.77**

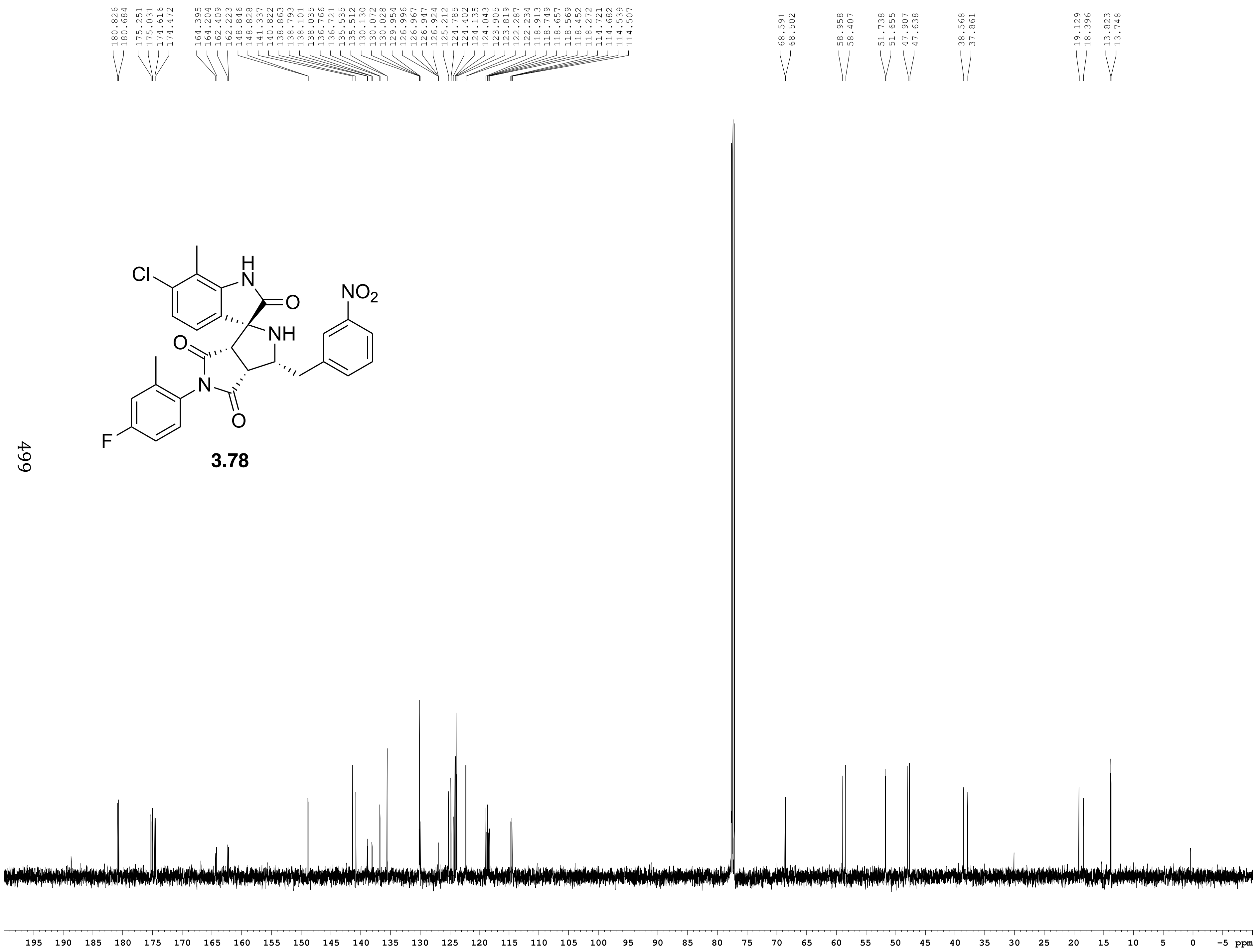


3.77

181.237
180.685
175.937
175.836
174.424
174.019
163.421
163.222
161.453
161.250
146.487
146.072
142.839
142.704
139.306
139.229
138.623
138.547
134.499
134.312
132.543
132.482
131.183
131.104
130.812
130.501
130.432
128.428
128.399
128.090
128.066
126.070
125.925
125.270
125.176
121.743
121.620
119.436
119.385
117.848
117.669
117.638
117.457
117.297
117.091
114.125
114.046
113.946
113.881
109.334
109.262
69.113
68.247
59.600
57.835
52.964
52.290
49.530
48.402
38.659
37.031
18.335
17.713
14.183
14.137
Cl
H
N
O
NH
CN
O
N
O
F
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5 ppm

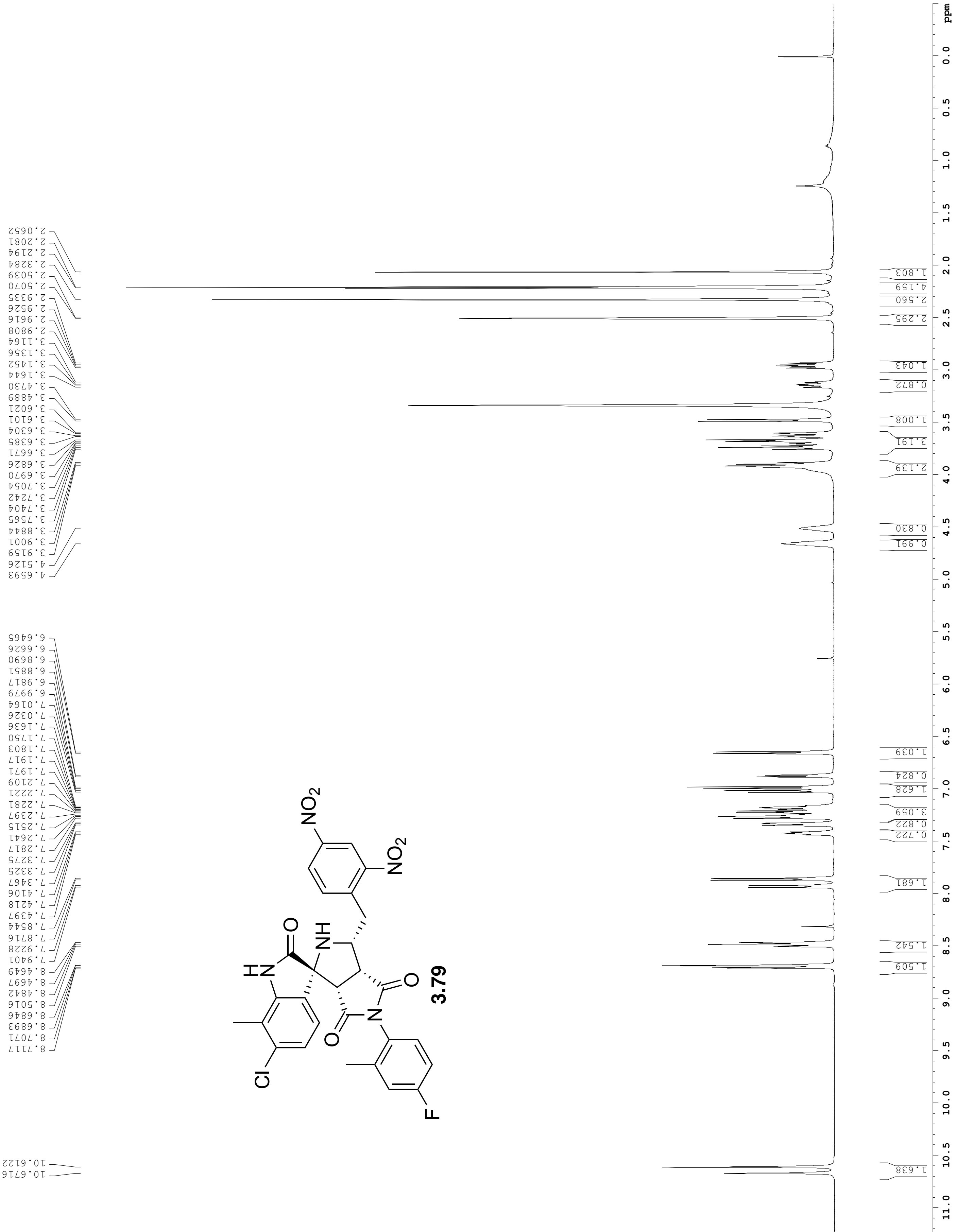
1.9444
2.0055
2.1287
2.1754
2.4523
2.7453
2.7650
2.7732
2.7928
2.8699
2.8885
2.8978
2.9166
3.5383
3.5477
3.5564
3.5653
3.5756
3.5841
3.5923
3.7203
3.7364
3.7485
3.7625
3.7781
3.7930
3.8272
3.8432
4.7354
4.7537
4.7594
4.7782
4.8019
6.7711
6.7874
6.8423
6.8585
6.9977
7.0140
7.0283
7.0337
7.0417
7.0580
7.0630
7.0687
7.0859
7.0964
7.1003
7.1031
7.1139
7.1229
7.1269
7.1323
7.1454
7.1506
7.2251
7.2355
7.2423
7.4453
7.4611
7.4770
7.6095
7.6249
7.6486
7.6640
8.0548
8.0567
8.0592
8.0610
8.0712
8.0732
8.0756
8.1164
8.1605
8.1639
8.2951
8.3641
2.475
2.534
4.092
2.656
1.042
0.964
1.787
3.504
1.865
1.000
0.944
5.839
0.906
1.772
1.804
3.408
1.869
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
$NO_2$
NH
H
N
O
O
O
N
Cl
F

**3.78**

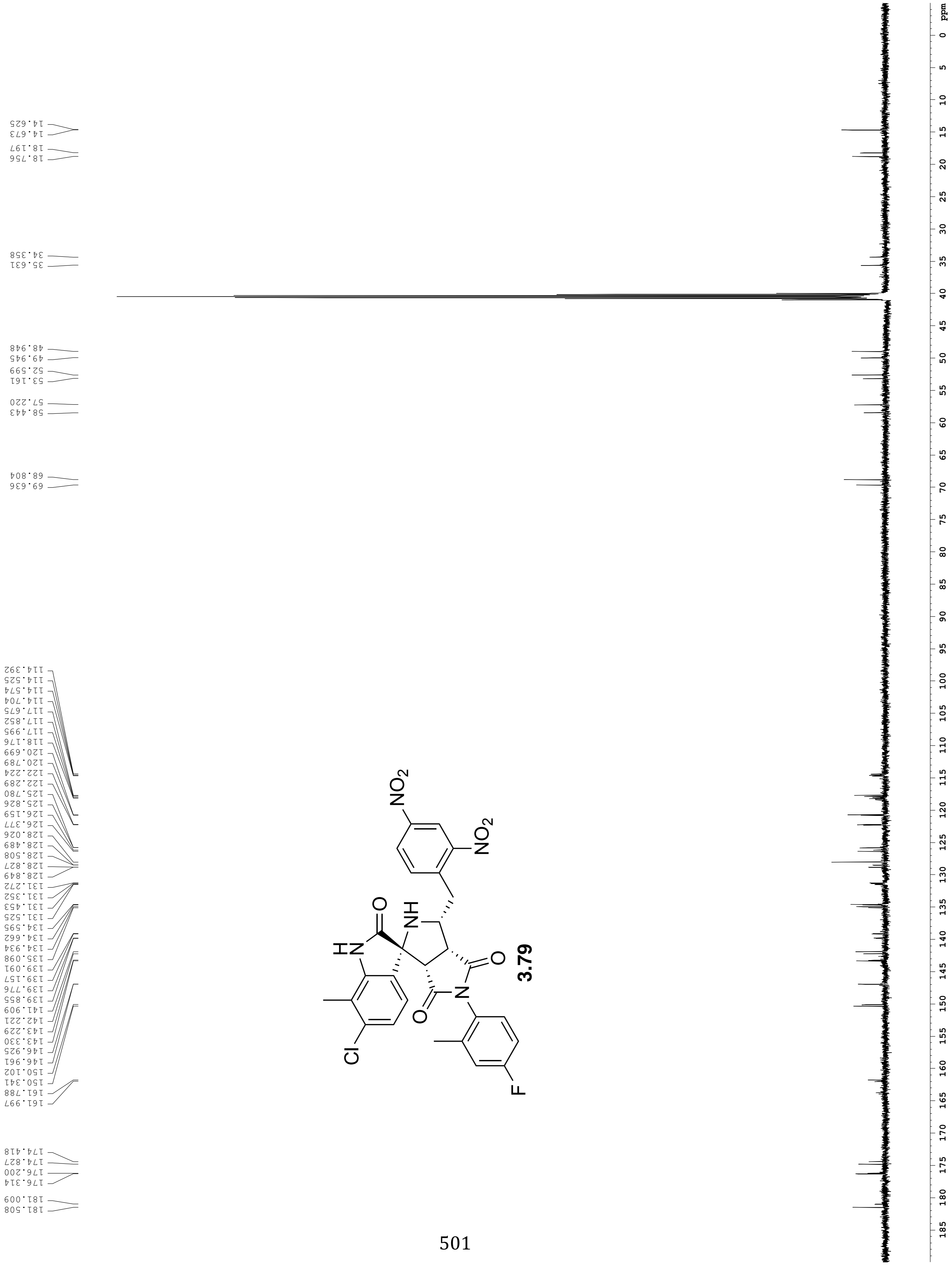


**3.78**

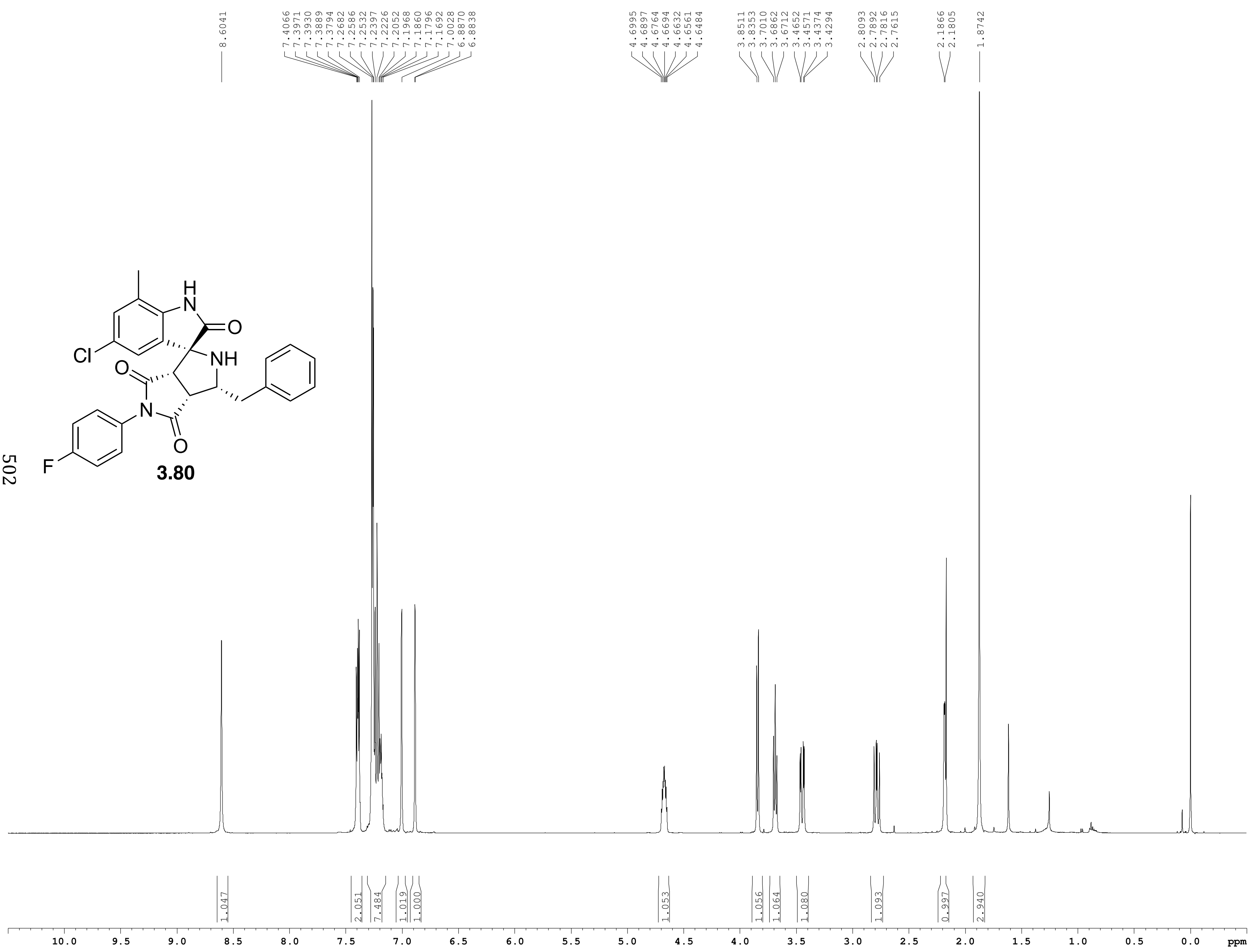
180.826
180.684
175.251
175.031
174.616
174.472
164.395
164.204
162.409
162.223
148.846
148.828
141.337
140.822
138.863
138.793
138.101
138.035
136.766
136.721
135.535
135.512
130.130
130.072
130.028
129.954
126.996
126.967
126.947
126.924
125.212
124.785
124.402
124.135
124.043
123.905
123.819
122.287
122.234
118.913
118.749
118.657
118.569
118.452
118.272
114.721
114.682
114.539
114.507
68.591
68.502
58.958
58.407
51.738
51.655
47.907
47.638
38.568
37.861
19.129
18.396
13.823
13.748
Cl
H
N
O
NH
NO$_2$
O
N
O
F
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5 ppm


2.0652
2.2081
2.2194
2.3284
2.5039
2.5070
2.9335
2.9526
2.9616
2.9808
3.1164
3.1356
3.1452
3.1644
3.4730
3.4889
3.6021
3.6101
3.6304
3.6385
3.6671
3.6826
3.6970
3.7054
3.7242
3.7404
3.7565
3.8844
3.9001
3.9159
4.5126
4.6593
6.6465
6.6626
6.8690
6.8851
6.9817
6.9979
7.0164
7.0326
7.1636
7.1750
7.1803
7.1917
7.1971
7.2109
7.2221
7.2281
7.2397
7.2515
7.2641
7.2817
7.3275
7.3325
7.3467
7.4106
7.4218
7.4397
7.8544
7.8716
7.9228
7.9401
8.4649
8.4697
8.4842
8.5016
8.6846
8.6893
8.7071
8.7117
10.6122
10.6716
1.803
4.159
2.560
2.295
1.043
0.872
1.008
3.191
2.139
0.830
0.991
1.039
0.824
1.628
3.059
0.822
0.722
1.681
1.542
1.509
1.638
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
$NO_2$
$NO_2$
O
NH
HN
O
N
O
Cl
F

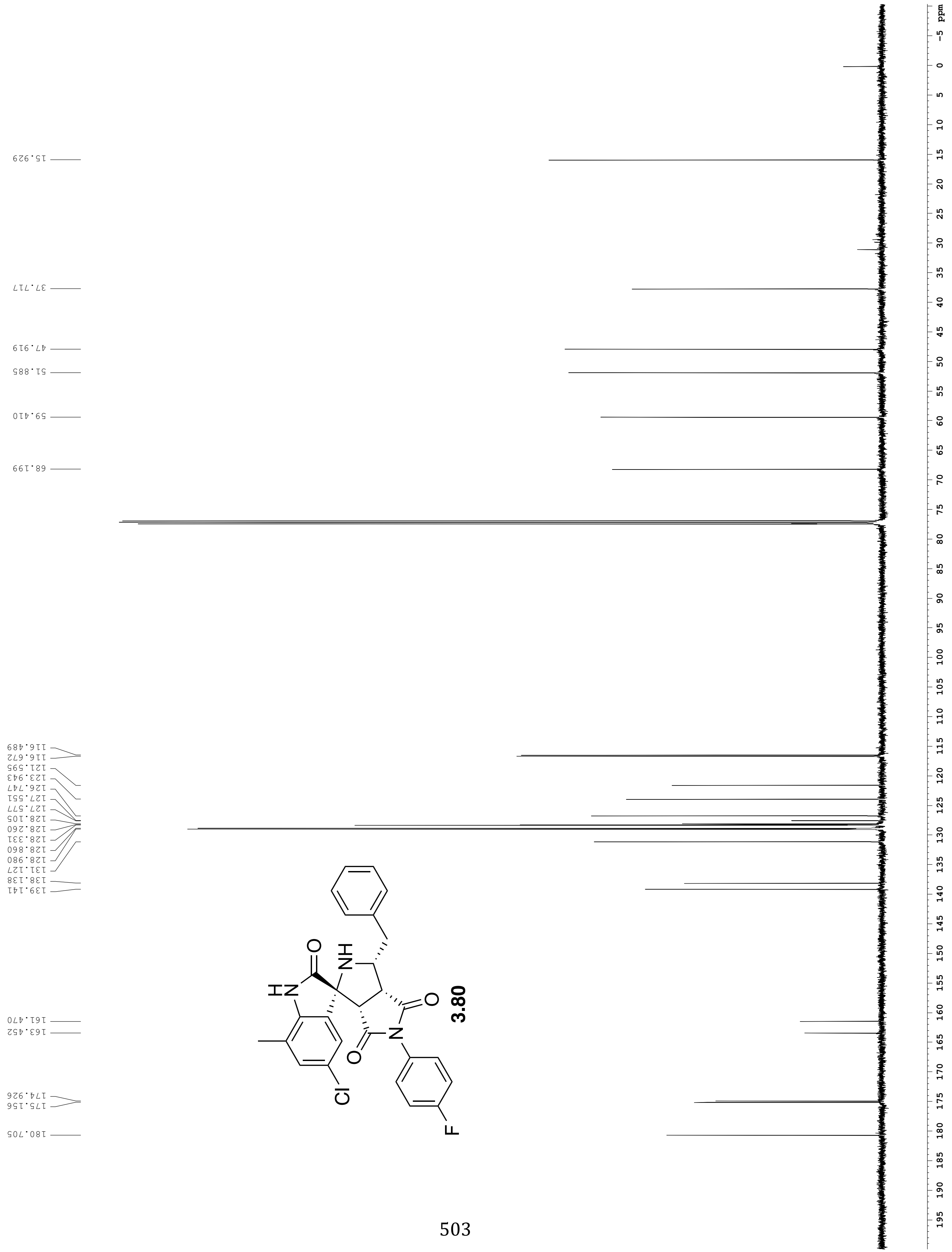
**3.79**


14.625
14.673
18.197
18.756
34.358
35.631
48.948
49.945
52.599
53.161
57.220
58.443
68.804
69.636
114.392
114.525
114.574
114.704
117.675
117.852
117.995
118.176
120.699
120.789
122.224
122.289
125.780
125.826
126.159
126.377
128.026
128.489
128.508
128.827
128.849
131.272
131.352
131.453
131.525
134.595
134.662
134.934
135.098
139.091
139.157
139.776
139.855
141.909
142.221
143.229
143.330
146.925
146.961
150.102
150.341
161.788
161.997
174.418
174.827
176.200
176.314
181.009
181.508
NO2
NO2
O
NH
HN
O
O
N
O
Cl
F
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185

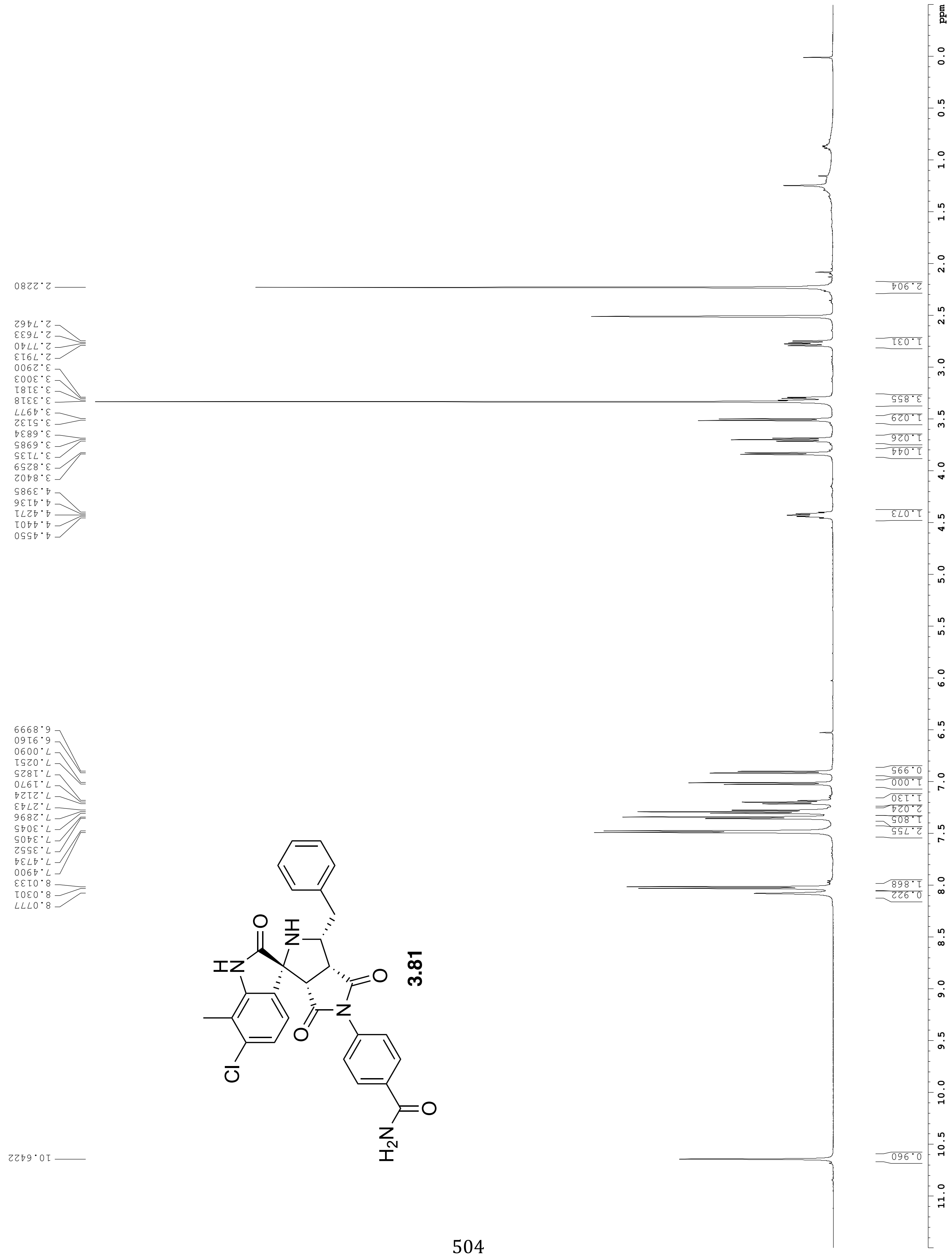
**3.79**


**3.80**

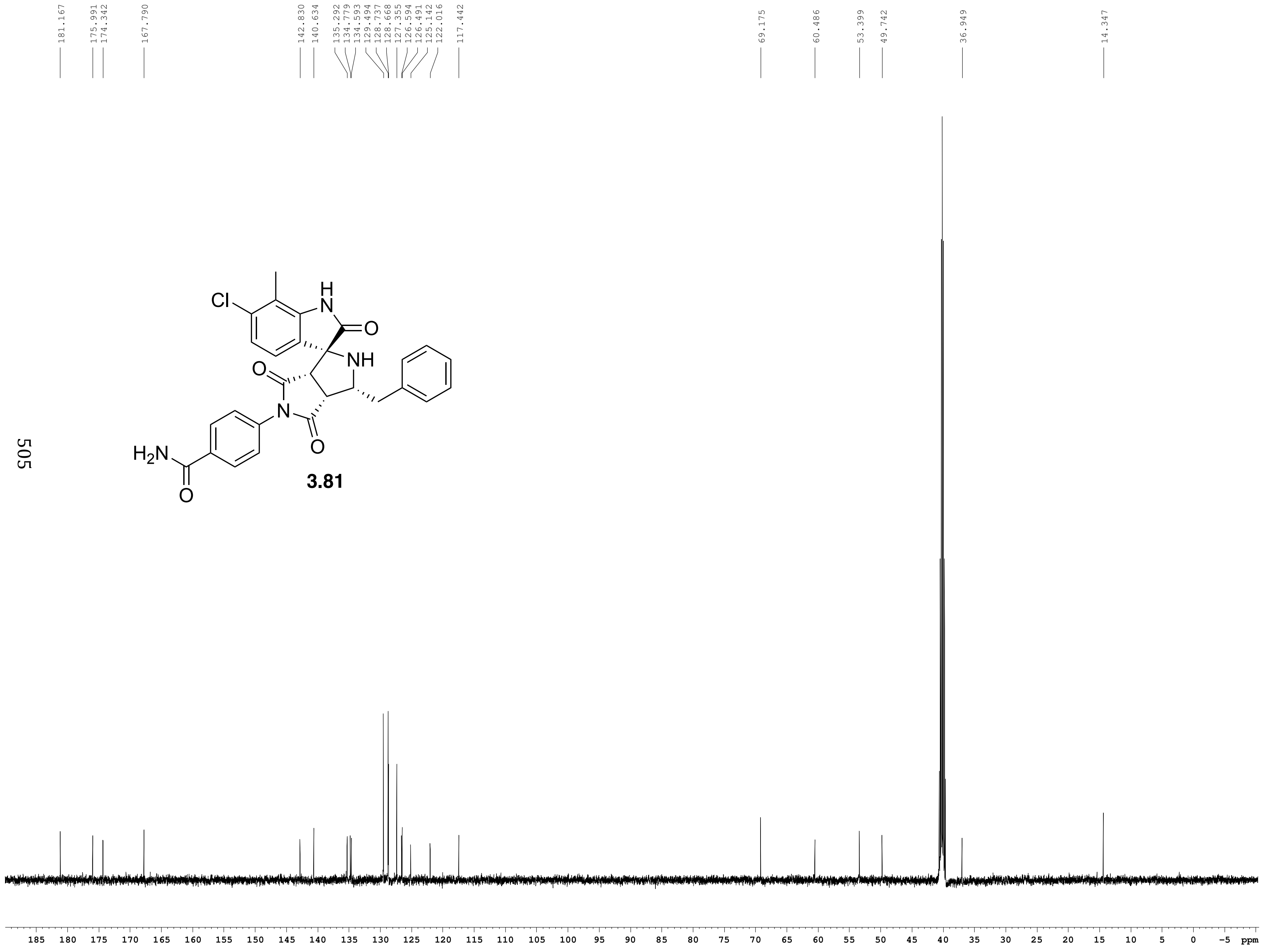
8.6041
7.4066
7.3971
7.3930
7.3889
7.3794
7.2682
7.2586
7.2532
7.2397
7.2226
7.2052
7.1968
7.1860
7.1796
7.1692
7.0028
6.8870
6.8838
4.6995
4.6897
4.6764
4.6694
4.6632
4.6561
4.6484
3.8511
3.8353
3.7010
3.6862
3.6712
3.4652
3.4571
3.4374
3.4294
2.8093
2.7892
2.7816
2.7615
2.1866
2.1805
1.8742
H
N
O
Cl
O
NH
N
O
F
1.047
2.051
7.484
1.019
1.000
1.053
1.056
1.064
1.080
1.093
0.997
2.940
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm


15.929
37.717
47.919
51.885
59.410
68.199
116.489
116.672
121.595
123.943
126.747
127.551
127.577
128.105
128.260
128.331
128.860
128.980
131.127
138.138
139.141
161.470
163.452
174.926
175.156
180.705
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
O
NH
HN
O
N
O
Cl
F

**3.80**

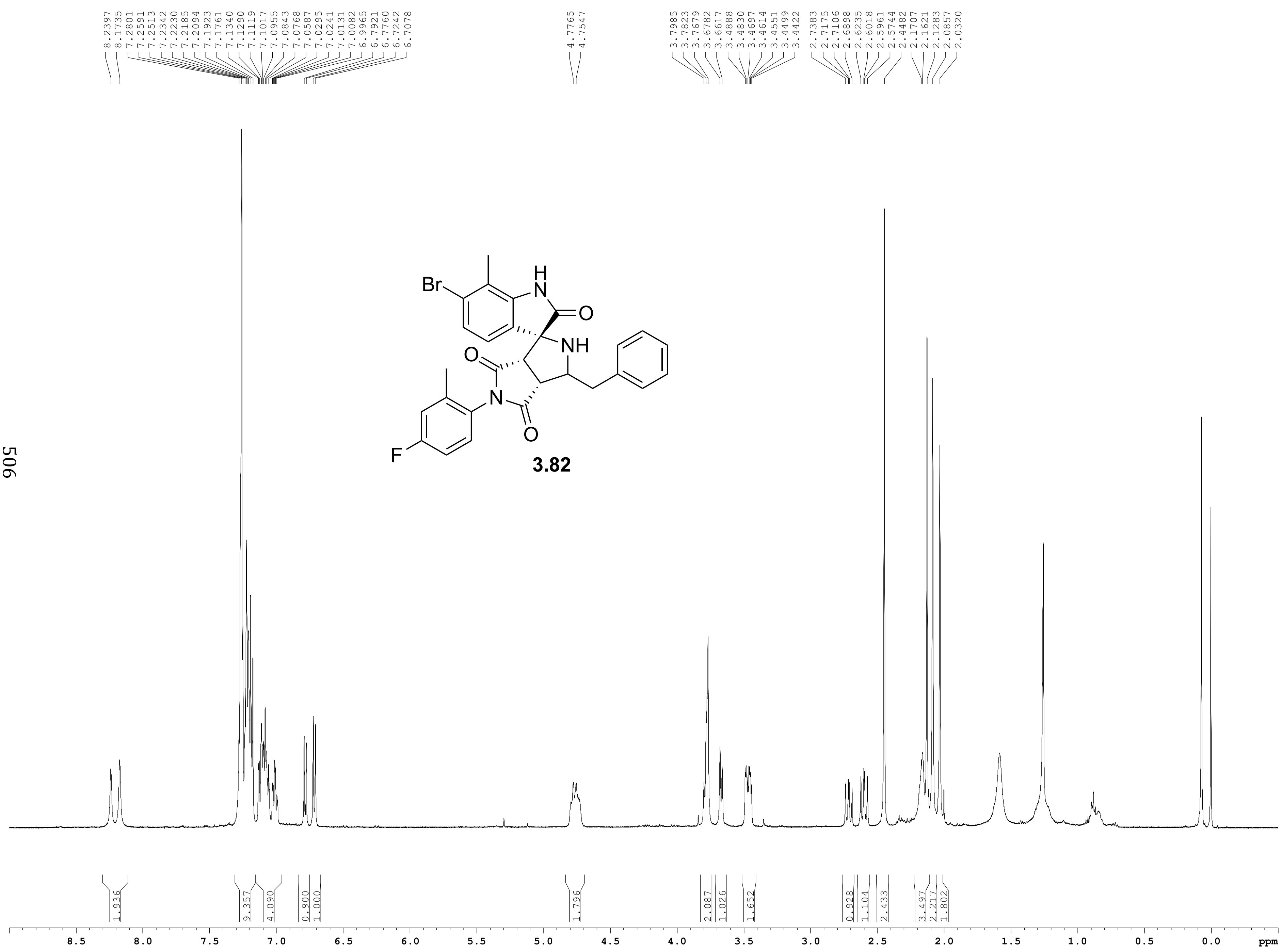

2.2280
2.7462
2.7633
2.7740
2.7913
3.2900
3.3003
3.3181
3.3318
3.4977
3.5132
3.6834
3.6985
3.7135
3.8259
3.8402
4.3985
4.4136
4.4271
4.4401
4.4550
6.8999
6.9160
7.0090
7.0251
7.1825
7.1970
7.2124
7.2743
7.2896
7.3045
7.3405
7.3552
7.4734
7.4900
8.0133
8.0301
8.0777
10.6422
2.904
1.031
3.855
1.029
1.026
1.044
1.073
0.995
1.000
1.130
2.024
1.805
2.755
1.868
0.922
0.960
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
O
NH
HN
Cl
O
N
O
H2N
O

**3.81**

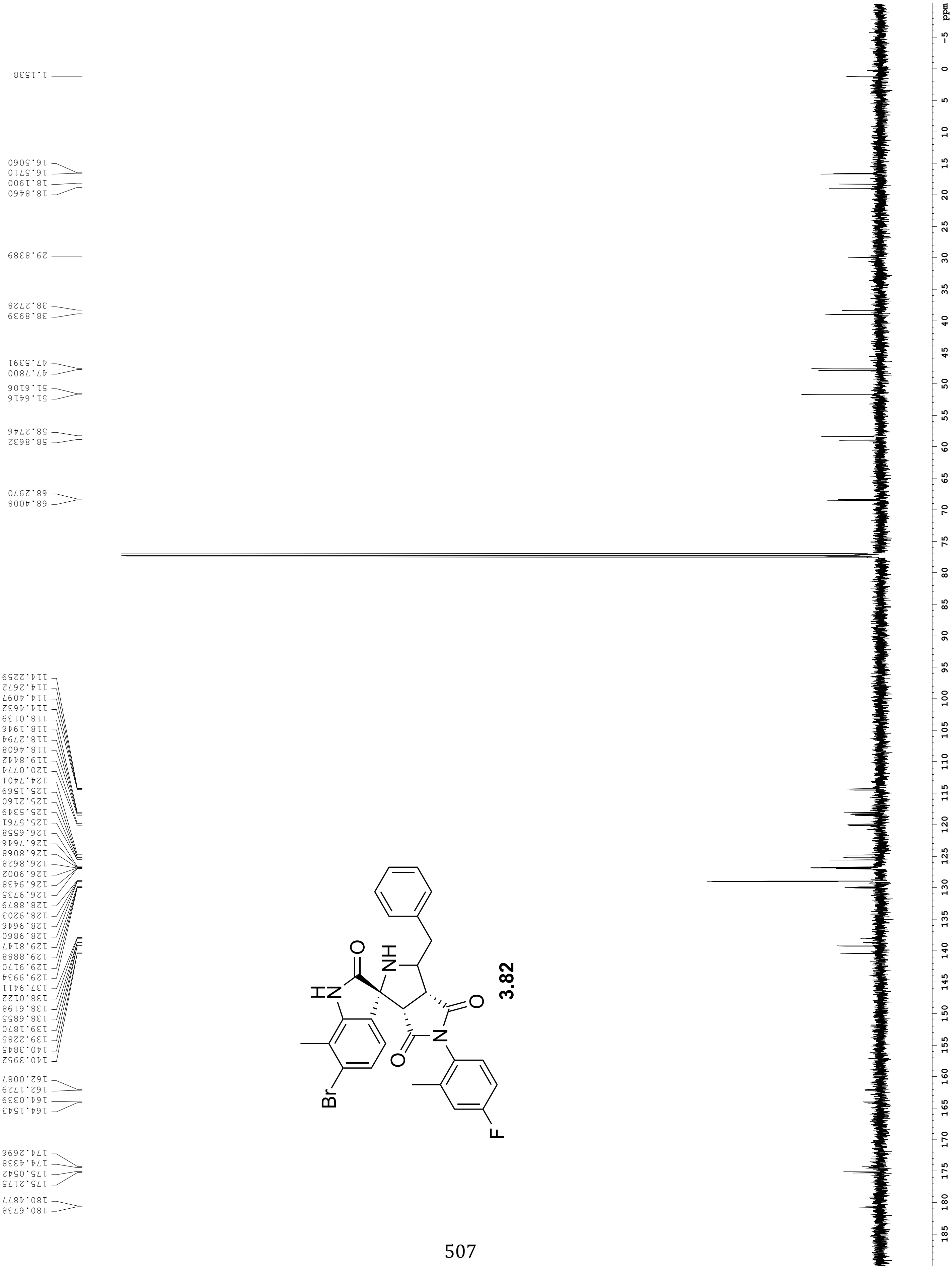


181.167
175.991
174.342
167.790
142.830
140.634
135.292
134.779
134.593
129.494
128.737
128.668
127.355
126.594
126.491
125.142
122.016
117.442
69.175
60.486
53.399
49.742
36.949
14.347
Cl
H
N
O
NH
O
N
O
H2N
O
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
ppm

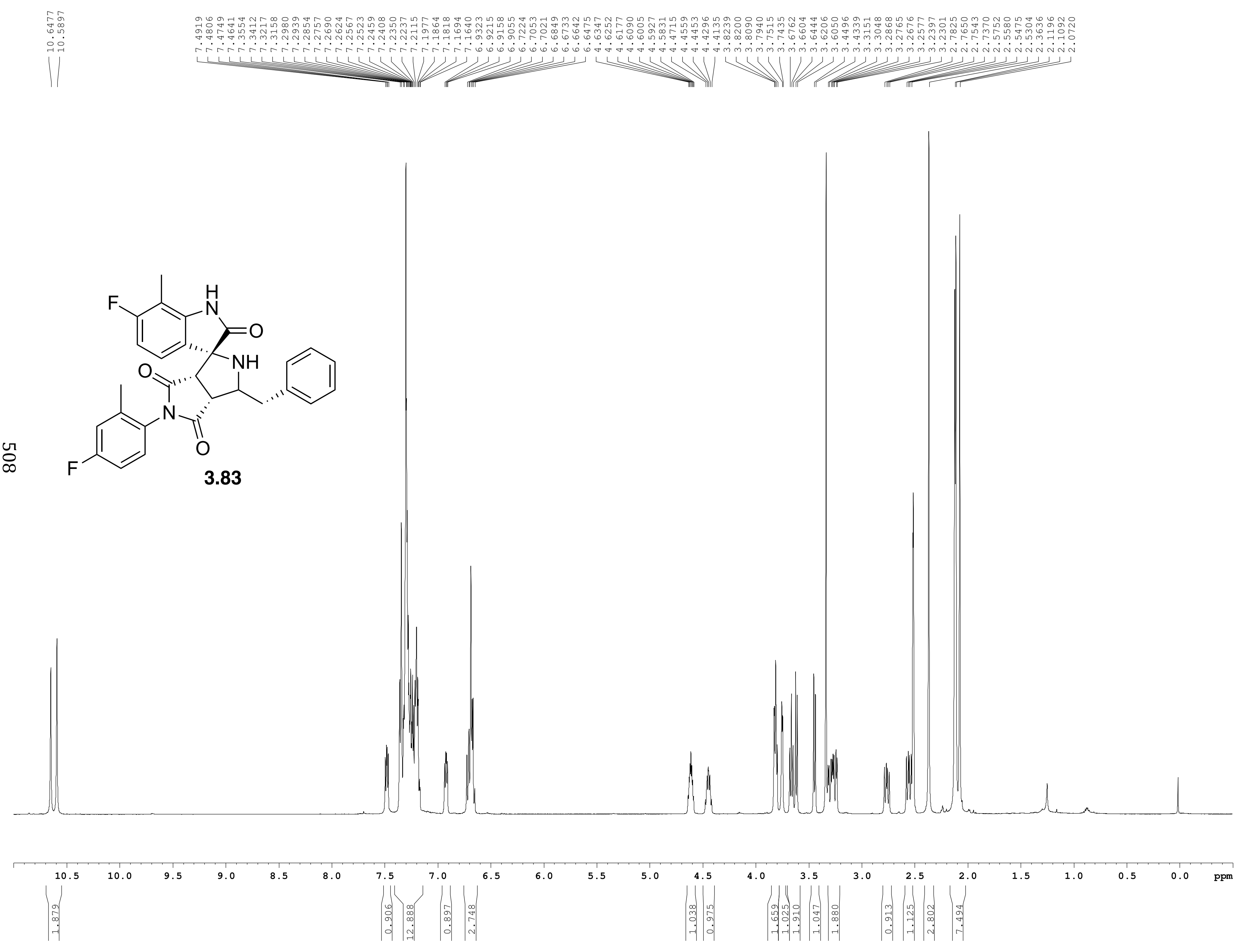
**3.81**



8.2397
8.1735
7.2801
7.2591
7.2513
7.2342
7.2230
7.2185
7.2094
7.1923
7.1761
7.1340
7.1290
7.1119
7.1017
7.0955
7.0843
7.0768
7.0587
7.0295
7.0241
7.0131
7.0082
6.9965
6.7921
6.7760
6.7242
6.7078
4.7765
4.7547
3.7985
3.7823
3.7679
3.6782
3.6617
3.4888
3.4830
3.4697
3.4614
3.4551
3.4499
3.4422
2.7383
2.7175
2.7106
2.6898
2.6235
2.6018
2.5961
2.5744
2.4482
2.1707
2.1621
2.1283
2.0857
2.0320
Br
H
N
O
NH
O
N
O
F
3.82
1.936
9.357
4.090
0.900
1.000
1.796
2.087
1.026
1.652
0.928
1.104
2.433
3.497
2.217
1.802
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

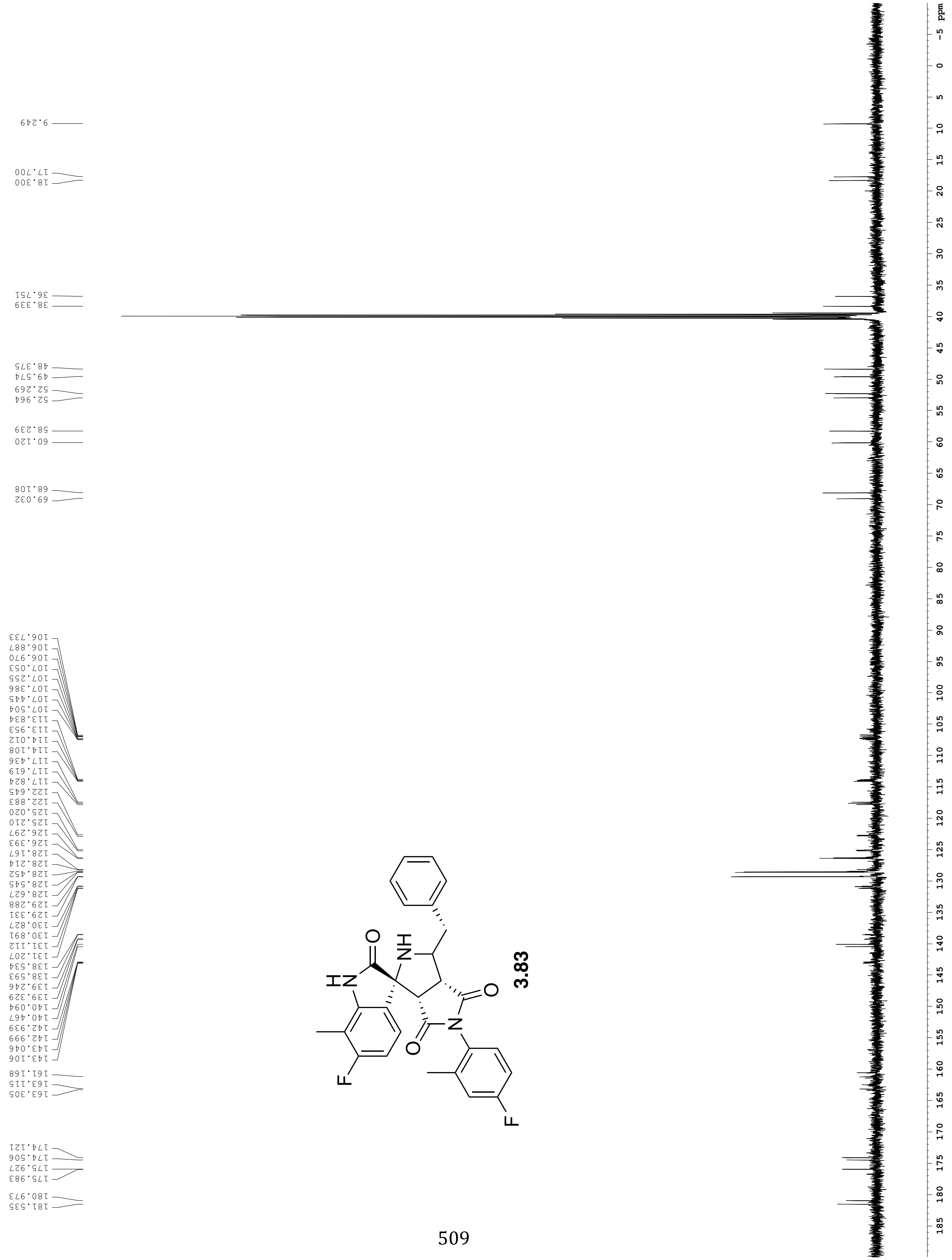

1.1538
16.5060
16.5710
18.1900
18.8460
29.8389
38.2728
38.8939
47.5391
47.7800
51.6106
51.6416
58.2746
58.8632
68.2970
68.4008
114.2259
114.2672
114.4097
114.4632
118.0139
118.1946
118.2794
118.4608
119.8442
120.0774
124.7401
125.1569
125.2160
125.5349
125.5761
126.6558
126.7646
126.8068
126.8628
126.9002
126.9438
126.9735
128.8879
128.9203
128.9646
128.9860
129.8147
129.8888
129.9170
129.9934
137.9411
138.0122
138.6198
138.6855
139.1870
139.2285
140.3845
140.3952
162.0087
162.1729
164.0339
164.1543
174.2696
174.4338
175.0542
175.2175
180.4877
180.6738
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
NH
O
HN
Br
O
N
O
F

**3.82**

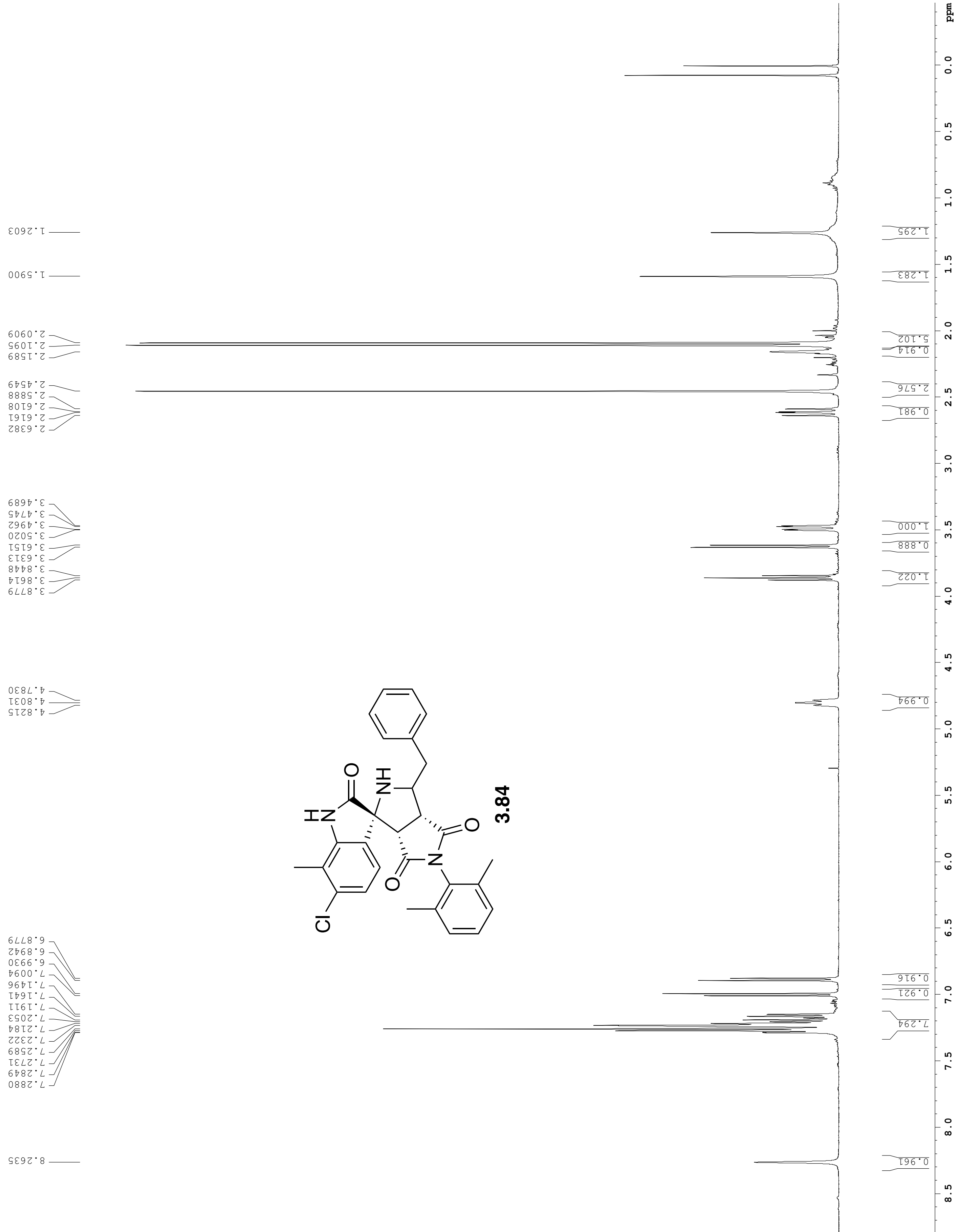


**3.83**

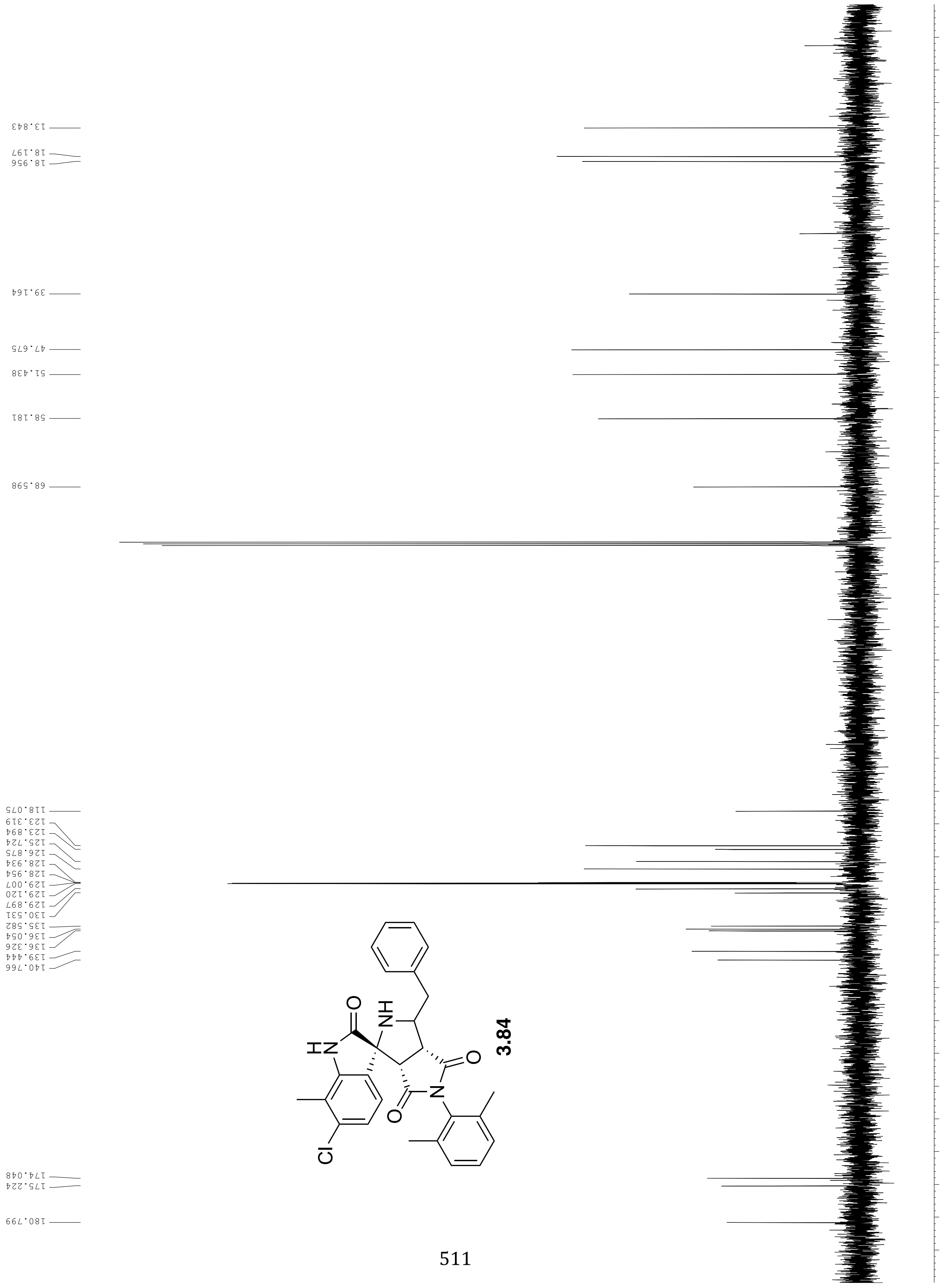
10.6477
10.5897
7.4919
7.4806
7.4749
7.4641
7.3554
7.3412
7.3217
7.3158
7.2980
7.2939
7.2854
7.2757
7.2690
7.2624
7.2567
7.2523
7.2459
7.2408
7.2350
7.2237
7.2115
7.1977
7.1864
7.1818
7.1694
7.1640
6.9323
6.9215
6.9158
6.9055
6.7224
6.7053
6.7021
6.6849
6.6733
6.6642
6.6475
4.6347
4.6252
4.6177
4.6090
4.6005
4.5927
4.5831
4.4715
4.4559
4.4453
4.4296
4.4135
3.8239
3.8200
3.8090
3.7940
3.7515
3.7435
3.6762
3.6604
3.6444
3.6206
3.6050
3.4496
3.4339
3.3151
3.3048
3.2868
3.2765
3.2676
3.2577
3.2397
3.2301
2.7825
2.7650
2.7543
2.7370
2.5752
2.5580
2.5475
2.5304
2.3636
2.1196
2.1092
2.0720
F
H
N
O
NH
O
N
O
F
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm
1.879
0.906
12.888
0.897
2.748
1.038
0.975
1.659
1.025
1.910
1.047
1.880
0.913
1.125
2.802
7.494


9.249
17.700
18.300
36.751
38.339
48.375
49.574
52.269
52.964
58.239
60.120
68.108
69.032
106.733
106.887
106.970
107.053
107.255
107.386
107.445
107.504
113.834
113.953
114.012
114.108
117.436
117.619
117.824
122.645
122.883
125.020
125.210
126.297
126.393
128.167
128.214
128.452
128.545
128.627
129.288
129.331
130.827
130.891
131.112
131.207
138.534
138.593
139.246
139.329
140.094
140.467
142.939
142.999
143.046
143.106
161.168
163.115
163.305
174.121
174.506
175.927
175.983
180.973
181.535
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
ppm
NH
HN
O
O
O
N
F
F

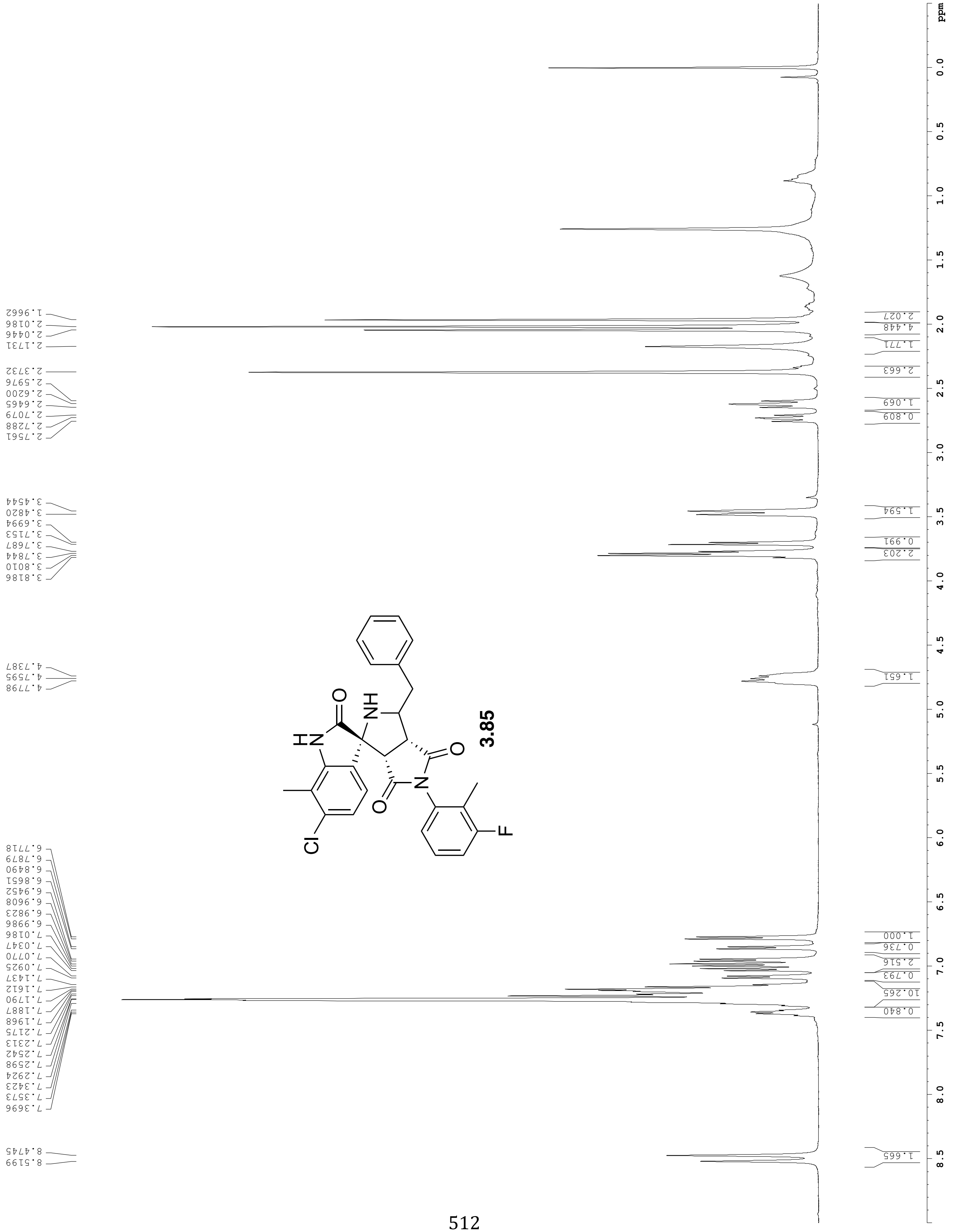
**3.83**


1.2603
1.5900
2.0909
2.1095
2.1589
2.4549
2.5888
2.6108
2.6161
2.6382
3.4689
3.4745
3.4962
3.5020
3.6151
3.6313
3.8448
3.8614
3.8779
4.7830
4.8031
4.8215
6.8779
6.8942
6.9930
7.0094
7.1496
7.1641
7.1911
7.2053
7.2184
7.2322
7.2589
7.2731
7.2849
7.2880
8.2635
1.295
1.283
5.102
0.914
2.576
0.981
1.000
0.888
1.022
0.994
0.916
0.921
7.294
0.961
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
O
NH
H
N
Cl
O
N
O

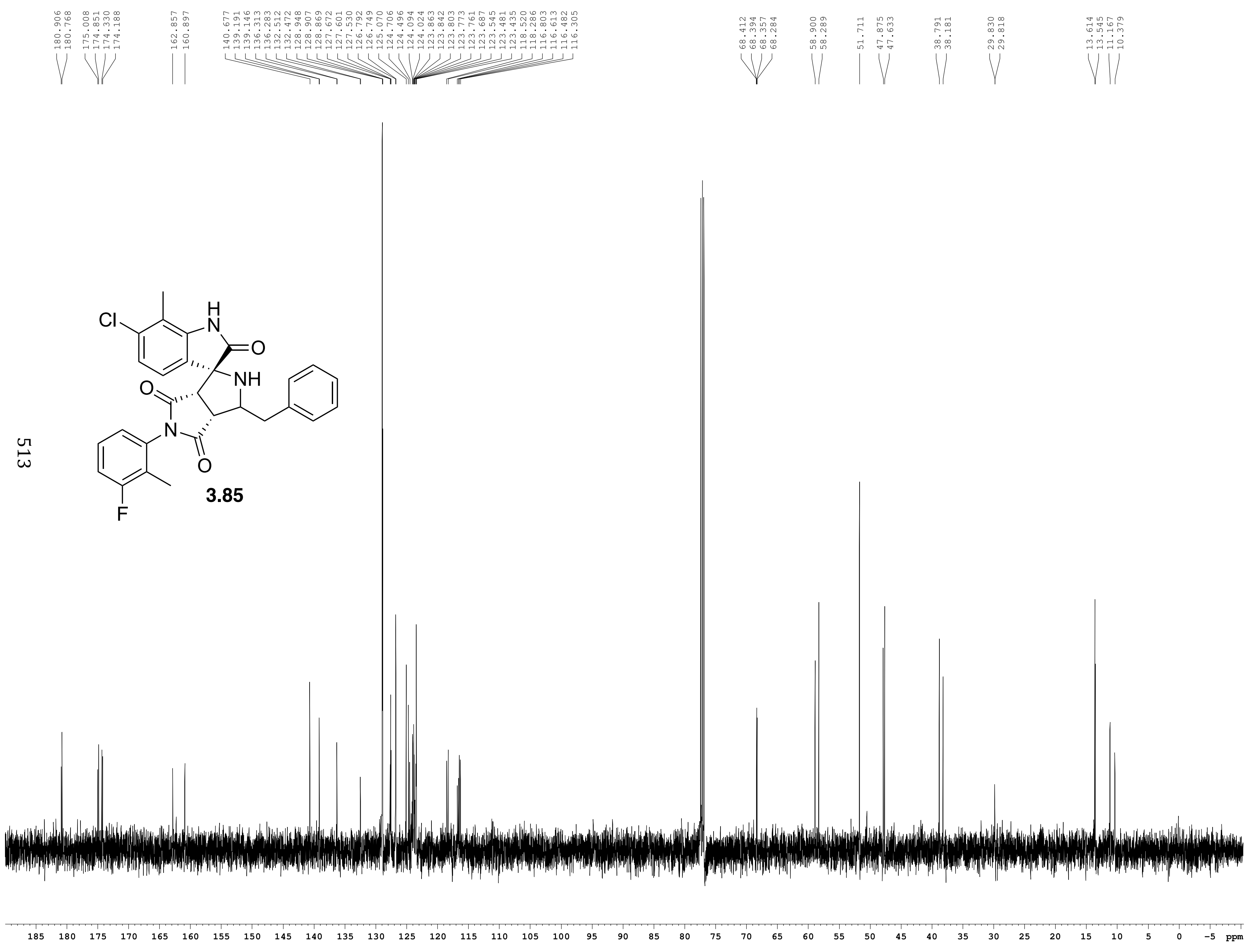
**3.84**


13.843
18.197
18.956
39.164
47.675
51.438
58.181
68.598
118.075
123.319
123.894
125.724
126.875
128.934
128.954
129.007
129.120
129.897
130.531
135.582
136.054
136.326
139.444
140.766
174.048
175.224
180.799
NH
HN
O
O
O
N
Cl
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185

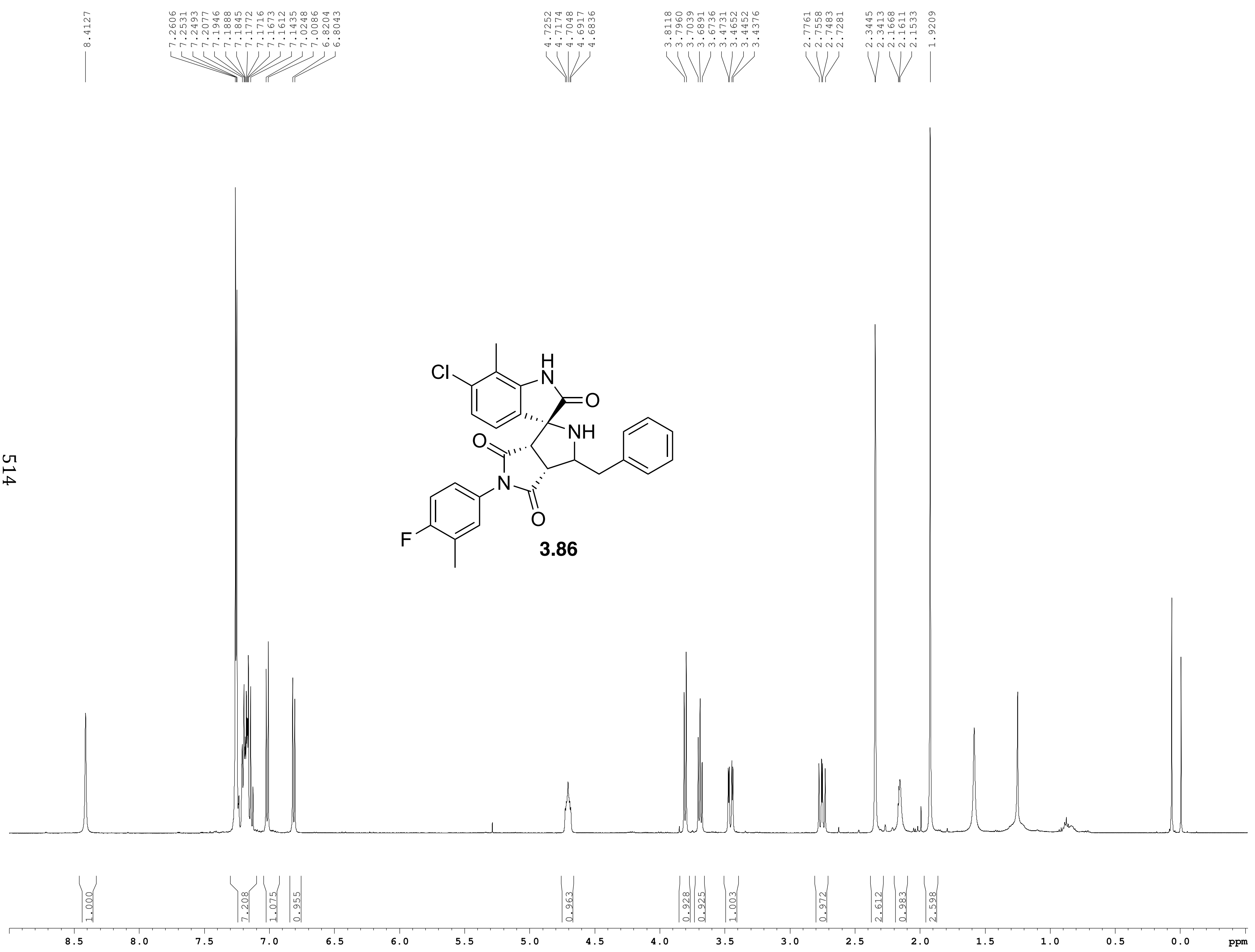
**3.84**


ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
1.9662
2.0186
2.0446
2.1731
2.3732
2.5976
2.6200
2.6465
2.7079
2.7288
2.7561
3.4544
3.4820
3.6994
3.7153
3.7687
3.7844
3.8010
3.8186
4.7387
4.7595
4.7798
6.7718
6.7879
6.8490
6.8651
6.9452
6.9608
6.9823
6.9986
7.0186
7.0347
7.0770
7.0925
7.1437
7.1612
7.1790
7.1887
7.1968
7.2175
7.2313
7.2542
7.2598
7.2924
7.3423
7.3573
7.3696
8.4745
8.5199
2.027
4.448
1.771
2.663
1.069
0.809
1.594
0.991
2.203
1.651
1.000
0.736
2.516
0.793
10.265
0.840
1.665
O
NH
H
N
O
O
N
Cl
F

**3.85**

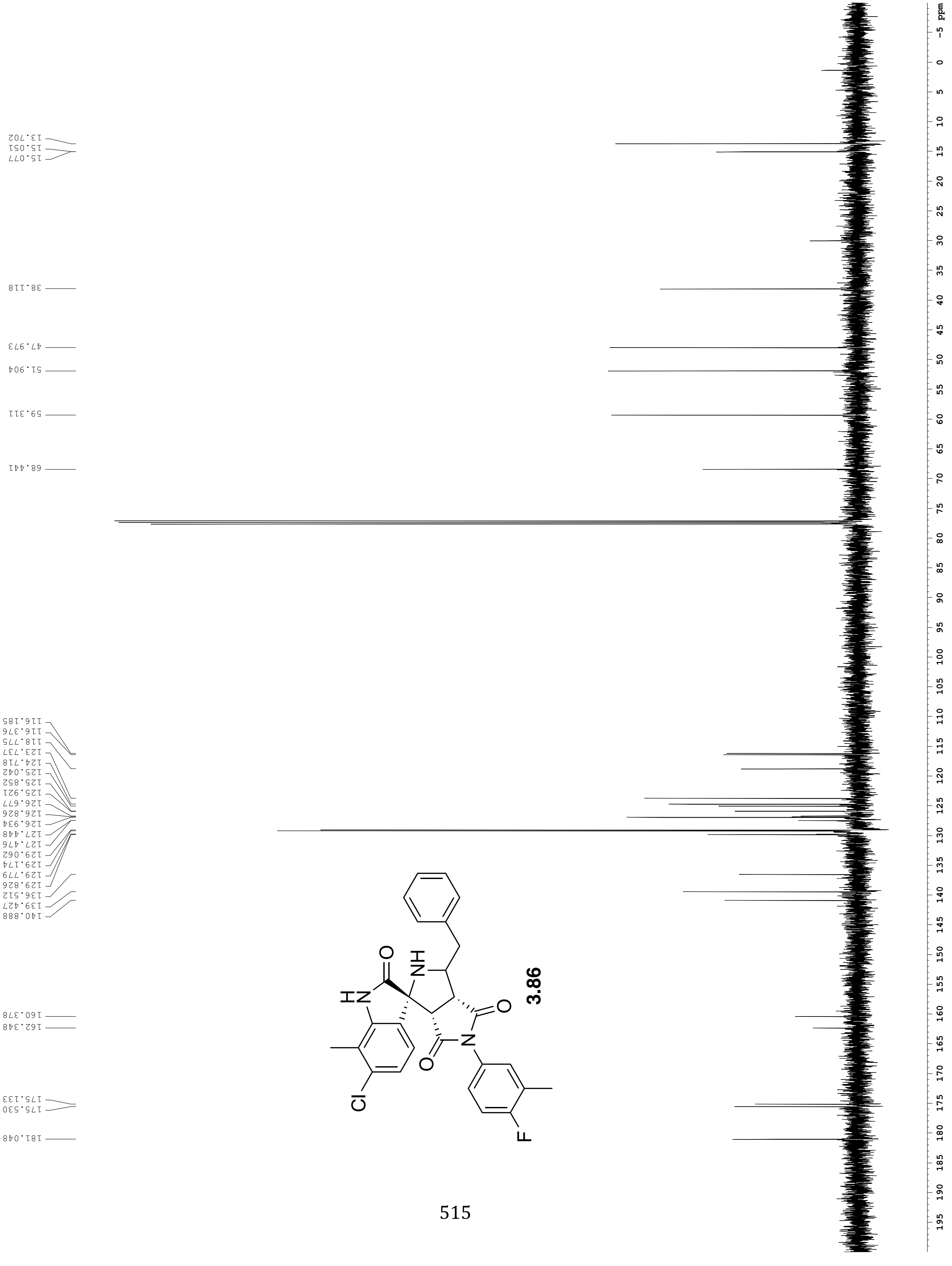

180.906
180.768
175.008
174.851
174.330
174.188
162.857
160.897
140.677
139.191
139.146
136.313
136.283
132.512
132.472
128.948
128.907
128.869
127.672
127.601
127.530
126.792
126.749
125.070
124.706
124.496
124.094
124.024
123.863
123.842
123.803
123.773
123.761
123.687
123.545
123.481
123.435
118.520
118.286
116.803
116.613
116.482
116.305
68.412
68.394
68.357
68.284
58.900
58.289
51.711
47.875
47.633
38.791
38.181
29.830
29.818
13.614
13.545
11.167
10.379
Cl
H
N
O
NH
O
N
O
F
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
ppm

**3.85**

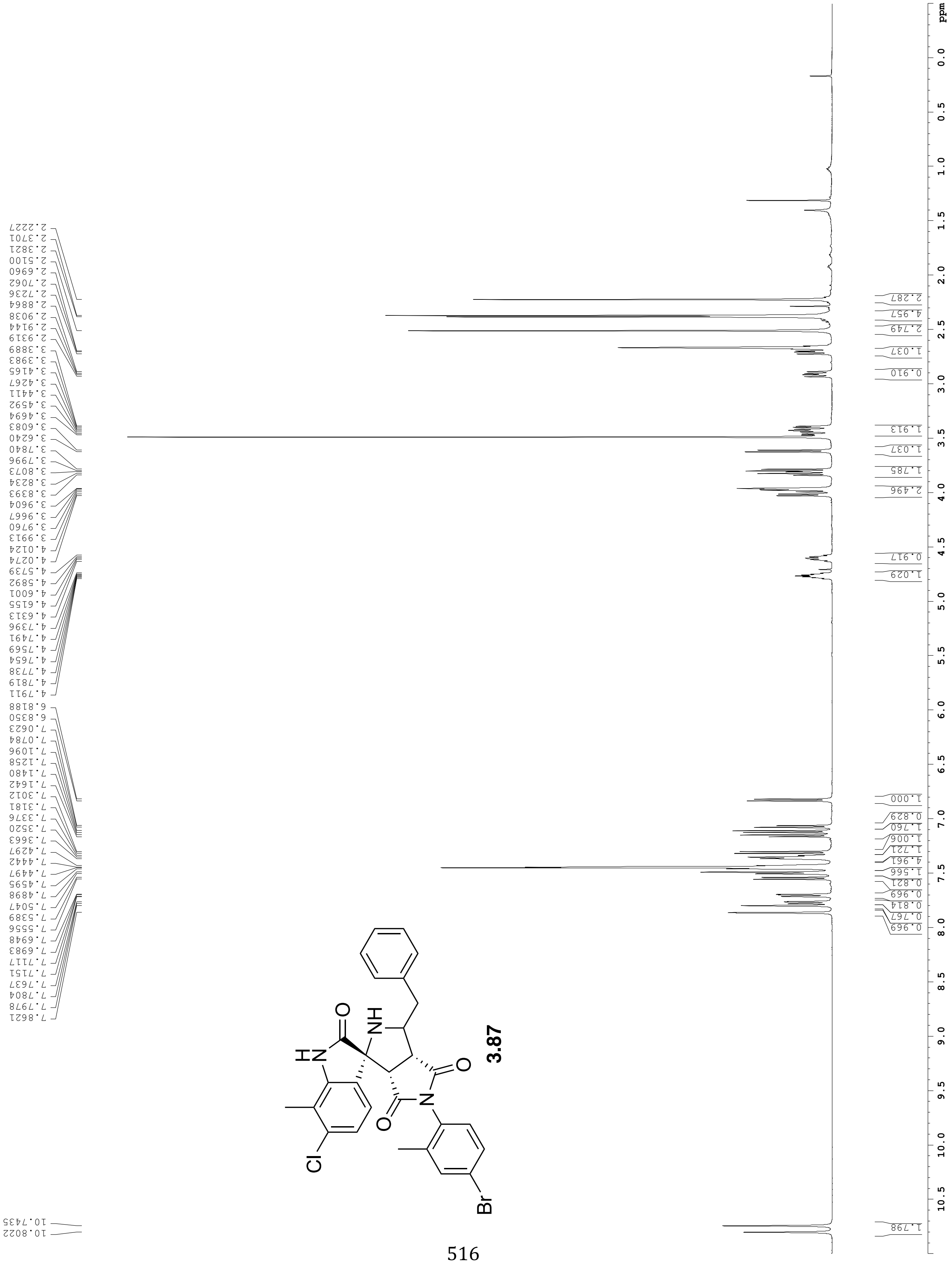


**3.86**

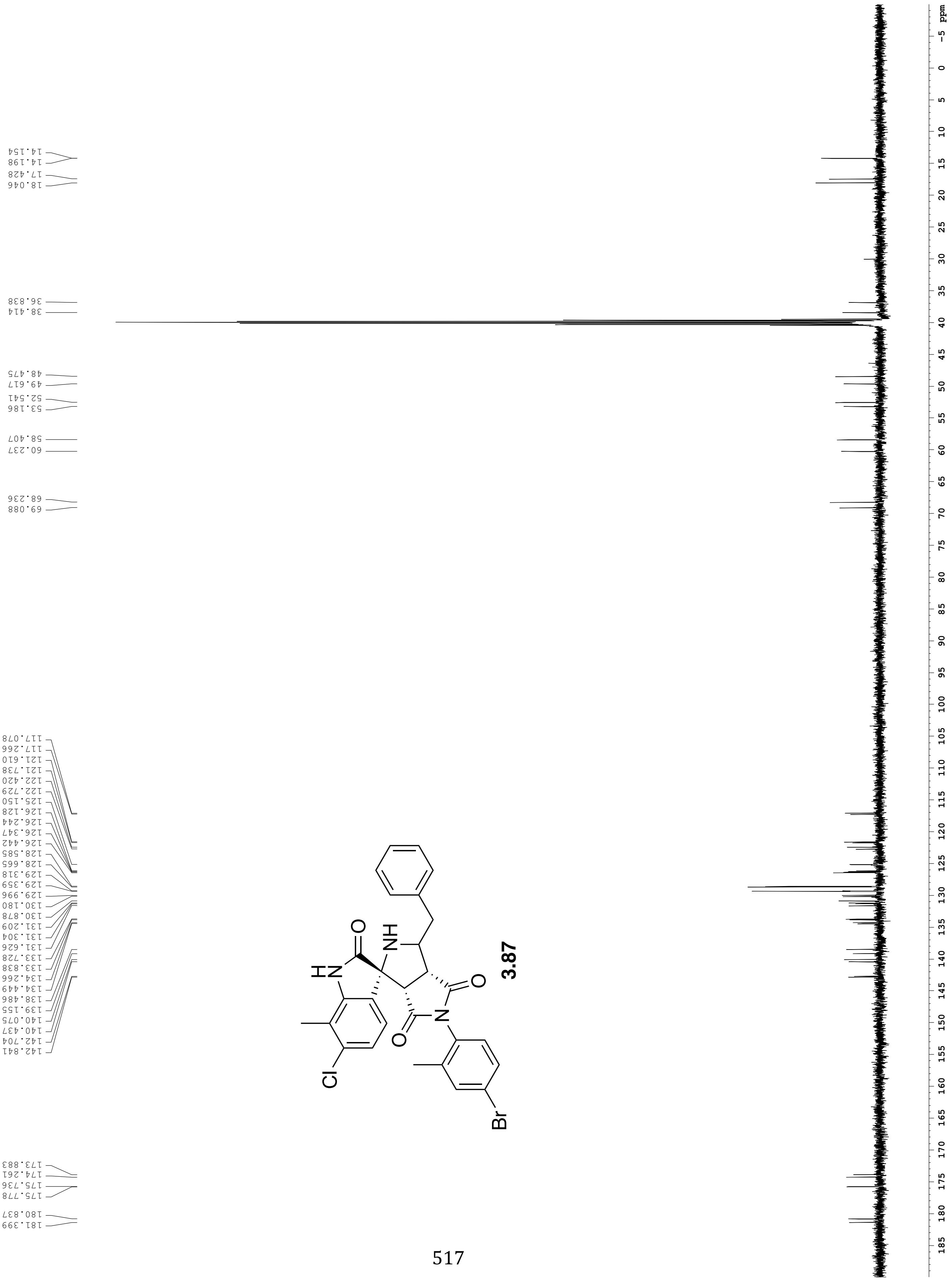
8.4127
7.2606
7.2531
7.2493
7.2077
7.1946
7.1888
7.1845
7.1772
7.1716
7.1673
7.1612
7.1435
7.0248
7.0086
6.8204
6.8043
4.7252
4.7174
4.7048
4.6917
4.6836
3.8118
3.7960
3.7039
3.6891
3.6736
3.4731
3.4652
3.4452
3.4376
2.7761
2.7558
2.7483
2.7281
2.3445
2.3413
2.1668
2.1611
2.1533
1.9209
Cl
H
N
O
NH
O
N
O
F
1.000
7.208
1.075
0.955
0.963
0.928
0.925
1.003
0.972
2.612
0.983
2.598
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm


13.702
15.051
15.077
38.118
47.973
51.904
59.311
68.441
116.185
116.376
118.775
123.737
124.718
125.042
125.852
125.921
126.677
126.826
126.934
127.448
127.476
129.062
129.174
129.779
129.826
136.512
139.427
140.888
160.378
162.348
175.133
175.530
181.048
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
NH
HN
O
O
O
N
Cl
F

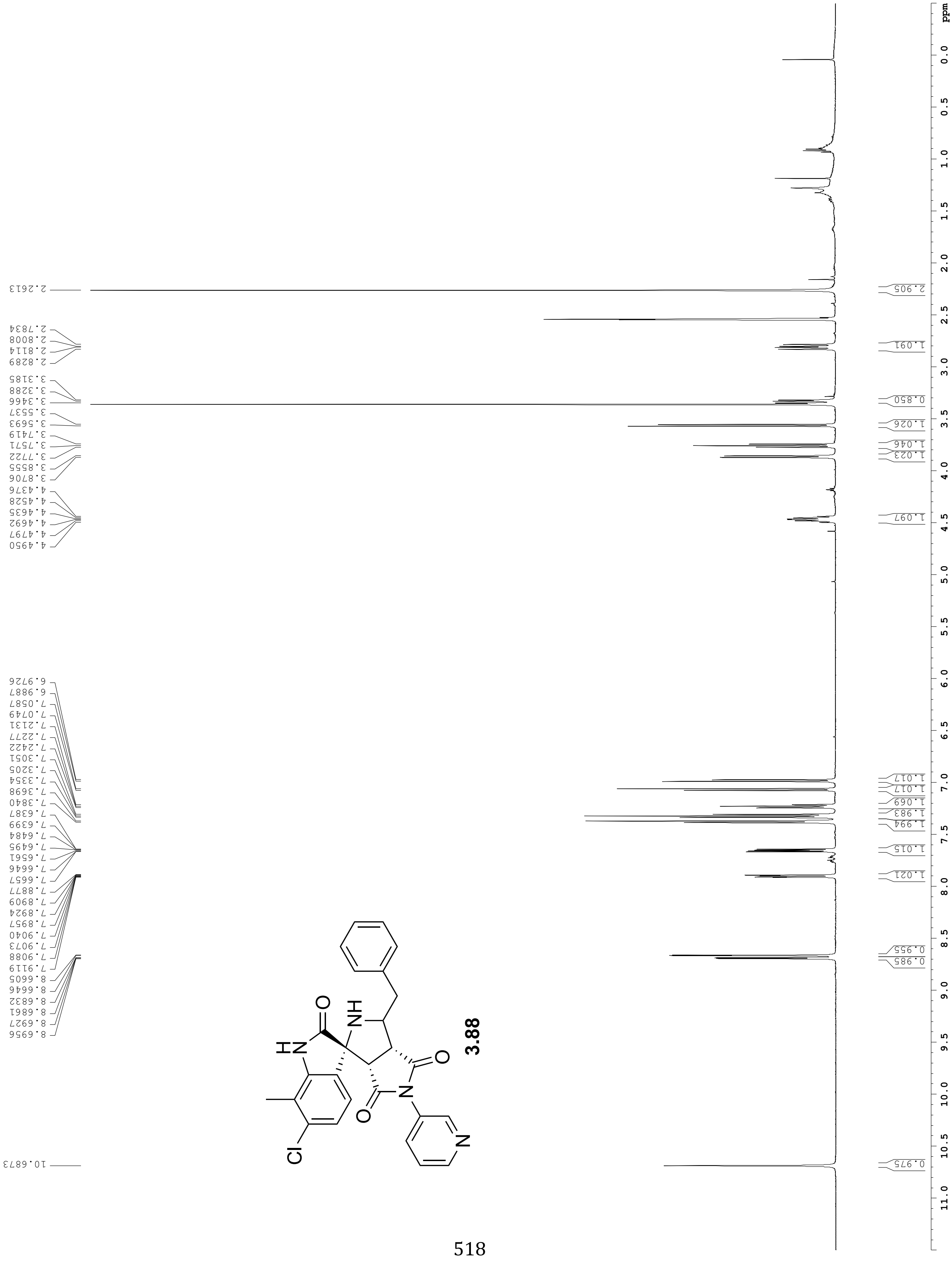
**3.86**


2.2227
2.3701
2.3821
2.5100
2.6960
2.7062
2.7236
2.8864
2.9038
2.9144
2.9319
3.3889
3.3983
3.4165
3.4267
3.4411
3.4592
3.4694
3.6083
3.6240
3.7840
3.7996
3.8073
3.8234
3.8393
3.9604
3.9667
3.9760
3.9913
4.0124
4.0274
4.5739
4.5892
4.6001
4.6155
4.6313
4.7396
4.7491
4.7569
4.7654
4.7738
4.7819
4.7911
6.8188
6.8350
7.0623
7.0784
7.1096
7.1258
7.1480
7.1642
7.3012
7.3181
7.3376
7.3520
7.3663
7.4297
7.4442
7.4497
7.4595
7.4898
7.5047
7.5389
7.5556
7.6948
7.6983
7.7117
7.7151
7.7637
7.7804
7.7978
7.8621
10.7435
10.8022
2.287
4.957
2.749
1.037
0.910
1.913
1.037
1.785
2.496
0.917
1.029
1.000
0.829
1.760
1.006
1.721
4.961
1.566
0.821
0.969
0.814
0.767
0.969
1.798
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
O
NH
H
N
O
N
O
Cl
Br

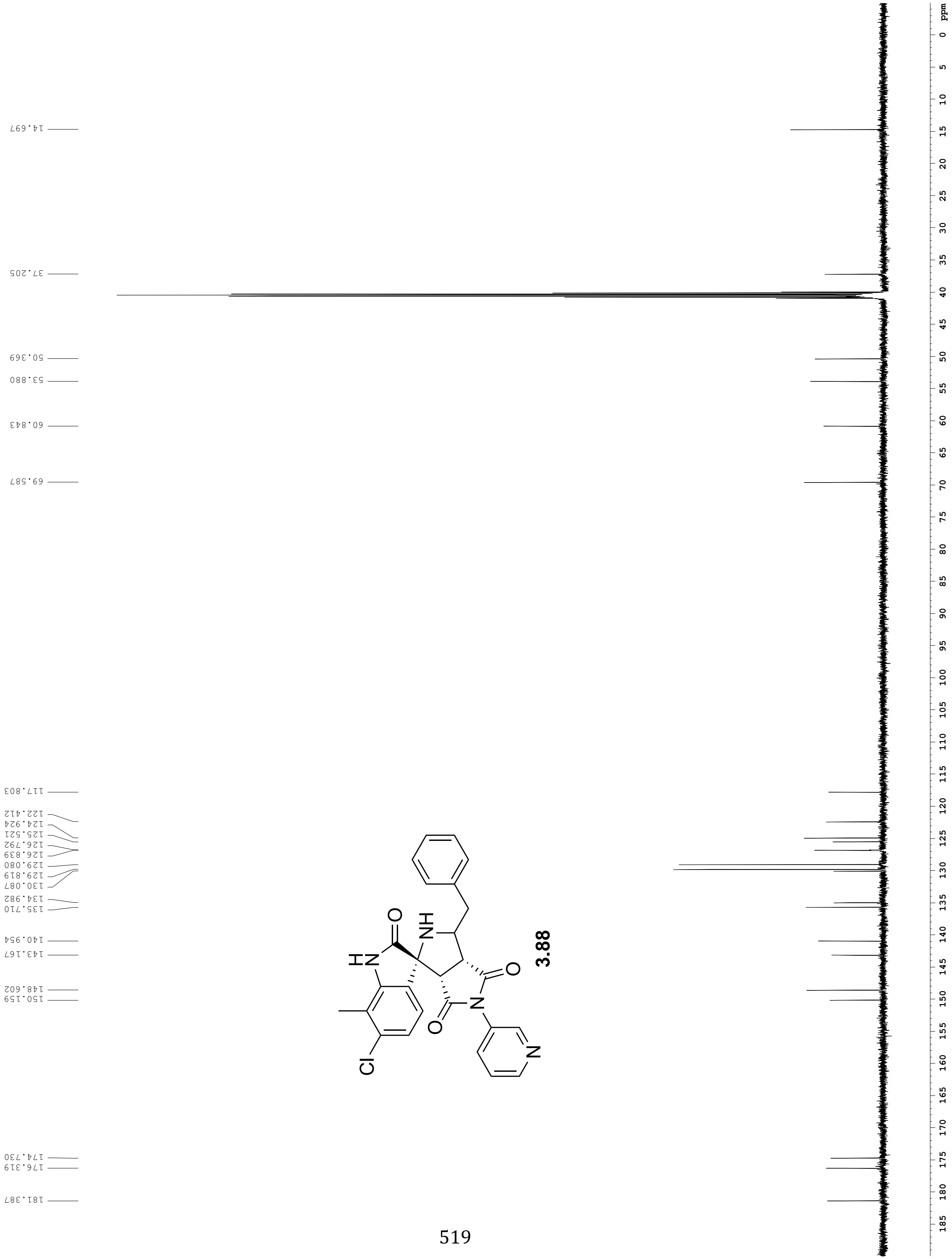
**3.87**


14.154
14.198
17.428
18.046
36.838
38.414
48.475
49.617
52.541
53.186
58.407
60.237
68.236
69.088
117.078
117.266
121.610
121.738
122.420
122.729
125.150
126.128
126.244
126.347
126.442
128.585
128.665
129.318
129.359
129.996
130.180
130.878
131.209
131.304
131.626
133.728
133.838
134.266
134.449
138.486
139.155
140.075
140.437
142.704
142.841
173.883
174.261
175.736
175.778
180.837
181.399
ppm
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
O
NH
H
N
O
N
O
Cl
Br

**3.87**


2.2613
2.7834
2.8008
2.8114
2.8289
3.3185
3.3288
3.3466
3.5537
3.5693
3.7419
3.7571
3.7722
3.8555
3.8706
4.4376
4.4528
4.4635
4.4692
4.4797
4.4950
6.9726
6.9887
7.0587
7.0749
7.2131
7.2277
7.2422
7.3051
7.3205
7.3354
7.3698
7.3840
7.6387
7.6399
7.6484
7.6495
7.6561
7.6646
7.6657
7.8877
7.8909
7.8924
7.8957
7.9040
7.9073
7.9088
7.9119
8.6605
8.6646
8.6832
8.6861
8.6927
8.6956
10.6873
2.905
1.091
0.850
1.026
1.046
1.023
1.097
1.017
1.017
1.069
1.983
1.994
1.015
1.021
0.955
0.985
0.975
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
O
NH
HN
O
N
O
Cl
N

**3.88**

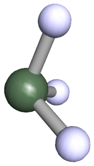

14.697
37.205
50.369
53.880
60.843
69.587
117.803
122.412
124.924
125.521
126.792
126.839
129.080
129.819
130.087
134.982
135.710
140.954
143.167
148.602
150.159
174.730
176.319
181.387
ppm
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
O
NH
HN
O
N
O
Cl
N

**3.88**

# Appendix B: Energies and Coordinates of Calculated Molecules for Chapter 5

## Energies and Coordinates of Molecules Calculated at the B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p), B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p), and B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) Levels of Theory

Methanide Anion:



B3LYP/6-31G(d,p) geometry

```
                 atomic coordinates                 atom    charge  isotop
        -0.03609377   -0.23130248    0.20446837     c       6.000     0
        -0.03609377    1.88481285   -0.11584021     h       1.000     0
         1.59908625   -0.78555915   -1.05994739     h       1.000     0
        -1.67127379   -0.78555915   -1.05994739     h       1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -39.82188180543 hartree
Enthalpy Correction = 0.030973 hartree
Entropy = 0.000074 hartree/K

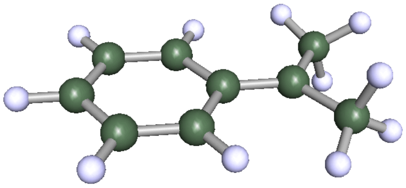
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -39.93678287046 hartree
Enthalpy Correction = 0.031203 hartree
Entropy = 0.000074 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -39.9303430849 hartree
Free Energy Correction = 5.059 kcal/mol

2-Phenylpropan-2-ylium (E = 5.74):



B3LYP/6-31G(d,p) geometry

```
                 atomic coordinates                 atom    charge  isotop
       -14.18031594    4.12621701    4.31632346     c       6.000     0
```

| | | | | | |
|---|---|---|---|---|---|
| -13.98945360 | 1.48116734 | 4.25339558 | c | 6.000 | 0 |
| -12.13789993 | 5.59132169 | 3.61202253 | c | 6.000 | 0 |
| -9.82147364 | 4.44709251 | 2.80000721 | c | 6.000 | 0 |
| -9.69977527 | 1.74213852 | 2.75049639 | c | 6.000 | 0 |
| -11.74786046 | 0.29555317 | 3.47388355 | c | 6.000 | 0 |
| -7.71896434 | 5.93581876 | 2.07813183 | c | 6.000 | 0 |
| -7.74126311 | 8.74867611 | 2.09740704 | c | 6.000 | 0 |
| -5.27158002 | 4.82220315 | 1.24079418 | c | 6.000 | 0 |
| -15.92377727 | 5.01590008 | 4.92424836 | h | 1.000 | 0 |
| -15.59855540 | 0.33656022 | 4.81407733 | h | 1.000 | 0 |
| -12.31836878 | 7.62787954 | 3.67438349 | h | 1.000 | 0 |
| -7.98787237 | 0.79576367 | 2.15183115 | h | 1.000 | 0 |
| -11.62861874 | -1.75026435 | 3.43249855 | h | 1.000 | 0 |
| -5.90085883 | 9.47111841 | 2.70930036 | h | 1.000 | 0 |
| -9.22545401 | 9.62135164 | 3.21914847 | h | 1.000 | 0 |
| -7.95706983 | 9.38267923 | 0.12547782 | h | 1.000 | 0 |
| -4.36470045 | 6.03710808 | -0.16535104 | h | 1.000 | 0 |
| -5.38345181 | 2.90243037 | 0.51362756 | h | 1.000 | 0 |
| -3.99525899 | 4.81237657 | 2.88655667 | h | 1.000 | 0 |

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 825.9 kJ/mol)

Total Energy = -349.19704651821 hartree
Enthalpy Correction = 0.180526 hartree
Entropy = 0.000139 hartree/K

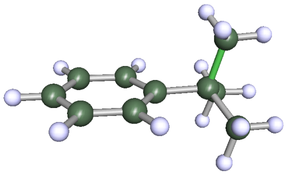
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 325.4 kJ/mol)

Total Energy = -349.27721765696 hartree
Enthalpy Correction = 0.180067 hartree
Entropy = 0.000139 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 351.6 kJ/mol)

Total Energy = -349.2815794165 hartree
Free Energy Correction = 87.187 kcal/mol

2-Phenylpropan-2-ylium Product:



B3LYP/6-31G(d,p) geometry

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.30766064 | 2.12044091 | -2.26530731 | c | 6.000 | 0 |
| -0.57521185 | 4.74515146 | -2.27122972 | c | 6.000 | 0 |
| -0.17387370 | 0.74222773 | 0.00000000 | c | 6.000 | 0 |
| -0.30766064 | 2.12044091 | 2.26530731 | c | 6.000 | 0 |
| -0.57521185 | 4.74515146 | 2.27122972 | c | 6.000 | 0 |
| -0.71371555 | 6.07571896 | 0.00000000 | c | 6.000 | 0 |
| -0.92746436 | 8.11768522 | 0.00000000 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -0.67973827 | 5.74720519 | -4.06135594 | h | 1.000 | 0 |
| -0.20627495 | 1.14679542 | -4.06669442 | h | 1.000 | 0 |
| -0.20627495 | 1.14679542 | 4.06669442 | h | 1.000 | 0 |
| -0.67973827 | 5.74720519 | 4.06135594 | h | 1.000 | 0 |
| 0.22866631 | -2.14452358 | 0.00000000 | c | 6.000 | 0 |
| -0.96052890 | -3.39440356 | -2.35538489 | c | 6.000 | 0 |
| -0.96052890 | -3.39440356 | 2.35538489 | c | 6.000 | 0 |
| 3.10677024 | -2.67534954 | 0.00000000 | c | 6.000 | 0 |
| -2.97815547 | -2.95767840 | -2.50475451 | h | 1.000 | 0 |
| -0.75856820 | -5.45099251 | -2.23468241 | h | 1.000 | 0 |
| -0.04437077 | -2.79959525 | -4.11081008 | h | 1.000 | 0 |
| 4.01196228 | -1.85749685 | -1.67142686 | h | 1.000 | 0 |
| 3.47671247 | -4.71461726 | 0.00000000 | h | 1.000 | 0 |
| 4.01196228 | -1.85749685 | 1.67142686 | h | 1.000 | 0 |
| -0.04437077 | -2.79959525 | 4.11081008 | h | 1.000 | 0 |
| -2.97815547 | -2.95767840 | 2.50475451 | h | 1.000 | 0 |
| -0.75856820 | -5.45099251 | 2.23468241 | h | 1.000 | 0 |

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

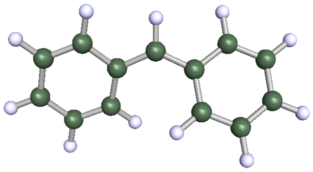
Total Energy = -389.36404450845 hartree
Enthalpy Correction = 0.223271 hartree
Entropy = 0.00015 hartree/K

B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -389.3691012365 hartree
Enthalpy Correction = 0.221552 hartree
Entropy = 0.000143 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -389.375799857 hartree
Free Energy Correction = 111.043 kcal/mol
Diphenylmethylium (E = 5.47):



B3LYP/6-31G(d,p) geometry

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -8.19007306 | 4.27002517 | 0.53932784 | c | 6.000 | 0 |
| -8.53853856 | 1.72777660 | -0.11867480 | c | 6.000 | 0 |
| -5.78123916 | 5.28991037 | 0.51551729 | c | 6.000 | 0 |
| -3.64528171 | 3.75507480 | -0.07936850 | c | 6.000 | 0 |
| -4.05818687 | 1.18920466 | -0.79462984 | c | 6.000 | 0 |
| -6.47854810 | 0.20371248 | -0.81163737 | c | 6.000 | 0 |
| -1.23588089 | 4.92009096 | 0.00925966 | c | 6.000 | 0 |
| 1.22567637 | 3.86751351 | 0.09202966 | c | 6.000 | 0 |
| 1.76519318 | 1.32526494 | 0.80710203 | c | 6.000 | 0 |
| 4.22996298 | 0.45636886 | 0.80710203 | c | 6.000 | 0 |
| 6.21001802 | 2.07473032 | 0.09448631 | c | 6.000 | 0 |

```
   5.73645265    4.59656985   -0.56238250    c      6.000     0
   3.28264327    5.50118175   -0.51797393    c      6.000     0
  -9.80106459    5.43485236    1.03840451    h      1.000     0
 -10.43223312    0.93673724   -0.13813898    h      1.000     0
  -5.49267798    7.26108370    1.00986965    h      1.000     0
  -2.49292672    0.04478651   -1.45074275    h      1.000     0
  -6.79262059   -1.73533551   -1.39801939    h      1.000     0
  -1.28104535    6.98008142    0.01096041    h      1.000     0
   0.25945940    0.10998206    1.47474227    h      1.000     0
   4.64154533   -1.46510467    1.39178330    h      1.000     0
   8.13886149    1.37345295    0.09939959    h      1.000     0
   7.28602808    5.83623019   -1.07638801    h      1.000     0
   2.89619427    7.45667035   -1.00873581    h      1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 824.4 kJ/mol)

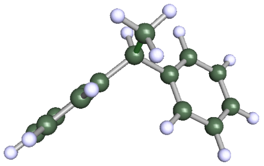
Total Energy = -501.58434760415 hartree
Enthalpy Correction = 0.209635 hartree
Entropy =  0.000156 hartree/K

B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 352.0 kJ/mol)

Total Energy = -501.6582058686 hartree
Enthalpy Correction = 0.209431 hartree
Entropy =  0.000156 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 363.4 kJ/mol)

Total Energy = -501.6670762708 hartree
Free Energy Correction = 101.747 kcal/mol
Diphenylmethylium Product:



B3LYP/6-31G(d,p) geometry

```
               atomic coordinates             atom    charge  isotop
  -5.82772642   -0.83129053   -2.72215050    c      6.000     0
  -7.44041871   -2.01766059   -0.99890923    c      6.000     0
  -3.50241842    0.10676953   -1.92355223    c      6.000     0
  -2.72725276   -0.10639158    0.60546825    c      6.000     0
  -4.36281073   -1.29559624    2.31113506    c      6.000     0
  -6.69813428   -2.24537259    1.51669420    c      6.000     0
  -7.93514901   -3.16113388    2.87654112    h      1.000     0
  -9.25701244   -2.74974050   -1.61495995    h      1.000     0
  -6.38481769   -0.63702668   -4.68897746    h      1.000     0
  -2.25293150    1.01629471   -3.27867484    h      1.000     0
  -3.83349844   -1.48249015    4.28363120    h      1.000     0
  -0.14513097    0.94977635    1.36098076    c      6.000     0
   2.02805409   -0.57409880    0.21391700    c      6.000     0
   0.23357015    1.23966034    4.23374243    c      6.000     0
  -0.02759000    2.85462030    0.54556393    h      1.000     0
```

```
     2.10175341   -3.21612491    0.40326756     c      6.000     0
     4.04325804    0.65667983   -0.98152375     c      6.000     0
     6.08302843   -0.70543477   -1.95586655     c      6.000     0
     6.13707459   -3.33272101   -1.74837462     c      6.000     0
     4.13623256   -4.58315279   -0.56427222     c      6.000     0
     0.53989476   -4.20860907    1.29389548     h      1.000     0
     4.01529009    2.70552091   -1.15141013     h      1.000     0
     7.62372214    0.28761632   -2.88202133     h      1.000     0
     7.71858639   -4.39871552   -2.50823350     h      1.000     0
     4.15588571   -6.63029311   -0.40251167     h      1.000     0
     0.27476618   -0.59715346    5.18540851     h      1.000     0
    -1.27348644    2.37840931    5.07901693     h      1.000     0
     2.04090422    2.16751588    4.61452225     h      1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -541.74567802067 hartree
Enthalpy Correction = 0.248776 hartree
Entropy = 0.000172 hartree/K

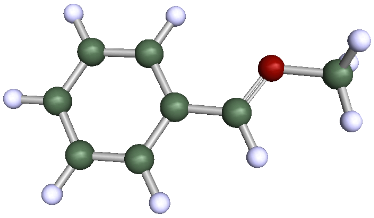
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -541.75378242447 hartree
Enthalpy Correction = 0.248661 hartree
Entropy = 0.000174 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -541.7641352035 hartree
Free Energy Correction = 124.565 kcal/mol

(*E*)-Benzylidene(methyl)oxonium (E = 2.97):



B3LYP/6-31G(d,p) geometry

```
                   atomic coordinates            atom    charge  isotop
    -8.31196040    4.48734368   -0.12869035     c      6.000     0
    -8.50584630    1.84550654   -0.10639158     c      6.000     0
    -5.94772403    5.60625052   -0.03174740     c      6.000     0
    -3.75186227    4.06366708    0.08749432     c      6.000     0
    -3.97333817    1.38498028    0.10847028     c      6.000     0
    -6.34683419    0.29952159    0.01171630     c      6.000     0
    -1.38573617    5.28367427    0.18368138     c      6.000     0
     0.69541922    4.04250215    0.28950604     o      8.000     0
     3.13297696    5.33998811    0.39986605     c      6.000     0
   -10.00118659    5.64442299   -0.22072001     h      1.000     0
   -10.36231326    0.97301999   -0.18065782     h      1.000     0
    -5.76347574    7.65112317   -0.04667624     h      1.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.28524581 | 0.22601125 | 0.20106686 | h | 1.000 | 0 |
| -6.54941283 | -1.74005982 | 0.02721206 | h | 1.000 | 0 |
| -1.28161226 | 7.34763315 | 0.17045330 | h | 1.000 | 0 |
| 4.20388476 | 4.70844164 | -1.24230596 | h | 1.000 | 0 |
| 4.04080139 | 4.72053588 | 2.14143765 | h | 1.000 | 0 |
| 2.85707694 | 7.38448281 | 0.37889009 | h | 1.000 | 0 |

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 802.3 kJ/mol)

Total Energy = -385.11854248365 hartree
Enthalpy Correction = 0.160058 hartree
Entropy = 0.000145 hartree/K

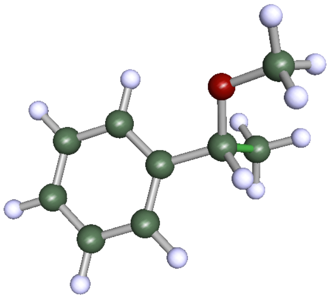
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 309.1 kJ/mol)

Total Energy = -385.20091797221 hartree
Enthalpy Correction = 0.159864 hartree
Entropy = 0.000142 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 323.3 kJ/mol)

Total Energy = -385.2046586233 hartree
Free Energy Correction = 73.576 kcal/mol

(*E*)-Benzylidene(methyl)oxonium Product:



B3LYP/6-31G(d,p) geometry

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -6.55375921 | 0.44238489 | -0.83412512 | c | 6.000 | 0 |
| -6.51861030 | -2.13161108 | -0.25756967 | c | 6.000 | 0 |
| -4.32992949 | 1.85363236 | -0.70959216 | c | 6.000 | 0 |
| -2.04657340 | 0.71960771 | -0.00245664 | c | 6.000 | 0 |
| -2.02484155 | -1.86251408 | 0.57107524 | c | 6.000 | 0 |
| -4.24697051 | -3.27754101 | 0.44068413 | c | 6.000 | 0 |
| -8.30855889 | 1.35002035 | -1.39442891 | h | 1.000 | 0 |
| -8.24525307 | -3.23785676 | -0.36112666 | h | 1.000 | 0 |
| -4.36829093 | 3.85579720 | -1.17692144 | h | 1.000 | 0 |
| -0.25265638 | -2.75276406 | 1.08829328 | h | 1.000 | 0 |
| -4.20161709 | -5.28310735 | 0.88117930 | h | 1.000 | 0 |
| 0.33429255 | 2.30886739 | 0.21637364 | c | 6.000 | 0 |
| 2.45267555 | 0.69825381 | -0.21240522 | o | 8.000 | 0 |
| 0.49491927 | 3.61447918 | 2.80775509 | c | 6.000 | 0 |

```
  0.28723837    3.77529487   -1.26668343    h      1.000     0
  4.72129177    1.97419689   -0.80256669    c      6.000     0
  6.11307507    0.52855640   -1.29162781    h      1.000     0
  5.46168647    3.08592278    0.78933861    h      1.000     0
  4.48261936    3.24787231   -2.43207753    h      1.000     0
  0.55368976    2.19094848    4.30649689    h      1.000     0
 -1.15934698    4.81634500    3.11672531    h      1.000     0
  2.18036601    4.80425075    2.95779934    h      1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -425.27263207834 hartree
Enthalpy Correction = 0.197371 hartree
Entropy = 0.000151 hartree/K

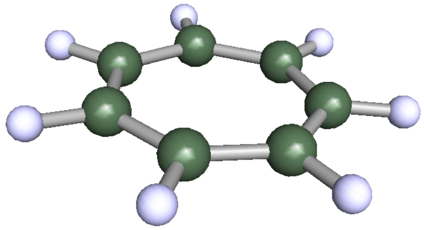
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -425.28064867168 hartree
Enthalpy Correction = 0.197216 hartree
Entropy = 0.000152 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -425.2866141972 hartree
Free Energy Correction = 96.507 kcal/mol

Cyclohepta-2,4,6-trien-1-ylium (E = -3.72):



B3LYP/6-31G(d,p) geometry

```
                atomic coordinates            atom    charge  isotop
 -1.66619107    2.55115738   -0.01812049    c      6.000     0
  0.95482031    2.89211007   -0.09006707    c      6.000     0
  2.85683896    1.05533575   -0.09419740    c      6.000     0
  2.60772970   -1.57617417   -0.02731144    c      6.000     0
  0.39487457   -3.02099607    0.05993599    c      6.000     0
 -2.11547916   -2.19079114    0.10216697    c      6.000     0
 -3.03273356    0.28913676    0.06734036    c      6.000     0
 -2.78981612    4.27186132   -0.03008628    h      1.000     0
  1.59891795    4.84268652   -0.15064272    h      1.000     0
  4.78364657    1.76727264   -0.15769692    h      1.000     0
  4.36654725   -2.63907325   -0.04557279    h      1.000     0
  0.66116797   -5.05839851    0.10041776    h      1.000     0
 -3.54218285   -3.66827560    0.17102121    h      1.000     0
 -5.07814053    0.48414831    0.11281283    h      1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 753.3 kJ/mol)

Total Energy = -270.58457746788 hartree
Enthalpy Correction = 0.12526 hartree
Entropy =  0.000118 hartree/K

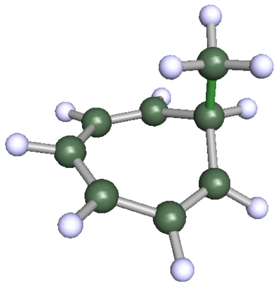
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 236.0 kJ/mol)

Total Energy = -270.67120125704 hartree
Enthalpy Correction = 0.125126 hartree
Entropy =  0.000118 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 253.1 kJ/mol)

Total Energy = -270.6746746147 hartree
Free Energy Correction = 55.753 kcal/mol

Cyclohepta-2,4,6-trien-1-ylium Product:



B3LYP/6-31G(d,p) geometry

```
                   atomic coordinates              atom    charge  isotop
 -3.49218530   -0.30621204    0.89103066    h      1.000      0
 -1.43281701   -0.09180585    0.97019311    c      6.000      0
 -0.75861042    2.27874042   -0.48981974    c      6.000      0
  1.61673231    3.08109993   -0.98583864    c      6.000      0
  3.94496756    1.71072862   -0.57184858    c      6.000      0
  4.20831328   -0.85007318   -0.49568213    c      6.000      0
  2.21022413   -2.68693353   -0.81519223    c      6.000      0
 -0.28163237   -2.35611257   -0.35404919    c      6.000      0
 -0.69220356    0.06692445    3.78871006    c      6.000      0
 -2.32365812    3.45533092   -1.12433501    h      1.000      0
  1.82474651    4.93977408   -1.84880781    h      1.000      0
  5.66631399    2.83743457   -0.53165167    h      1.000      0
  6.12273493   -1.59886995   -0.39955739    h      1.000      0
  2.79730640   -4.51173517   -1.56901638    h      1.000      0
 -1.57081772   -3.86082211   -0.91096017    h      1.000      0
  1.34934672    0.28306398    4.00924353    h      1.000      0
 -1.61610564    1.68703301    4.68769077    h      1.000      0
 -1.27291755   -1.65225862    4.78582999    h      1.000      0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -310.71826645837 hartree
Enthalpy Correction = 0.162933 hartree
Entropy = 0.000131 hartree/K

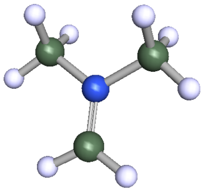
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -310.7229824 hartree
Enthalpy Correction = 0.163247 hartree
Entropy = 0.000131 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -310.7290268656 hartree
Free Energy Correction = 78.123 kcal/mol

*N*-Methyl-*N*-methylenemethanaminium (E = -6.69):



B3LYP/6-31G(d,p) geometry

```
                  atomic coordinates             atom    charge  isotop
     -7.84500907    1.79958620   -0.00018897    n       7.000     0
     -7.74863304   -0.61775147    0.00018897    c       6.000     0
    -10.27047257    3.19288128   -0.00037795    c       6.000     0
     -5.53916524    3.38298772    0.00000000    c       6.000     0
     -9.48453547   -1.71303674    0.00037795    h       1.000     0
     -5.93071650   -1.57036242    0.00037795    h       1.000     0
    -11.84234676    1.86383689    0.00037795    h       1.000     0
    -10.34058140    4.38321977   -1.68582468    h       1.000     0
    -10.34058140    4.38435360    1.68412393    h       1.000     0
     -3.86430097    2.18660211   -0.00113384    h       1.000     0
     -5.56543244    4.57502697    1.68582468    h       1.000     0
     -5.56656627    4.57729464   -1.68393496    h       1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 786.2 kJ/mol)

Total Energy = -173.56676746901 hartree
Enthalpy Correction = 0.11495 hartree
Entropy = 0.000107 hartree/K

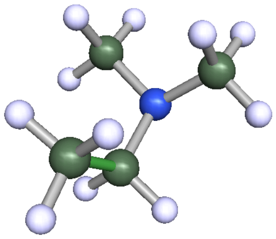
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 240.7 kJ/mol)

Total Energy = -173.66296375356 hartree
Enthalpy Correction = 0.115749 hartree
Entropy = 0.000114 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 263.1 kJ/mol)

Total Energy = -173.6616520519 hartree
Free Energy Correction = 52.115 kcal/mol

*N*-Methyl-*N*-methylenemethanaminium Product:



B3LYP/6-31G(d,p) geometry

```
                 atomic coordinates            atom    charge  isotop
     -6.73366113    1.79883031   -0.05650281    c      6.000     0
     -4.16306667    0.43652674    0.01568473    c      6.000     0
     -6.99916765    3.03338839    1.58264564    h      1.000     0
     -8.26944156    0.41025954   -0.04724315    h      1.000     0
     -6.94682224    2.95231914   -1.76103578    h      1.000     0
     -1.88613565    2.00764504    0.01285014    n      7.000     0
     -4.02889612   -0.83979429   -1.61439304    h      1.000     0
     -4.08010770   -0.76231552    1.70680064    h      1.000     0
     -1.53521351    3.46178930   -2.29374958    c      6.000     0
     -1.58831482    3.55098438    2.26786033    c      6.000     0
     -1.70302119    2.21627081   -3.93856721    h      1.000     0
      0.36660687    4.28193045   -2.30773355    h      1.000     0
     -2.89392660    5.03290761   -2.53525658    h      1.000     0
     -2.95080736    5.13060645    2.41979431    h      1.000     0
      0.31256070    4.37320422    2.29280472    h      1.000     0
     -1.79278318    2.37066144    3.95576372    h      1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -213.71380154097 hartree
Enthalpy Correction = 0.153741 hartree
Entropy =  0.000121 hartree/K

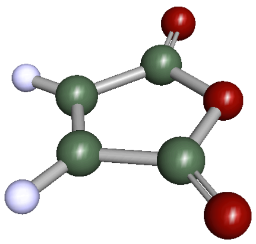
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -213.71784688568 hartree
Enthalpy Correction = 0.153415 hartree
Entropy =  0.000121 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -213.7202789009 hartree
Free Energy Correction = 74.792 kcal/mol

Furan-2,5-dione (E = -11.31):



B3LYP/6-31G(d,p) geometry

```
                  atomic coordinates              atom    charge  isotop
         -4.22675777   -2.04203112   -0.22370615    o      8.000     0
         -2.12926313   -1.19597301   -0.11242618    c      6.000     0
         -1.26978731    1.48766508   -0.05098901    c      6.000     0
          1.25180191    1.50203564    0.07034959    c      6.000     0
          0.01629963   -2.71965776   -0.01708772    o      8.000     0
          2.14347569   -1.17167961    0.09728464    c      6.000     0
          4.25108140   -1.99372249    0.19700714    o      8.000     0
         -2.58518623    3.05206816   -0.10343019    h      1.000     0
          2.54833582    3.08129512    0.14299790    h      1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 262.3 kJ/mol)

Total Energy = -379.26164206206 hartree
Enthalpy Correction = 0.061451 hartree
Entropy = 0.000117 hartree/K

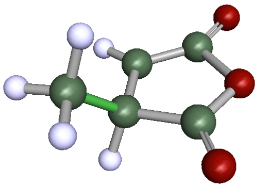
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 206.9 kJ/mol)

Total Energy = -379.26164206206 hartree
Enthalpy Correction = 0.061338 hartree
Entropy = 0.000115 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 188.0 kJ/mol)

Total Energy = -379.2688861518 hartree
Free Energy Correction = 16.523 kcal/mol

Furan-2,5-dione Product:



B3LYP/6-31G(d,p) geometry

```
                  atomic coordinates              atom    charge  isotop
          6.02969508   -0.18974396   -0.66083031    o      8.000     0
          3.77449311   -0.01410134   -0.18239274    c      6.000     0
          1.81275041   -1.41138258    0.77919314    c      6.000     0
         -0.60955903    0.03374086    0.88136257    c      6.000     0
```

| | | | | | |
|---|---|---|---|---|---|
| -2.87916511 | -1.07397446 | -0.57752853 | c | 6.000 | 0 |
| 0.14592087 | 2.60642228 | -0.24507154 | c | 6.000 | 0 |
| 2.57819967 | 2.64320745 | -0.82943352 | o | 8.000 | 0 |
| -1.30103508 | 4.38446926 | -0.58096250 | o | 8.000 | 0 |
| 2.06255942 | -3.33510772 | 1.43500615 | h | 1.000 | 0 |
| -1.29411145 | 0.42943057 | 2.82234492 | h | 1.000 | 0 |
| -4.46946504 | 0.25584613 | -0.58009148 | h | 1.000 | 0 |
| -2.34328937 | -1.47223352 | -2.53823968 | h | 1.000 | 0 |
| -3.50699348 | -2.85657296 | 0.27664351 | h | 1.000 | 0 |

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -419.20750379579 hartree
Enthalpy Correction = 0.099527 hartree
Entropy =  0.000134 hartree/K

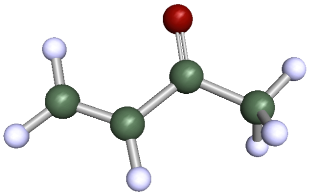
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -419.30140911931 hartree
Enthalpy Correction = 0.100022 hartree
Entropy =  0.000133 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -419.2971087481 hartree
Free Energy Correction = 38.068 kcal/mol

But-3-en-2-one (E = -16.76):



B3LYP/6-31G(d,p) geometry

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.38099517 | -1.01157040 | -0.68426983 | c | 6.000 | 0 |
| -4.97130254 | 1.47889967 | -0.73226888 | c | 6.000 | 0 |
| -2.49935178 | 2.57645261 | 0.09562014 | c | 6.000 | 0 |
| -2.27277362 | 5.43220674 | -0.02872384 | c | 6.000 | 0 |
| -0.76344936 | 1.24854206 | 0.83280231 | o | 8.000 | 0 |
| -7.16281794 | -1.83624688 | -1.27896665 | h | 1.000 | 0 |
| -3.89963885 | -2.27560821 | -0.03382610 | h | 1.000 | 0 |
| -6.42544680 | 2.78318865 | -1.37628754 | h | 1.000 | 0 |
| -3.68987925 | 6.31640960 | 1.19959815 | h | 1.000 | 0 |
| -2.64618351 | 6.10457130 | -1.95359888 | h | 1.000 | 0 |
| -0.38607105 | 6.01575417 | 0.56030380 | h | 1.000 | 0 |

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 224.5 kJ/mol)

Total Energy = -231.18409269704 hartree
Enthalpy Correction = 0.095166 hartree
Entropy =  0.000122 hartree/K

B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 151.3 kJ/mol)

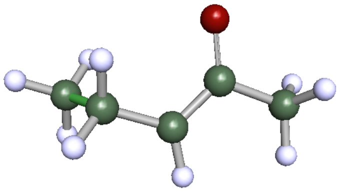
Total Energy = -231.19422139417 hartree
Enthalpy Correction = 0.094006 hartree
Entropy = 0.000115 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 137.1 kJ/mol)

Total Energy = -231.1957900185 hartree
Free Energy Correction = 37.9 kcal/mol

But-3-en-2-one Product:

The $CH_3$-$CH_2$-C-C Torsion Angle was constrained to 90°.



B3LYP/6-31G(d,p) geometry

```
                   atomic coordinates              atom    charge  isotop
  -6.07323397    0.30356561   -3.43040473    c      6.000     0
  -3.86580519   -1.01530072   -2.03903151    c      6.000     0
  -7.15897235    1.42569821   -2.07150267    h      1.000     0
  -7.37408932   -1.04220664   -4.35439955    h      1.000     0
  -5.37036735    1.60193974   -4.89156366    h      1.000     0
  -2.06488296    0.74578609   -0.72847242    c      6.000     0
  -2.88499198   -2.25403510   -3.40789809    h      1.000     0
  -4.70040274   -2.25263670   -0.59236678    h      1.000     0
  -2.46538774    1.46037469    1.76233970    c      6.000     0
  -0.53806928    1.59536538   -1.82139931    h      1.000     0
  -0.55941374    3.35555079    2.91526728    c      6.000     0
   0.95719731    3.93132011    1.61883200    h      1.000     0
   0.30119400    2.52780161    4.61676157    h      1.000     0
  -1.56365578    5.06163901    3.55152673    h      1.000     0
  -4.21634561    0.70953736    3.23669647    o      8.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -271.11589532563 hartree
Enthalpy Correction = 0.131469 hartree
Entropy = 0.000132 hartree/K

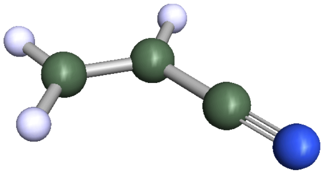
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -271.21315520678 hartree
Enthalpy Correction = 0.131867 hartree
Entropy = 0.000129 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -271.2047227588 hartree
Free Energy Correction = 59.507 kcal/mol

Acrylonitrile (E = -19.05):



B3LYP/6-31G(d,p) geometry

```
                atomic coordinates                 atom    charge  isotop
    -3.68609980   -0.98964958    0.00000000     c       6.000     0
    -3.53756732    1.53502454    0.00000000     c       6.000     0
    -1.18637007    2.87181681    0.00000000     c       6.000     0
     0.70108840    4.00036125    0.00000000     n       7.000     0
    -5.50874065   -1.92789860    0.00000000     h       1.000     0
    -2.01010169   -2.17091738    0.00000000     h       1.000     0
    -5.22887221    2.70174145    0.00000000     h       1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 206.1 kJ/mol)

Total Energy = -170.79211210583 hartree
Enthalpy Correction = 0.055509 hartree
Entropy = 0.000104 hartree/K

B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 128.8 kJ/mol)

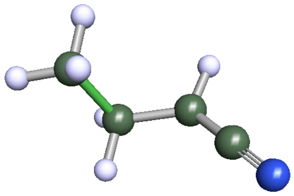
Total Energy = -170.80297510552 hartree
Enthalpy Correction = 0.055514 hartree
Entropy = 0.000104 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 136.9 kJ/mol)

Total Energy = -170.8016521707 hartree
Free Energy Correction = 15.517 kcal/mol

Acrylonitrile Product:

The $CH_3$-C-C-C Torsion Angle was constrained to 90°.



B3LYP/6-31G(d,p) geometry

```
                 atomic coordinates              atom    charge  isotop
     -4.16210669    2.24575243    0.34243160    c       6.000     0
     -4.25003565   -0.54801302   -0.18408956    c       6.000     0
     -1.99614228    3.39598715    1.25818155    c       6.000     0
     -0.11990312    4.41339302    1.96677594    n       7.000     0
     -5.95887153    3.18953835    0.71215841    h       1.000     0
     -2.37061041   -1.20174110   -0.79471110    h       1.000     0
     -5.52579543   -0.98134990   -1.78991269    h       1.000     0
     -5.09957904   -2.25622907    2.04366134    c       6.000     0
     -3.80383729   -2.03772571    3.64633429    h       1.000     0
     -5.18695620   -4.28294901    1.54117749    h       1.000     0
     -6.98505896   -1.69372563    2.70605381    h       1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -210.71570594231 hartree
Enthalpy Correction = 0.093593 hartree
Entropy = 0.000124 hartree/K

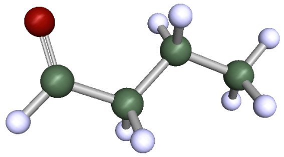
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -210.81296800959 hartree
Enthalpy Correction = 0.093885 hartree
Entropy = 0.000121 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -210.8092727782 hartree
Free Energy Correction = 36.355 kcal/mol

Butyraldehyde (E = -18.7):



B3LYP/6-31G(d,p) geometry

```
                 atomic coordinates              atom    charge  isotop
     -6.45643831    0.59715346    0.56956346    c       6.000     0
     -5.77632587    3.31514656   -0.19350796    c       6.000     0
     -8.13905046    0.56332736    1.77653154    h       1.000     0
     -4.90931952   -0.30027748    1.62100708    h       1.000     0
     -6.85139107   -0.57844517   -1.09358451    h       1.000     0
     -3.43136471    3.44194718   -1.89482839    c       6.000     0
     -5.44808044    4.46863539    1.49855282    h       1.000     0
     -7.37390035    4.20048325   -1.17654349    h       1.000     0
     -2.67982063    6.07603644   -2.68189933    c       6.000     0
     -3.70537500    2.32077267   -3.63148671    h       1.000     0
     -1.78371250    2.57380699   -0.95582348    h       1.000     0
     -3.79475905    8.02623381   -2.03504607    o       8.000     0
     -1.00060999    6.19282151   -3.92647296    h       1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 146.2 kJ/mol)

Total Energy = -232.3995097356 hartree
Enthalpy Correction = 0.118044 hartree
Entropy =  0.000123 hartree/K

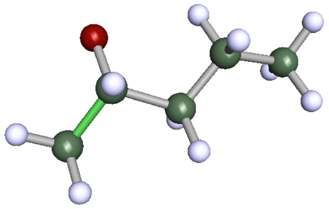
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 88.9 kJ/mol)

Total Energy = -232.40920944202 hartree
Enthalpy Correction = 0.117771 hartree
Entropy =  0.000123 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 62.2 kJ/mol)

Total Energy = -232.4122762436 hartree
Free Energy Correction = 52.167 kcal/mol

Butyraldehyde Product:



B3LYP/6-31G(d,p) geometry

```
                 atomic coordinates                atom    charge  isotop
     -3.36692505   -1.64576249    0.81220429    c       6.000     0
     -3.15943312    1.28709247    0.46033729    c       6.000     0
     -0.82089703    2.06925012    0.05140055    o       8.000     0
     -4.41647895    2.58420049    2.84309297    c       6.000     0
     -4.59751471    1.70585578   -1.12854445    h       1.000     0
     -4.20105017    5.45374962    2.61613686    c       6.000     0
     -3.34840574    1.96342545    4.52381539    h       1.000     0
     -6.40617159    2.00499943    3.11955990    h       1.000     0
     -4.76645623    6.93642875    5.03800987    c       6.000     0
     -5.46168647    6.11761041    1.09679705    h       1.000     0
     -2.25992348    5.77802663    1.95624449    h       1.000     0
     -2.20096403   -2.22553047    2.43358932    h       1.000     0
     -2.58609021   -2.57890925   -0.86851813    h       1.000     0
     -5.31315400   -2.34401630    1.10794643    h       1.000     0
     -6.70115784    6.60270311    5.72001203    h       1.000     0
     -4.55386204    8.98810441    4.77250335    h       1.000     0
     -3.48314321    6.37574700    6.57001085    h       1.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -272.30176473616 hartree
Enthalpy Correction = 0.156117 hartree
Entropy =  0.000138 hartree/K

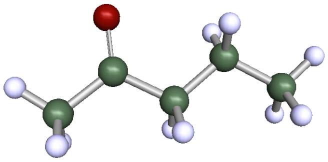
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

Total Energy = -272.40588445876 hartree
Enthalpy Correction = 0.156814 hartree
Entropy =  0.000136 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -272.3917844908 hartree
Free Energy Correction = 73.221 kcal/mol

Pentan-2-one (E = -22.3):



B3LYP/6-31G(d,p) geometry

```
                  atomic coordinates              atom    charge  isotop
   -7.88790586    2.37255116   -0.32767851     c      6.000     0
   -5.39006585    3.57800746    0.50002154     c      6.000     0
   -7.89527579    1.95813422   -2.35800027     h      1.000     0
   -9.48661416    3.62751829    0.05914843     h      1.000     0
   -8.23315882    0.59129531    0.67274250     h      1.000     0
   -3.10935538    1.87252963    0.00566918     c      6.000     0
   -5.45545038    4.04193523    2.51711521     h      1.000     0
   -5.10944152    5.38118414   -0.47847866     h      1.000     0
   -0.59318503    2.99389311    0.85321135     c      6.000     0
   -2.95439784    1.40406652   -2.01482600     h      1.000     0
   -3.33839019    0.03760555    0.95884704     h      1.000     0
    1.74705181    1.39253919    0.38644899     c      6.000     0
    3.41775869    2.37840931    1.08489177     h      1.000     0
    1.96663799    1.00079896   -1.63631386     h      1.000     0
    1.57244112   -0.43992824    1.33754816     h      1.000     0
   -0.45882551    5.05936378    1.85533312     o      8.000     0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p) (MAA = 116.1 kJ/mol)

Total Energy = -271.7104964846 hartree
Enthalpy Correction = 0.149009 hartree
Entropy =  0.000141 hartree/K

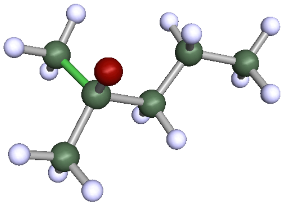
B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p) (MAA* = 51.9 kJ/mol)

Total Energy = -271.72028169782 hartree
Enthalpy Correction = 0.148533 hartree
Entropy =  0.00014 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p) (MAA* = 24.9 kJ/mol)

Total Energy = -271.7245486011 hartree
Free Energy Correction = 68.775 kcal/mol

Pentan-2-one Product:



B3LYP/6-31G(d,p) geometry

```
                  atomic coordinates              atom    charge  isotop
   -8.75415632   -0.22393255    0.36282742     c       6.000      0
   -6.47080023   -1.96871669    0.00831479     c       6.000      0
   -8.48392548    1.03065663    1.99385004     h       1.000      0
  -10.51292443   -1.28652555    0.68162422     h       1.000      0
   -9.06331551    0.99550773   -1.29143884     h       1.000      0
   -3.95330707   -0.60622414   -0.38626002     c       6.000      0
   -6.84817854   -3.25543121   -1.58226769     h       1.000      0
   -6.15086959   -3.16037799    1.67883270     h       1.000      0
   -1.62610934   -2.45154171    0.14248535     c       6.000      0
   -3.82367186    0.92313122    1.02158595     h       1.000      0
   -3.87809597    0.29914365   -2.26767136     h       1.000      0
    0.80445642   -0.73907189    0.11886377     c       6.000      0
   -1.38573617   -4.29893798   -2.18962567     c       6.000      0
   -1.88537976   -3.69082411    2.31132403     o       8.000      0
    1.08016746    0.39174023   -1.61458201     h       1.000      0
    2.47591918   -1.94074874    0.38588208     h       1.000      0
    0.71129292    0.55520154    1.73798113     h       1.000      0
   -1.15367780   -3.37070451   -4.04476982     h       1.000      0
   -3.06097839   -5.51800031   -2.27882074     h       1.000      0
    0.24793207   -5.53878730   -1.87252963     h       1.000      0
```

B3LYP/6-311++G(3df,2dp)//B3LYP/6-31G(d,p)

Total Energy = -311.60217192367 hartree
Enthalpy Correction = 0.183477 hartree
Entropy = 0.000141 hartree/K

B3LYP/6-311++G(3df,2dp) COSMO (∞)//B3LYP/6-31G(d,p)

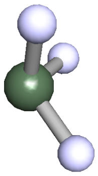
Total Energy = -311.70357890725 hartree
Enthalpy Correction = 0.184122 hartree
Entropy = 0.000139 hartree/K

B3LYP/6-311++G(3df,2pd) SMD(DMSO)//B3LYP/6-31G(d,p)

Total Energy = -311.6900573884 hartree
Free Energy Correction = 89.955 kcal/mol

## Energies and Coordinates of Molecules with Experimental E Values Calculated at the PBE0(disp)/def2-TZVP COSMO (∞) level of theory.

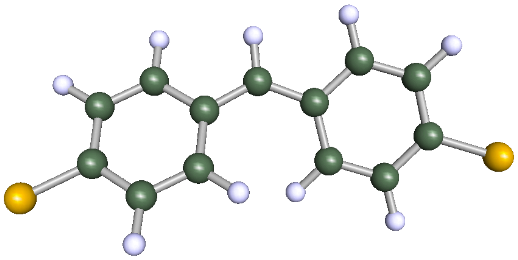
Methanide Anion:



Total Energy = -39.90909816942 hartree
Enthalpy Correction = 0.033249 hartree
Entropy = 0.000074 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | 0.60369755 | c | 6.000 | 0 |
| -0.96200051 | -1.66623376 | -0.20072885 | h | 1.000 | 0 |
| -0.96200051 | 1.66623376 | -0.20072885 | h | 1.000 | 0 |
| 1.92400102 | 0.00000000 | -0.20072885 | h | 1.000 | 0 |

Bis(4-chlorophenyl)methylium (MAA* = 414.1 kJ/mol, E = 5.48):

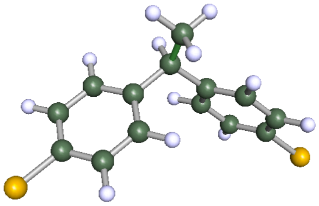


Total Energy = -1420.34595036446 hartree
Enthalpy Correction = 0.195101 hartree
Entropy = 0.000177 hartree/K
LUMO Energy = -0.1547 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 10.01441033 | 3.21570065 | -0.17848427 | cl | 17.000 | 0 |
| 7.14750713 | 1.73668487 | -0.08531016 | c | 6.000 | 0 |
| 7.00611145 | -0.82270287 | -0.68527008 | c | 6.000 | 0 |
| 4.69664184 | -1.99814787 | -0.57444505 | c | 6.000 | 0 |
| 2.48509085 | -0.63119648 | 0.04283657 | c | 6.000 | 0 |
| 0.19440293 | -1.97674548 | 0.00009422 | c | 6.000 | 0 |
| -2.31381079 | -1.10150495 | -0.03746927 | c | 6.000 | 0 |
| -4.21917267 | -2.87958414 | 0.55347337 | c | 6.000 | 0 |
| -6.71433844 | -2.17860226 | 0.66031242 | c | 6.000 | 0 |
| -7.34995846 | 0.31031680 | 0.08281737 | c | 6.000 | 0 |
| -10.45093327 | 1.19972965 | 0.16880653 | cl | 17.000 | 0 |
| -5.53106693 | 2.08851271 | -0.62099349 | c | 6.000 | 0 |
| -3.03675086 | 1.38979338 | -0.67753912 | c | 6.000 | 0 |
| 2.71238039 | 1.94622899 | 0.70688941 | c | 6.000 | 0 |
| 5.02179285 | 3.11878621 | 0.64605158 | c | 6.000 | 0 |

```
  8.69227747   -1.85569498   -1.20357330     h       1.000      0
  4.54580215   -3.99122904   -1.01878816     h       1.000      0
  0.39504296   -4.02199125   -0.00803553     h       1.000      0
 -3.68428047   -4.80991892    0.97842597     h       1.000      0
 -8.16890849   -3.52624789    1.15731021     h       1.000      0
 -6.09989058    3.98067169   -1.14567196     h       1.000      0
 -1.64895797    2.73698560   -1.33417927     h       1.000      0
  1.09283163    2.98933314    1.38524176     h       1.000      0
  5.21377696    5.08082244    1.18750024     h       1.000      0
```

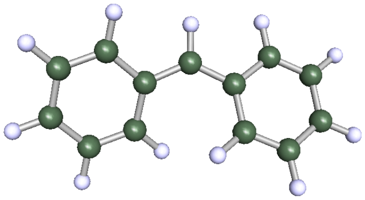
Bis(4-chlorophenyl)methylium Product:



Total Energy = -1460.43719239932 hartree
Enthalpy Correction = 0.235201 hartree
Entropy = 0.000192 hartree/K

```
                   atomic coordinates            atom    charge  isotop
  9.54215168    3.57584692   -1.14847157    cl     17.000      0
  6.76966820    1.97070102   -0.44649166     c      6.000      0
  5.16038558    2.92393413    1.39022347     c      6.000      0
  2.95436975    1.62946310    1.93189029     c      6.000      0
  2.32171529   -0.60091389    0.67978321     c      6.000      0
 -0.14996418   -1.88879225    1.31868300     c      6.000      0
 -0.31422035   -4.62652495    0.43653228     c      6.000      0
 -2.36108262   -0.37792107    0.31207642     c      6.000      0
 -2.48642120    0.30160518   -2.22796192     c      6.000      0
 -4.52850209    1.63571563   -3.17646872     c      6.000      0
 -6.47400130    2.30514805   -1.55277184     c      6.000      0
 -9.03624109    3.98828324   -2.71988552    cl     17.000      0
 -6.40244156    1.66145269    0.98101793     c      6.000      0
 -4.33941174    0.32082645    1.89238523     c      6.000      0
  3.97922561   -1.51194463   -1.14189983     c      6.000      0
  6.20190190   -0.23967486   -1.71894705     c      6.000      0
  5.63053395    4.65121819    2.38218435     h      1.000      0
  1.69048772    2.37588448    3.36435653     h      1.000      0
 -0.31129467   -1.88063700    3.38094479     h      1.000      0
  1.26378130   -5.73669970    1.17047810     h      1.000      0
 -0.30346699   -4.76275187   -1.62366854     h      1.000      0
 -2.07205730   -5.47085153    1.10768747     h      1.000      0
 -0.95736580   -0.20320458   -3.49666200     h      1.000      0
 -4.60818896    2.15813024   -5.15345791     h      1.000      0
 -7.93094179    2.20122911    2.23012819     h      1.000      0
 -4.27691560   -0.18476693    3.87814888     h      1.000      0
  3.56158153   -3.24555742   -2.14671645     h      1.000      0
  7.47671475   -0.96919776   -3.14408377     h      1.000      0
```

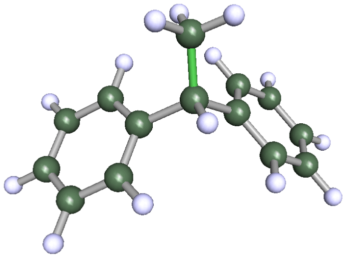
Diphenylmethylium (MAA* = 406.7 kJ/mol, E = 5.47):



Total Energy = -501.40767076378 hartree
Enthalpy Correction = 0.212047 hartree
Entropy = 0.000156 hartree/K
LUMO Energy = -0.1519 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.36323507 | -0.70492562 | -0.35097640 | c | 6.000 | 0 |
| -0.08690232 | -1.07320274 | -1.31635195 | c | 6.000 | 0 |
| -2.43826305 | -0.21552294 | -0.41858237 | c | 6.000 | 0 |
| -4.48607505 | -0.32307249 | -2.13292578 | c | 6.000 | 0 |
| -6.82679274 | 0.57782044 | -1.44695690 | c | 6.000 | 0 |
| -7.19126877 | 1.51118980 | 0.98535220 | c | 6.000 | 0 |
| -5.22393997 | 1.53217591 | 2.74104911 | c | 6.000 | 0 |
| -2.86579813 | 0.68250723 | 2.06084891 | c | 6.000 | 0 |
| 4.27239323 | -2.33001436 | -1.27795270 | c | 6.000 | 0 |
| 6.69960520 | -2.16927703 | -0.35893055 | c | 6.000 | 0 |
| 7.28741264 | -0.32795101 | 1.42574875 | c | 6.000 | 0 |
| 5.45699971 | 1.36492064 | 2.28451360 | c | 6.000 | 0 |
| 3.01553182 | 1.19037368 | 1.41565171 | c | 6.000 | 0 |
| -0.17771926 | -2.20139067 | -3.03228683 | h | 1.000 | 0 |
| -4.16863272 | -1.07495507 | -4.01143793 | h | 1.000 | 0 |
| -8.38009146 | 0.53653325 | -2.77753043 | h | 1.000 | 0 |
| -9.04309569 | 2.18695398 | 1.54121653 | h | 1.000 | 0 |
| -5.56517083 | 2.18720625 | 4.64901379 | h | 1.000 | 0 |
| -1.37911561 | 0.59110210 | 3.45897175 | h | 1.000 | 0 |
| 3.78116719 | -3.73770012 | -2.68216948 | h | 1.000 | 0 |
| 8.14786061 | -3.44431875 | -1.03844649 | h | 1.000 | 0 |
| 9.20691424 | -0.17368465 | 2.12352765 | h | 1.000 | 0 |
| 5.96941489 | 2.83734887 | 3.60927336 | h | 1.000 | 0 |
| 1.63233098 | 2.57788329 | 1.99401369 | h | 1.000 | 0 |

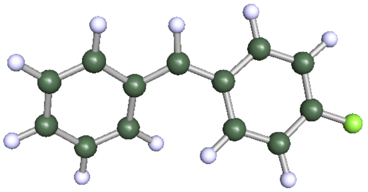
Diphenylmethylium Product:



Total Energy = -541.49618169661 hartree
Enthalpy Correction = 0.251928 hartree
Entropy = 0.00017 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.35590129 | -4.45505598 | -0.48127139 | c | 6.000 | 0 |
| -0.19090373 | -1.95164766 | -1.30797303 | c | 6.000 | 0 |
| 2.11168787 | -1.23839021 | 0.23768885 | c | 6.000 | 0 |
| 4.29848854 | -0.42097265 | -0.97541660 | c | 6.000 | 0 |
| 6.41998862 | 0.29517912 | 0.39307394 | c | 6.000 | 0 |
| 6.38544279 | 0.20466106 | 3.01392686 | c | 6.000 | 0 |
| 4.21607210 | -0.61108632 | 4.24661435 | c | 6.000 | 0 |
| 2.10234809 | -1.32593199 | 2.86960472 | c | 6.000 | 0 |
| -2.08021182 | 0.20040547 | -1.32952085 | c | 6.000 | 0 |
| -2.16435153 | 1.84179202 | -3.38388650 | c | 6.000 | 0 |
| -3.83525301 | 3.86407278 | -3.43584371 | c | 6.000 | 0 |
| -5.45952269 | 4.27836944 | -1.41888226 | c | 6.000 | 0 |
| -5.39714950 | 2.65192576 | 0.64019548 | c | 6.000 | 0 |
| -3.72419432 | 0.63317627 | 0.68141664 | c | 6.000 | 0 |
| -2.94857532 | -4.93979355 | -1.70103028 | h | 1.000 | 0 |
| 0.04351642 | -5.96708048 | -0.60139633 | h | 1.000 | 0 |
| -2.04716941 | -4.39052424 | 1.46068389 | h | 1.000 | 0 |
| 0.45974039 | -2.17787766 | -3.25661265 | h | 1.000 | 0 |
| 4.34072994 | -0.34843490 | -3.02500433 | h | 1.000 | 0 |
| 8.10437979 | 0.92006113 | -0.59294229 | h | 1.000 | 0 |
| 8.03812466 | 0.75937356 | 4.09004380 | h | 1.000 | 0 |
| 4.16931229 | -0.69510594 | 6.29364065 | h | 1.000 | 0 |
| 0.43093910 | -1.95993001 | 3.87071306 | h | 1.000 | 0 |
| -0.90221560 | 1.52719945 | -4.97018288 | h | 1.000 | 0 |
| -3.87027959 | 5.11394698 | -5.05950494 | h | 1.000 | 0 |
| -6.77020637 | 5.85257385 | -1.45264951 | h | 1.000 | 0 |
| -6.66241322 | 2.95321308 | 2.22400587 | h | 1.000 | 0 |
| -3.71242316 | -0.61411837 | 2.30654315 | h | 1.000 | 0 |

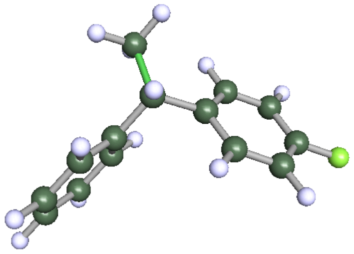
(4-Fluorophenyl)(phenyl)methylium (MAA* = 403.8 kJ/mol, E = 5.2):



Total Energy = -600.60272492371 hartree
Enthalpy Correction = 0.20461 hartree
Entropy = 0.000163 hartree/K
LUMO Energy = -0.1504 hartree

```
              atomic coordinates            atom    charge  isotop
    9.48251919   -0.56869804    2.22680467    f      9.000     0
    7.16945790   -0.61900315    1.28733323    c      6.000     0
    5.37045441    0.98985879    2.33241418    c      6.000     0
    2.96821697    0.94217199    1.36804857    c      6.000     0
    2.34902253   -0.70893555   -0.64465525    c      6.000     0
   -0.06356390   -0.91392314   -1.72324428    c      6.000     0
   -2.43222226   -0.08527213   -0.82826408    c      6.000     0
   -2.94890909    0.53179628    1.71697272    c      6.000     0
   -5.31190784    1.37569328    2.39150908    c      6.000     0
   -7.19517158    1.62839304    0.56430268    c      6.000     0
   -6.74308313    0.97224766   -1.94194179    c      6.000     0
   -4.39908499    0.07651352   -2.62781023    c      6.000     0
    4.27754886   -2.22912686   -1.70992514    c      6.000     0
    6.67578625   -2.22647171   -0.72658368    c      6.000     0
    5.90064295    2.26498572    3.84082963    h      1.000     0
    1.58465994    2.26331369    2.08241394    h      1.000     0
   -0.11442830   -1.85733714   -3.54843518    h      1.000     0
   -1.53515875    0.22641478    3.15995681    h      1.000     0
   -5.72162388    1.81376581    4.34764956    h      1.000     0
   -9.05032906    2.29840260    1.11589690    h      1.000     0
   -8.23222402    1.13786160   -3.33490588    h      1.000     0
   -4.01783551   -0.46334806   -4.56649515    h      1.000     0
    3.82375372   -3.44493755   -3.29343368    h      1.000     0
    8.16347958   -3.40436544   -1.48843762    h      1.000     0
```

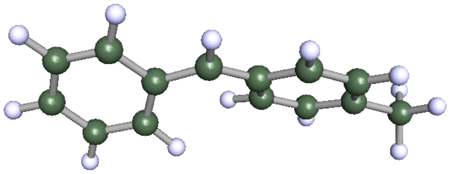
(4-Fluorophenyl)(phenyl)methylium Product:



Total Energy = -640.69039312617 hartree
Enthalpy Correction = 0.244446 hartree
Entropy = 0.000176 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 9.00828164 | -0.46964518 | 2.95501540 | f | 9.000 | 0 |
| 6.81413688 | -0.37014210 | 1.66562598 | c | 6.000 | 0 |
| 5.79112522 | -2.57844205 | 0.74087128 | c | 6.000 | 0 |
| 3.52642360 | -2.45203409 | -0.58508598 | c | 6.000 | 0 |
| 2.30099107 | -0.16116974 | -0.97585351 | c | 6.000 | 0 |
| -0.20784808 | 0.05059364 | -2.33427471 | c | 6.000 | 0 |
| -0.84258878 | -2.21853340 | -3.99332758 | c | 6.000 | 0 |
| -2.32152597 | 0.56019351 | -0.47151750 | c | 6.000 | 0 |
| -3.90894527 | 2.63237269 | -0.77991515 | c | 6.000 | 0 |
| -5.87522999 | 3.08554708 | 0.90206670 | c | 6.000 | 0 |
| -6.27884897 | 1.46225948 | 2.92120167 | c | 6.000 | 0 |
| -4.70231461 | -0.61453237 | 3.24676704 | c | 6.000 | 0 |
| -2.74144748 | -1.05578423 | 1.56567750 | c | 6.000 | 0 |
| 3.41207412 | 2.02655879 | -0.01392231 | c | 6.000 | 0 |
| 5.66917152 | 1.94949905 | 1.30838695 | c | 6.000 | 0 |
| 6.74639816 | -4.36283492 | 1.04827291 | h | 1.000 | 0 |
| 2.72728931 | -4.18770336 | -1.31811178 | h | 1.000 | 0 |
| -0.08305842 | 1.71032959 | -3.56324859 | h | 1.000 | 0 |
| -2.58461377 | -1.85480608 | -5.03641055 | h | 1.000 | 0 |
| -1.13539904 | -3.92476448 | -2.86819310 | h | 1.000 | 0 |
| 0.66622684 | -2.58819555 | -5.35287098 | h | 1.000 | 0 |
| -3.59993710 | 3.90955244 | -2.35483525 | h | 1.000 | 0 |
| -7.08933045 | 4.71447644 | 0.63375760 | h | 1.000 | 0 |
| -7.80737758 | 1.81315991 | 4.23930859 | h | 1.000 | 0 |
| -4.99863084 | -1.89024403 | 4.82297462 | h | 1.000 | 0 |
| -1.50855920 | -2.66988753 | 1.84930894 | h | 1.000 | 0 |
| 2.48779610 | 3.83446116 | -0.30146135 | h | 1.000 | 0 |
| 6.53574107 | 3.64971533 | 2.04979318 | h | 1.000 | 0 |

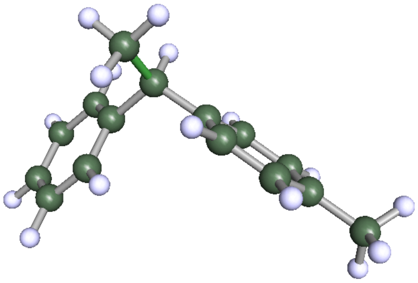
Phenyl(*p*-tolyl)methylium (MAA* = 396.0 kJ/mol, E = 4.43):



Total Energy = -540.69729549861 hartree
Enthalpy Correction = 0.240989 hartree
Entropy = 0.000168 hartree/K
LUMO Energy = -0.1476 hartree

```
          atomic coordinates                  atom    charge  isotop
    8.67167531    2.14198848   -0.15223653    c       6.000      0
    6.10818825    1.00143347   -0.08219900    c       6.000      0
    5.73754436   -1.55383078   -0.65192890    c       6.000      0
    3.36441989   -2.59303447   -0.54635661    c       6.000      0
    1.23550116   -1.08356748    0.04508957    c       6.000      0
   -1.12573768   -2.27292500   -0.00343580    c       6.000      0
   -3.58600432   -1.23496827   -0.00152779    c       6.000      0
   -5.57979799   -2.87628797    0.67063987    c       6.000      0
   -8.02388331   -1.99401316    0.81675683    c       6.000      0
   -8.53559525    0.51117854    0.20274162    c       6.000      0
   -6.60831068    2.13293797   -0.57144586    c       6.000      0
   -4.15322191    1.28334066   -0.67416883    c       6.000      0
    1.63472651    1.48685107    0.68371763    c       6.000      0
    4.01828015    2.48523282    0.61854600    c       6.000      0
   10.10603829    0.77214673   -0.69885081    h       1.000      0
    8.70756529    3.72411898   -1.48320119    h       1.000      0
    9.15590149    2.92166029    1.70013487    h       1.000      0
    7.34471702   -2.71758554   -1.15575697    h       1.000      0
    3.08297958   -4.57686854   -0.97232315    h       1.000      0
   -1.05921607   -4.32742416   -0.04410369    h       1.000      0
   -5.15028317   -4.82793354    1.12071846    h       1.000      0
   -9.54053591   -3.24758615    1.37745577    h       1.000      0
  -10.46311082    1.19926188    0.27966037    h       1.000      0
   -7.04911921    4.05338968   -1.12319271    h       1.000      0
   -2.68667078    2.51427164   -1.38728646    h       1.000      0
    0.07857382    2.63688691    1.33877196    h       1.000      0
    4.31537598    4.44132592    1.14791428    h       1.000      0
```

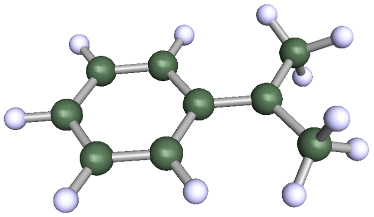
Phenyl(*p*-tolyl)methylium Product:



Total Energy = -580.78146870683 hartree
Enthalpy Correction = 0.280927 hartree
Entropy = 0.000183 hartree/K

```
                 atomic coordinates              atom    charge  isotop
     -8.47709641    2.26880565   -0.98614853     c       6.000     0
     -5.96964638    1.22950767   -0.17924795     c       6.000     0
     -4.87929350   -0.81263344   -1.44583876     c       6.000     0
     -2.56681752   -1.77899559   -0.70324407     c       6.000     0
     -1.24352511   -0.75480118    1.33494214     c       6.000     0
      1.30878883   -1.84785565    2.02264585     c       6.000     0
      2.15947177   -1.24454056    4.70912824     c       6.000     0
      3.30018466   -1.04051922    0.13162052     c       6.000     0
      3.74833008    1.50995498   -0.34871257     c       6.000     0
      5.60266901    2.25123007   -2.04435075     c       6.000     0
      7.04150840    0.44702188   -3.30032724     c       6.000     0
      6.60754950   -2.09729005   -2.84108159     c       6.000     0
      4.74957014   -2.82958966   -1.13535272     c       6.000     0
     -2.32913591    1.27056231    2.60228720     c       6.000     0
     -4.65283155    2.24550127    1.85204206     c       6.000     0
     -9.95925353    0.83622987   -0.83762574     h       1.000     0
     -9.02672827    3.87953397    0.17749441     h       1.000     0
     -8.42706461    2.88683452   -2.95707419     h       1.000     0
     -5.86444464   -1.65842598   -3.03448122     h       1.000     0
     -1.76008400   -3.36596559   -1.72453877     h       1.000     0
      1.13987553   -3.90416425    1.86526681     h       1.000     0
      0.73645995   -1.83086238    6.08517463     h       1.000     0
      3.91902249   -2.23766662    5.12684404     h       1.000     0
      2.50869701    0.77448486    4.95970890     h       1.000     0
      2.62020880    2.93285925    0.60473809     h       1.000     0
      5.92387197    4.24474393   -2.39486549     h       1.000     0
      8.48703436    1.02476317   -4.63235890     h       1.000     0
      7.71417201   -3.52137709   -3.81438825     h       1.000     0
      4.41739323   -4.82316561   -0.78424994     h       1.000     0
     -1.37361543    2.11594615    4.20399420     h       1.000     0
     -5.45527087    3.82987331    2.87877907     h       1.000     0
```

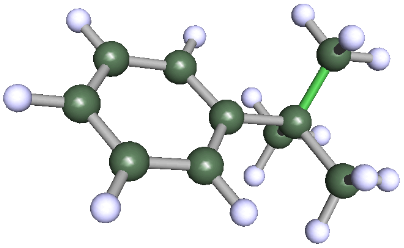
2-Phenylpropan-2-ylium (MAA* = 388.0 kJ/mol, E = 5.74):



Total Energy = -349.10350946272 hartree
Enthalpy Correction = 0.183482 hartree
Entropy = 0.000141 hartree/K
LUMO Energy = -0.1408 hartree

```
                   atomic coordinates            atom    charge  isotop
          -3.97127231    2.19896364    0.54846317    c      6.000     0
          -2.43498879   -0.06417867    0.09942234    c      6.000     0
          -3.87906364   -2.40737725   -0.23391095    c      6.000     0
           0.23169797    0.00627855   -0.00600296    c      6.000     0
           1.55707018    2.28953326    0.42547909    c      6.000     0
           4.15205935    2.34567862    0.33524024    c      6.000     0
           5.48750754    0.14649945   -0.22224438    c      6.000     0
           4.22988975   -2.12220961   -0.67160204    c      6.000     0
           1.63704873   -2.20445236   -0.54829848    c      6.000     0
          -4.42934342    2.19258178    2.57761998    h      1.000     0
          -5.77951338    2.03499294   -0.42924271    h      1.000     0
          -3.06056603    3.97959562    0.09737685    h      1.000     0
          -4.47178869   -2.44121041   -2.22762919    h      1.000     0
          -2.84633519   -4.13482787    0.15997879    h      1.000     0
          -5.62239887   -2.33196847    0.86439315    h      1.000     0
           0.54010622    4.00757984    0.85557941    h      1.000     0
           5.15433792    4.09397332    0.68589967    h      1.000     0
           7.53326145    0.20122106   -0.30749434    h      1.000     0
           5.29149787   -3.81549381   -1.10713561    h      1.000     0
           0.68079333   -3.97517963   -0.89589202    h      1.000     0
```

2-Phenylpropan-2-ylium Product:

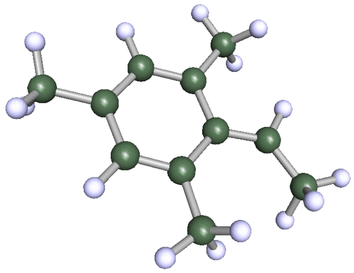


Total Energy = -389.18756620518 hartree
Enthalpy Correction = 0.224253 hartree
Entropy = 0.000149 hartree/K

```
                   atomic coordinates            atom    charge  isotop
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.98558076 | 0.19969139 | 2.82160567 | c | 6.000 | 0 |
| -2.14018904 | 0.07110488 | 0.05524939 | c | 6.000 | 0 |
| -3.16849670 | -2.35509479 | -1.14528543 | c | 6.000 | 0 |
| -3.26694259 | 2.32410921 | -1.34475219 | c | 6.000 | 0 |
| 0.73751771 | 0.04105585 | -0.05872629 | c | 6.000 | 0 |
| 2.07479587 | -1.90134076 | 1.12976489 | c | 6.000 | 0 |
| 4.69092033 | -1.99835903 | 1.06798410 | c | 6.000 | 0 |
| 6.05319735 | -0.14101073 | -0.19378117 | c | 6.000 | 0 |
| 4.75916703 | 1.80006438 | -1.38285131 | c | 6.000 | 0 |
| 2.13287251 | 1.88610930 | -1.31334486 | c | 6.000 | 0 |
| -2.28567426 | 1.92164705 | 3.72274789 | h | 1.000 | 0 |
| -2.29636003 | -1.41685979 | 3.90286809 | h | 1.000 | 0 |
| -5.04926323 | 0.20590875 | 2.93150711 | h | 1.000 | 0 |
| -5.23325161 | -2.36266691 | -1.06553057 | h | 1.000 | 0 |
| -2.48776788 | -4.03732940 | -0.16305539 | h | 1.000 | 0 |
| -2.59735357 | -2.49250087 | -3.12558432 | h | 1.000 | 0 |
| -2.64116335 | 4.11881957 | -0.53672907 | h | 1.000 | 0 |
| -2.76947480 | 2.30643371 | -3.34887378 | h | 1.000 | 0 |
| -5.32569841 | 2.25358680 | -1.20519046 | h | 1.000 | 0 |
| 1.05697741 | -3.37428882 | 2.12655129 | h | 1.000 | 0 |
| 5.67190597 | -3.53219225 | 2.00924491 | h | 1.000 | 0 |
| 8.10007082 | -0.21113386 | -0.24648294 | h | 1.000 | 0 |
| 5.79069645 | 3.26629171 | -2.37647708 | h | 1.000 | 0 |
| 1.17909479 | 3.42795462 | -2.26085848 | h | 1.000 | 0 |

1-Mesitylethan-1-ylium (MAA* = 387.6 kJ/mol, E = 6.04):

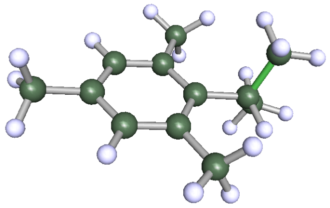


Total Energy = -427.66988059180 hartree
Enthalpy Correction = 0.241941 hartree
Entropy = 0.000164 hartree/K
LUMO Energy = -0.1375 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.54825121 | -4.41858870 | 0.93369197 | c | 6.000 | 0 |
| -0.10422946 | -2.07578938 | 0.37135923 | c | 6.000 | 0 |
| -1.28050008 | 0.36833381 | 0.02793110 | c | 6.000 | 0 |
| -3.84101187 | 0.79521527 | 0.16919494 | c | 6.000 | 0 |
| -5.95234607 | -0.93370396 | 0.64539108 | c | 6.000 | 0 |
| 0.29665945 | 2.54408256 | -0.50217501 | c | 6.000 | 0 |
| -0.77833985 | 5.12521135 | -0.87797672 | c | 6.000 | 0 |
| 2.86061954 | 2.22691586 | -0.67405265 | c | 6.000 | 0 |
| 3.98933974 | -0.14121650 | -0.33952946 | c | 6.000 | 0 |
| 6.77471679 | -0.40926840 | -0.47192865 | c | 6.000 | 0 |
| 2.47607050 | -2.24621727 | 0.17533173 | c | 6.000 | 0 |
| -0.25417152 | -6.00107278 | 1.16421227 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -2.86546382 | -4.87772911 | -0.58904369 | h | 1.000 | 0 |
| -2.66038751 | -4.23058421 | 2.66257281 | h | 1.000 | 0 |
| -4.40501591 | 2.74454678 | -0.11436909 | h | 1.000 | 0 |
| -5.78482180 | -1.78126107 | 2.52827713 | h | 1.000 | 0 |
| -5.94998428 | -2.51815396 | -0.68165364 | h | 1.000 | 0 |
| -7.74554580 | 0.05989897 | 0.52277766 | h | 1.000 | 0 |
| -2.08117353 | 5.17910771 | -2.47879316 | h | 1.000 | 0 |
| -1.81052958 | 5.76769982 | 0.79081519 | h | 1.000 | 0 |
| 0.73851213 | 6.46495492 | -1.24501901 | h | 1.000 | 0 |
| 4.05138215 | 3.84251139 | -1.08139095 | h | 1.000 | 0 |
| 7.32429071 | -2.28672455 | -1.11827690 | h | 1.000 | 0 |
| 7.61971086 | 1.03309367 | -1.67551220 | h | 1.000 | 0 |
| 7.55492868 | -0.16189365 | 1.43261373 | h | 1.000 | 0 |
| 3.37554171 | -4.06936856 | 0.42555228 | h | 1.000 | 0 |

1-Mesitylethan-1-ylium Product:

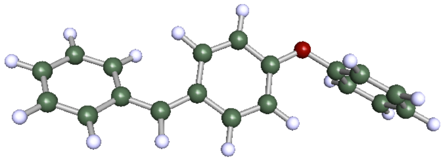


Total Energy = -467.75307842825 hartree
Enthalpy Correction = 0.283214 hartree
Entropy = 0.000176 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.43473834 | 4.55950430 | -0.40032235 | c | 6.000 | 0 |
| 0.74434086 | 2.03666601 | 0.16674149 | c | 6.000 | 0 |
| -0.65341522 | -0.19042101 | 0.54057481 | c | 6.000 | 0 |
| -3.51328948 | -0.31054311 | 0.34935618 | c | 6.000 | 0 |
| -4.95400605 | 1.63580438 | 1.92178954 | c | 6.000 | 0 |
| -4.39712555 | -0.32673072 | -2.40134466 | c | 6.000 | 0 |
| 0.67166200 | -2.43893392 | 1.05398242 | c | 6.000 | 0 |
| -0.65792056 | -4.92113668 | 1.43798358 | c | 6.000 | 0 |
| 3.29651174 | -2.42099825 | 1.21466197 | c | 6.000 | 0 |
| 4.69527421 | -0.23056633 | 0.86242014 | c | 6.000 | 0 |
| 7.52505083 | -0.25588212 | 0.97710701 | c | 6.000 | 0 |
| 3.37204521 | 1.97050701 | 0.33750509 | c | 6.000 | 0 |
| 0.99262461 | 5.84884591 | -1.14253536 | h | 1.000 | 0 |
| -1.22480175 | 5.42408588 | 1.30075011 | h | 1.000 | 0 |
| -1.95618546 | 4.43597366 | -1.78222573 | h | 1.000 | 0 |
| -4.05925533 | -2.13820762 | 1.12966004 | h | 1.000 | 0 |
| -6.92835236 | 1.05002640 | 2.08563916 | h | 1.000 | 0 |
| -4.17590665 | 1.78025348 | 3.82957342 | h | 1.000 | 0 |
| -4.94055753 | 3.51499809 | 1.08111449 | h | 1.000 | 0 |
| -3.51178535 | -1.86974573 | -3.44974567 | h | 1.000 | 0 |
| -3.93534368 | 1.43679521 | -3.36937490 | h | 1.000 | 0 |
| -6.44615202 | -0.57863469 | -2.49652594 | h | 1.000 | 0 |
| 0.71991943 | -6.42928713 | 1.71205180 | h | 1.000 | 0 |
| -1.89277048 | -4.89016044 | 3.09516937 | h | 1.000 | 0 |
| -1.83388921 | -5.42872195 | -0.18327318 | h | 1.000 | 0 |
| 4.27258129 | -4.18032643 | 1.62340386 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 8.26680615 | 1.56559470 | 1.59969485 | h | 1.000 | 0 |
| 8.33531884 | -0.64804080 | -0.88573575 | h | 1.000 | 0 |
| 8.20938567 | -1.71595910 | 2.26409261 | h | 1.000 | 0 |
| 4.41397419 | 3.71524101 | 0.04211696 | h | 1.000 | 0 |

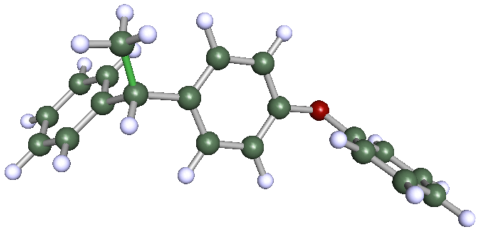
(4-Phenoxyphenyl)(phenyl)methylium (MAA* = 384.4 kJ/mol, E = 2.9):



Total Energy = -807.46017851526 hartree
Enthalpy Correction = 0.303109 hartree
Entropy = 0.000202 hartree/K
LUMO Energy = -0.1423 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.69470095 | 0.40611469 | -1.96594594 | c | 6.000 | 0 |
| 4.85515900 | 0.60836578 | -3.22112750 | o | 8.000 | 0 |
| 7.12927056 | -0.00383640 | -2.03768336 | c | 6.000 | 0 |
| 8.29913834 | -2.24440261 | -2.68846378 | c | 6.000 | 0 |
| 10.61983448 | -2.80532848 | -1.60060617 | c | 6.000 | 0 |
| 11.72198223 | -1.13869638 | 0.09938381 | c | 6.000 | 0 |
| 10.50999738 | 1.10624910 | 0.71510794 | c | 6.000 | 0 |
| 8.19314612 | 1.69514950 | -0.36117405 | c | 6.000 | 0 |
| 0.54037235 | 1.31754430 | -3.23656699 | c | 6.000 | 0 |
| -1.76681341 | 1.17091280 | -2.10978759 | c | 6.000 | 0 |
| -2.02811663 | 0.09435631 | 0.33969988 | c | 6.000 | 0 |
| -4.30236636 | -0.18336576 | 1.62808254 | c | 6.000 | 0 |
| -6.83491890 | 0.07370855 | 0.77975716 | c | 6.000 | 0 |
| -7.59367961 | -0.08920251 | -1.76802350 | c | 6.000 | 0 |
| -10.09708192 | 0.23081970 | -2.40477291 | c | 6.000 | 0 |
| -11.88500615 | 0.72278383 | -0.53504478 | c | 6.000 | 0 |
| -11.18159365 | 0.83108962 | 1.99502007 | c | 6.000 | 0 |
| -8.68788385 | 0.46404917 | 2.65369651 | c | 6.000 | 0 |
| 0.19563043 | -0.72067650 | 1.60455519 | c | 6.000 | 0 |
| 2.51461521 | -0.60982598 | 0.47654734 | c | 6.000 | 0 |
| 7.40504534 | -3.51662450 | -4.01956262 | h | 1.000 | 0 |
| 11.56462906 | -4.55545544 | -2.08768881 | h | 1.000 | 0 |
| 13.53307581 | -1.58719368 | 0.94281736 | h | 1.000 | 0 |
| 11.36981013 | 2.41434569 | 2.03496956 | h | 1.000 | 0 |
| 7.22355816 | 3.44236892 | 0.08635404 | h | 1.000 | 0 |
| 0.77691181 | 2.17174970 | -5.08011014 | h | 1.000 | 0 |
| -3.38496557 | 1.98600722 | -3.05205909 | h | 1.000 | 0 |
| -4.11441657 | -0.65822074 | 3.61889795 | h | 1.000 | 0 |
| -6.24231243 | -0.58388618 | -3.21855071 | h | 1.000 | 0 |
| -10.67997768 | 0.06980110 | -4.35964500 | h | 1.000 | 0 |
| -13.84956671 | 0.97652599 | -1.05507795 | h | 1.000 | 0 |
| -12.58748581 | 1.17358050 | 3.44206028 | h | 1.000 | 0 |
| -8.11668521 | 0.52106855 | 4.62003286 | h | 1.000 | 0 |
| 0.02359617 | -1.49885037 | 3.49122724 | h | 1.000 | 0 |
| 4.18239692 | -1.28102551 | 1.44741272 | h | 1.000 | 0 |

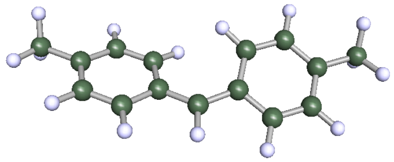
(4-Phenoxyphenyl)(phenyl)methylium Product:



Total Energy = -847.54000375646 hartree
Enthalpy Correction = 0.342816 hartree
Entropy = 0.000216 hartree/K

```
                   atomic coordinates             atom    charge  isotop
         -5.41044704    2.48134320   -3.96194704    c      6.000     0
         -4.42836938    1.92319629   -1.31082270    c      6.000     0
         -6.24711075    0.22110054    0.09952739    c      6.000     0
         -6.51939435   -2.31108726   -0.57049460    c      6.000     0
         -8.22070296   -3.85644990    0.68679092    c      6.000     0
         -9.67938580   -2.89368251    2.64832121    c      6.000     0
         -9.41830090   -0.37733737    3.33557091    c      6.000     0
         -7.71301661    1.16460159    2.06593623    c      6.000     0
         -1.77986689    0.84451962   -1.25324144    c      6.000     0
         -0.66678779   -0.33014688   -3.32068220    c      6.000     0
          1.75212903   -1.34381005   -3.16812005    c      6.000     0
          3.07365807   -1.19176449   -0.92056503    c      6.000     0
          5.40541196   -2.33696213   -0.78039561    o      8.000     0
          7.45181956   -0.94902066   -0.02242707    c      6.000     0
          9.47546345   -2.29396605    0.97208117    c      6.000     0
         11.64895766   -1.01781485    1.68421885    c      6.000     0
         11.81204212    1.58933468    1.41724476    c      6.000     0
          9.77835025    2.90987420    0.41747057    c      6.000     0
          7.59214884    1.65650623   -0.31141521    c      6.000     0
          2.00402444   -0.03319089    1.17804982    c      6.000     0
         -0.39971183    0.97429528    0.99061807    c      6.000     0
         -7.24486952    3.41751712   -3.84499263    h      1.000     0
         -5.66259061    0.75089587   -5.05863652    h      1.000     0
         -4.11260281    3.71654122   -4.98795319    h      1.000     0
         -4.36464150    3.71283887   -0.27608366    h      1.000     0
         -5.37507257   -3.08756352   -2.08497650    h      1.000     0
         -8.40684559   -5.82273919    0.13994078    h      1.000     0
        -11.00604789   -4.10232298    3.63661496    h      1.000     0
        -10.54144208    0.39251302    4.86721243    h      1.000     0
         -7.51558234    3.13184495    2.61213523    h      1.000     0
         -1.67254813   -0.45993619   -5.09895095    h      1.000     0
          2.61665603   -2.25143191   -4.78788012    h      1.000     0
          9.32233188   -4.32621438    1.17496770    h      1.000     0
         13.22345812   -2.07282148    2.46227180    h      1.000     0
         13.51167536    2.58190038    1.98152174    h      1.000     0
          9.88623625    4.94287805    0.18752111    h      1.000     0
          6.01508824    2.69535286   -1.09975254    h      1.000     0
          3.05183846    0.07768743    2.93444815    h      1.000     0
         -1.23595236    1.87352130    2.63374331    h      1.000     0
```

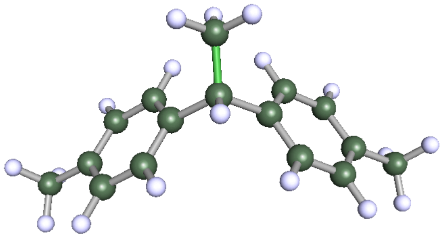
Di-*p*-tolylmethylium (MAA* = 383.5 kJ/mol, E = 3.63):



Total Energy = -579.98640318578 hartree
Enthalpy Correction = 0.26997 hartree
Entropy = 0.000181 hartree/K
LUMO Energy = -0.1439 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -9.94868974 | 1.68773916 | -0.25481831 | c | 6.000 | 0 |
| -7.36067662 | 0.67997855 | 0.16781035 | c | 6.000 | 0 |
| -5.29522812 | 1.75249551 | -1.11019250 | c | 6.000 | 0 |
| -2.88898669 | 0.87463564 | -0.73881779 | c | 6.000 | 0 |
| -2.44177332 | -1.15115127 | 0.94944799 | c | 6.000 | 0 |
| -0.05111487 | -2.16560624 | 1.50540365 | c | 6.000 | 0 |
| 2.38636116 | -1.20087247 | 1.07977399 | c | 6.000 | 0 |
| 2.94168546 | 1.35033632 | 0.50711619 | c | 6.000 | 0 |
| 5.38683034 | 2.08635009 | 0.07626179 | c | 6.000 | 0 |
| 7.38349500 | 0.34213139 | 0.18113493 | c | 6.000 | 0 |
| 10.01301630 | 1.16543026 | -0.36495613 | c | 6.000 | 0 |
| 6.85547042 | -2.16921847 | 0.81640731 | c | 6.000 | 0 |
| 4.41998641 | -2.92154768 | 1.29893636 | c | 6.000 | 0 |
| -4.54189691 | -2.29299587 | 2.14249618 | c | 6.000 | 0 |
| -6.93985694 | -1.36278499 | 1.78973291 | c | 6.000 | 0 |
| -10.41767296 | 1.64406736 | -2.26690615 | h | 1.000 | 0 |
| -11.36534067 | 0.61955125 | 0.78786950 | h | 1.000 | 0 |
| -10.04211201 | 3.66874297 | 0.33105377 | h | 1.000 | 0 |
| -5.62392398 | 3.27828662 | -2.43636388 | h | 1.000 | 0 |
| -1.35438891 | 1.66291639 | -1.83242979 | h | 1.000 | 0 |
| -0.09482436 | -4.00779063 | 2.41603806 | h | 1.000 | 0 |
| 1.46046893 | 2.75679374 | 0.52515497 | h | 1.000 | 0 |
| 5.79839144 | 4.05391477 | -0.31653434 | h | 1.000 | 0 |
| 10.35712354 | 3.07748960 | 0.32612824 | h | 1.000 | 0 |
| 10.30753849 | 1.19851863 | -2.41474798 | h | 1.000 | 0 |
| 11.39739532 | -0.12473108 | 0.44756648 | h | 1.000 | 0 |
| 8.38930333 | -3.51893631 | 0.95385622 | h | 1.000 | 0 |
| 4.02148908 | -4.86547261 | 1.80778853 | h | 1.000 | 0 |
| -4.22664575 | -3.88859195 | 3.38786175 | h | 1.000 | 0 |
| -8.52542337 | -2.22967867 | 2.75223302 | h | 1.000 | 0 |

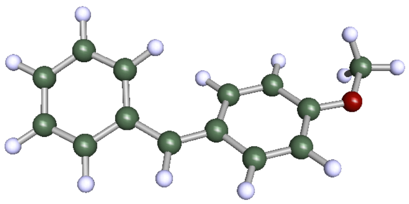
Di-*p*-tolylmethylium Product:



Total Energy = -620.06575288830 hartree
Enthalpy Correction = 0.310141 hartree
Entropy = 0.000197 hartree/K

```
            atomic coordinates              atom    charge  isotop
  -0.05696285   -3.51709258    4.18518827    c      6.000     0
  -0.13547111   -2.83290092    1.38634222    c      6.000     0
  -2.41278034   -1.23609301    0.70729913    c      6.000     0
  -3.87912047   -1.85005296   -1.38623731    c      6.000     0
  -5.93926702   -0.38357784   -2.08117279    c      6.000     0
  -6.61222799    1.75215409   -0.70197769    c      6.000     0
  -8.87232896    3.30422067   -1.40960766    c      6.000     0
  -5.13844938    2.36900151    1.39134168    c      6.000     0
  -3.08042776    0.90392486    2.08511665    c      6.000     0
   2.27390760   -1.57943151    0.48089235    c      6.000     0
   3.43372082    0.36777034    1.81879313    c      6.000     0
   5.59980207    1.52842558    0.90732943    c      6.000     0
   6.69577720    0.78605205   -1.36877884    c      6.000     0
   9.07104865    2.00271469   -2.31579302    c      6.000     0
   5.53336946   -1.15957508   -2.70516677    c      6.000     0
   3.36465608   -2.31907989   -1.79443707    c      6.000     0
   0.10754160   -1.84997743    5.38835457    h      1.000     0
  -1.78160254   -4.51357706    4.72573197    h      1.000     0
   1.55749466   -4.74068251    4.57990943    h      1.000     0
  -0.31621019   -4.59274435    0.31718199    h      1.000     0
  -3.39876050   -3.50566875   -2.49928460    h      1.000     0
  -7.04466022   -0.91136631   -3.72708814    h      1.000     0
 -10.56624162    2.62511855   -0.43523189    h      1.000     0
  -8.61522763    5.28341620   -0.88787433    h      1.000     0
  -9.24538771    3.20396672   -3.43587859    h      1.000     0
  -5.60973827    4.03007636    2.49983164    h      1.000     0
  -1.98232262    1.45461637    3.72558142    h      1.000     0
   2.64586870    1.00610703    3.59907077    h      1.000     0
   6.45794986    3.04646163    1.98837320    h      1.000     0
  10.74138021    1.01873453   -1.59347319    h      1.000     0
   9.20233921    3.96816190   -1.70265584    h      1.000     0
   9.16838179    1.95161342   -4.37561449    h      1.000     0
   6.33623091   -1.78053550   -4.48810305    h      1.000     0
   2.49771835   -3.83018077   -2.87796260    h      1.000     0
```

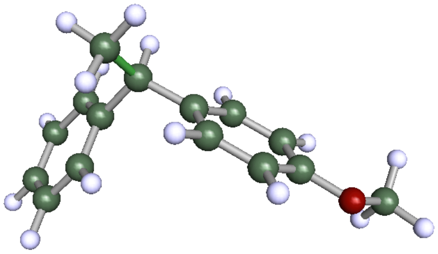
(4-Methoxyphenyl)(phenyl)methylium (MAA* = 375.6 kJ/mol, E = 2.11):



Total Energy = -615.87045780481 hartree
Enthalpy Correction = 0.247445 hartree
Entropy = 0.000175 hartree/K
LUMO Energy = -0.1395 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 9.26127588 | 2.04310617 | -0.82354107 | c | 6.000 | 0 |
| 8.23017112 | -0.11059942 | 0.44418512 | o | 8.000 | 0 |
| 5.78005153 | -0.49318075 | 0.42638359 | c | 6.000 | 0 |
| 4.93397267 | -2.66002017 | 1.72903451 | c | 6.000 | 0 |
| 2.42317969 | -3.19936488 | 1.79377159 | c | 6.000 | 0 |
| 0.61563602 | -1.57153039 | 0.63652796 | c | 6.000 | 0 |
| -1.91697675 | -2.20665665 | 0.87602981 | c | 6.000 | 0 |
| -4.12520511 | -0.78754608 | 0.29547528 | c | 6.000 | 0 |
| -4.19676904 | 1.86886134 | 0.15200047 | c | 6.000 | 0 |
| -6.41867326 | 3.08368076 | -0.45608101 | c | 6.000 | 0 |
| -8.59801966 | 1.68870955 | -0.93900610 | c | 6.000 | 0 |
| -8.57671794 | -0.93267433 | -0.74833826 | c | 6.000 | 0 |
| -6.37361575 | -2.15950178 | -0.09041330 | c | 6.000 | 0 |
| 1.52777702 | 0.55076381 | -0.73376614 | c | 6.000 | 0 |
| 4.04653643 | 1.08538159 | -0.84400746 | c | 6.000 | 0 |
| 8.86754138 | 1.94078793 | -2.84426973 | h | 1.000 | 0 |
| 11.28524196 | 1.95199766 | -0.49630591 | h | 1.000 | 0 |
| 8.49199967 | 3.78017572 | -0.02486880 | h | 1.000 | 0 |
| 6.31729736 | -3.85893532 | 2.64209560 | h | 1.000 | 0 |
| 1.75541929 | -4.86147272 | 2.78676586 | h | 1.000 | 0 |
| -2.27716318 | -4.09231314 | 1.61158055 | h | 1.000 | 0 |
| -2.54518315 | 2.97093930 | 0.63594539 | h | 1.000 | 0 |
| -6.47537209 | 5.12813236 | -0.52834005 | h | 1.000 | 0 |
| -10.33636811 | 2.65882341 | -1.42042374 | h | 1.000 | 0 |
| -10.28722279 | -2.00394376 | -1.08670672 | h | 1.000 | 0 |
| -6.33769948 | -4.19998696 | 0.08710945 | h | 1.000 | 0 |
| 0.22793715 | 1.70654624 | -1.80520068 | h | 1.000 | 0 |
| 4.70094914 | 2.67982052 | -1.93960249 | h | 1.000 | 0 |

(4-Methoxyphenyl)(phenyl)methylium Product:

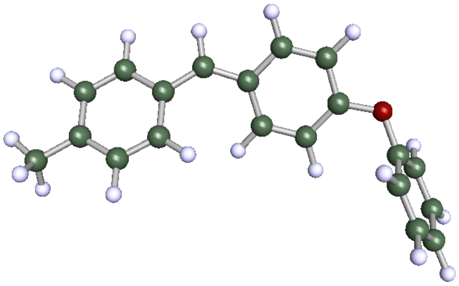


Total Energy = -655.94689752172 hartree
Enthalpy Correction = 0.287109 hartree
Entropy =  0.000189 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 9.43058889 | 2.03950260 | -1.11357197 | c | 6.000 | 0 |
| 7.78310055 | 0.52896164 | -2.58170207 | o | 8.000 | 0 |
| 5.52024591 | -0.09724994 | -1.56277182 | c | 6.000 | 0 |
| 3.93969679 | -1.58965260 | -3.04681538 | c | 6.000 | 0 |
| 1.59407590 | -2.32312061 | -2.15134842 | c | 6.000 | 0 |
| 0.74821171 | -1.59381486 | 0.23437629 | c | 6.000 | 0 |
| -1.83494425 | -2.28118305 | 1.25386247 | c | 6.000 | 0 |
| -2.90992643 | -4.71996402 | 0.15485648 | c | 6.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -3.67484824 | -0.11468297 | 0.91292537 | c | 6.000 | 0 |
| -4.22116183 | 0.83318181 | -1.48314143 | c | 6.000 | 0 |
| -5.92827649 | 2.79601546 | -1.79420848 | c | 6.000 | 0 |
| -7.11919582 | 3.85563054 | 0.29446539 | c | 6.000 | 0 |
| -6.58621016 | 2.93125679 | 2.68877655 | c | 6.000 | 0 |
| -4.87683383 | 0.95965821 | 2.98890935 | c | 6.000 | 0 |
| 2.35497630 | -0.11106126 | 1.68963796 | c | 6.000 | 0 |
| 4.71721478 | 0.64260596 | 0.83087725 | c | 6.000 | 0 |
| 11.11515656 | 2.32758414 | -2.25688214 | h | 1.000 | 0 |
| 9.95020756 | 1.08780137 | 0.64649549 | h | 1.000 | 0 |
| 8.57698069 | 3.87057068 | -0.67485304 | h | 1.000 | 0 |
| 4.57940008 | -2.17011282 | -4.90460593 | h | 1.000 | 0 |
| 0.41560954 | -3.49453379 | -3.34884657 | h | 1.000 | 0 |
| -1.61674358 | -2.55642251 | 3.29220943 | h | 1.000 | 0 |
| -4.67669005 | -5.20156663 | 1.10557342 | h | 1.000 | 0 |
| -3.31990793 | -4.53358971 | -1.85926043 | h | 1.000 | 0 |
| -1.58602003 | -6.28436737 | 0.40286459 | h | 1.000 | 0 |
| -3.28923022 | 0.03585448 | -3.12680870 | h | 1.000 | 0 |
| -6.32906429 | 3.50810945 | -3.67370326 | h | 1.000 | 0 |
| -8.44978029 | 5.39449857 | 0.05265024 | h | 1.000 | 0 |
| -7.49905686 | 3.74605106 | 4.33287948 | h | 1.000 | 0 |
| -4.46713684 | 0.24459290 | 4.86751104 | h | 1.000 | 0 |
| 1.75354554 | 0.48163344 | 3.55968950 | h | 1.000 | 0 |
| 5.90601633 | 1.78781304 | 2.03719248 | h | 1.000 | 0 |

(4-Phenoxyphenyl)(*p*-tolyl)methylium (MAA* = 375.5 kJ/mol, E = 2.16):

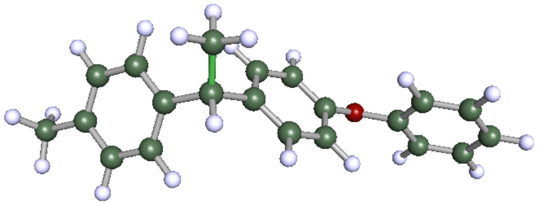


Total Energy = -846.74865561626 hartree
Enthalpy Correction = 0.332062 hartree
Entropy = 0.000215 hartree/K
LUMO Energy = -0.1395 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 12.02605186 | 2.68297407 | -0.87278610 | c | 6.000 | 0 |
| 9.74301716 | 1.10964876 | -0.40156207 | c | 6.000 | 0 |
| 7.40503515 | 2.26881330 | 0.07139915 | c | 6.000 | 0 |
| 5.27166348 | 0.86102795 | 0.49931118 | c | 6.000 | 0 |
| 5.39272153 | -1.80611705 | 0.47664677 | c | 6.000 | 0 |
| 3.30823281 | -3.42827991 | 0.85315735 | c | 6.000 | 0 |
| 0.71515590 | -2.96526539 | 0.69098175 | c | 6.000 | 0 |
| -0.38013456 | -0.80139732 | -0.44736368 | c | 6.000 | 0 |
| -2.93924076 | -0.46083590 | -0.47153255 | c | 6.000 | 0 |
| -4.50702769 | -2.28625826 | 0.65108389 | c | 6.000 | 0 |
| -7.01309607 | -2.09983516 | 0.70940919 | o | 8.000 | 0 |
| -8.19339448 | 0.13460087 | -0.02060273 | c | 6.000 | 0 |
| -9.65766882 | 0.09759309 | -2.18201019 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -10.94718782 | 2.27888971 | -2.86211563 | c | 6.000 | 0 |
| -10.75709947 | 4.44209894 | -1.38994550 | c | 6.000 | 0 |
| -9.27936509 | 4.42978934 | 0.77928747 | c | 6.000 | 0 |
| -7.98672643 | 2.26177414 | 1.48666885 | c | 6.000 | 0 |
| -3.48794935 | -4.49809297 | 1.69989907 | c | 6.000 | 0 |
| -0.93246402 | -4.83775861 | 1.68322887 | c | 6.000 | 0 |
| 7.76905101 | -2.95862385 | 0.10953213 | c | 6.000 | 0 |
| 9.88558680 | -1.52636217 | -0.36444004 | c | 6.000 | 0 |
| 12.37333033 | 3.94291313 | 0.72817989 | h | 1.000 | 0 |
| 13.69937105 | 1.52477520 | -1.18167306 | h | 1.000 | 0 |
| 11.73499407 | 3.88956803 | -2.52577242 | h | 1.000 | 0 |
| 7.29605909 | 4.31359876 | 0.13262351 | h | 1.000 | 0 |
| 3.52575668 | 1.81093627 | 0.97265919 | h | 1.000 | 0 |
| 3.80790102 | -5.35989513 | 1.34776391 | h | 1.000 | 0 |
| 0.79924379 | 0.55109162 | -1.42272055 | h | 1.000 | 0 |
| -3.75712717 | 1.17006279 | -1.39214540 | h | 1.000 | 0 |
| -9.77939328 | -1.61114528 | -3.30249155 | h | 1.000 | 0 |
| -12.10281581 | 2.28099839 | -4.55250037 | h | 1.000 | 0 |
| -11.76772199 | 6.13914364 | -1.92935421 | h | 1.000 | 0 |
| -9.13511175 | 6.11179629 | 1.93801538 | h | 1.000 | 0 |
| -6.83894301 | 2.21509958 | 3.18193631 | h | 1.000 | 0 |
| -4.75316606 | -5.89426488 | 2.49596518 | h | 1.000 | 0 |
| -0.12291925 | -6.53608027 | 2.49229750 | h | 1.000 | 0 |
| 7.89779051 | -5.00292595 | 0.15411086 | h | 1.000 | 0 |
| 11.68759067 | -2.44405578 | -0.68742061 | h | 1.000 | 0 |

(4-Phenoxyphenyl)(*p*-tolyl)methylium Product:

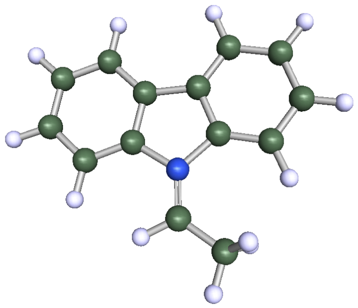


Total Energy = -886.82461636350 hartree
Enthalpy Correction = 0.371874 hartree
Entropy = 0.000231 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -11.61246604 | -4.10089678 | -0.11050646 | c | 6.000 | 0 |
| -9.46343836 | -2.27826032 | 0.17589429 | c | 6.000 | 0 |
| -7.91634611 | -2.30694582 | 2.30518114 | c | 6.000 | 0 |
| -5.93260508 | -0.61367851 | 2.55941822 | c | 6.000 | 0 |
| -5.41782053 | 1.17566185 | 0.70059234 | c | 6.000 | 0 |
| -3.17969320 | 2.92823319 | 1.02987374 | c | 6.000 | 0 |
| -3.40334721 | 5.40101123 | -0.43386061 | c | 6.000 | 0 |
| -0.74240919 | 1.57325742 | 0.38749361 | c | 6.000 | 0 |
| 1.16358796 | 1.30796748 | 2.17671319 | c | 6.000 | 0 |
| 3.41115593 | 0.07950819 | 1.61264137 | c | 6.000 | 0 |
| 3.77260929 | -0.88578387 | -0.79580233 | c | 6.000 | 0 |
| 5.88987537 | -2.23938248 | -1.44504859 | o | 8.000 | 0 |
| 8.22131666 | -1.45626716 | -0.63264405 | c | 6.000 | 0 |
| 9.98186937 | -3.32875511 | -0.11081596 | c | 6.000 | 0 |
| 12.41503244 | -2.65334126 | 0.59238446 | c | 6.000 | 0 |
| 13.08852798 | -0.12451908 | 0.78723130 | c | 6.000 | 0 |

```
  11.30946020    1.73036885    0.25536348    c      6.000     0
   8.87350908    1.08100626   -0.46377165    c      6.000     0
   1.89874285   -0.64669269   -2.61436661    c      6.000     0
  -0.34028999    0.56600638   -2.01059320    c      6.000     0
  -6.96918425    1.21515616   -1.42317997    c      6.000     0
  -8.95122958   -0.48356502   -1.67988046    c      6.000     0
 -11.39452070   -5.24700232   -1.81573669    h      1.000     0
 -13.41633669   -3.10639606   -0.27447955    h      1.000     0
 -11.73022946   -5.37461389    1.50650218    h      1.000     0
  -8.27460077   -3.67482054    3.79137439    h      1.000     0
  -4.75603251   -0.68368084    4.23945569    h      1.000     0
  -3.08293156    3.39654283    3.04203937    h      1.000     0
  -1.82469065    6.64137532    0.04063798    h      1.000     0
  -5.16322895    6.37667081    0.02888097    h      1.000     0
  -3.35682321    5.08799628   -2.47329889    h      1.000     0
   0.88770101    2.06251602    4.06345688    h      1.000     0
   4.86733965   -0.12491239    3.03724333    h      1.000     0
   9.42777288   -5.29439748   -0.26466396    h      1.000     0
  13.78747391   -4.11871056    1.00008825    h      1.000     0
  14.98773438    0.39835468    1.34600603    h      1.000     0
  11.81895692    3.71029733    0.38754990    h      1.000     0
   7.49295656    2.53065866   -0.89049379    h      1.000     0
   2.20784942   -1.42560954   -4.48331287    h      1.000     0
  -1.80195471    0.72127059   -3.43980567    h      1.000     0
  -6.64545435    2.58933076   -2.90673479    h      1.000     0
 -10.12783875   -0.40495858   -3.35905617    h      1.000     0
```

9-Ethylidene-9*H*-carbazol-9-ium (MAA* = 371.3 kJ/mol, E = 2.41):



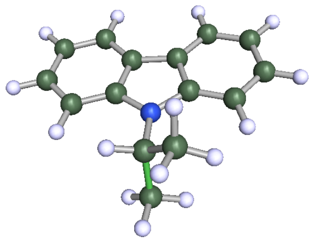
Total Energy = -594.84488901472 hartree
Enthalpy Correction = 0.236633 hartree
Entropy = 0.000163 hartree/K
LUMO Energy = -0.1114 hartree

```
               atomic coordinates            atom    charge  isotop
   0.73847195    6.28525500    0.19780565    c      6.000     0
  -0.99259337    4.21165829   -0.37839525    c      6.000     0
  -0.51367532    1.82793540   -0.18249073    n      7.000     0
   1.74830415    0.58328673    0.62083755    c      6.000     0
   1.33416609   -2.02748193    0.50987628    c      6.000     0
   3.23541026   -3.68368667    1.19455250    c      6.000     0
   5.53500657   -2.69132854    1.98293816    c      6.000     0
   5.91993730   -0.09569238    2.08230466    c      6.000     0
   4.02677256    1.59567845    1.40065821    c      6.000     0
  -1.22972103   -2.45171841   -0.37994416    c      6.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.33008489 | -0.09969241 | -0.79223237 | c | 6.000 | 0 |
| -4.76935604 | 0.20066457 | -1.64871266 | c | 6.000 | 0 |
| -6.13922429 | -1.99437816 | -2.10305818 | c | 6.000 | 0 |
| -5.07793149 | -4.36904725 | -1.70502281 | c | 6.000 | 0 |
| -2.61396574 | -4.62569997 | -0.83960786 | c | 6.000 | 0 |
| 2.43497853 | 6.16209870 | -0.97943789 | h | 1.000 | 0 |
| -0.19594937 | 8.08002104 | -0.14528018 | h | 1.000 | 0 |
| 1.34514117 | 6.19717382 | 2.17359107 | h | 1.000 | 0 |
| -2.88052536 | 4.65129447 | -1.04055296 | h | 1.000 | 0 |
| 2.93924391 | -5.70757573 | 1.11766057 | h | 1.000 | 0 |
| 7.04912350 | -3.95697456 | 2.52719144 | h | 1.000 | 0 |
| 7.72532981 | 0.64267974 | 2.70035094 | h | 1.000 | 0 |
| 4.39108195 | 3.59645238 | 1.50002476 | h | 1.000 | 0 |
| -5.62143455 | 2.03285399 | -1.96840964 | h | 1.000 | 0 |
| -8.06469895 | -1.84291778 | -2.77890474 | h | 1.000 | 0 |
| -6.19573639 | -6.04301922 | -2.07797790 | h | 1.000 | 0 |
| -1.79807095 | -6.47783959 | -0.53363152 | h | 1.000 | 0 |

9-Ethylidene-9*H*-carbazol-9-ium Product:

The $CH_3$-C-N-C Torsion Angle was constrained to 90°.

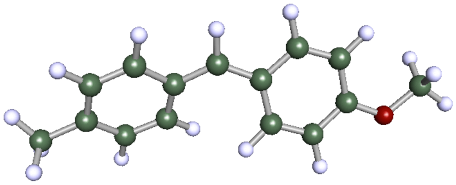


Total Energy = -634.91876861337 hartree
Enthalpy Correction = 0.276859 hartree
Entropy = 0.000182 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.08111297 | -2.32615981 | 3.30007128 | c | 6.000 | 0 |
| -3.54979429 | -1.46002025 | 0.61177486 | c | 6.000 | 0 |
| -5.50310532 | 0.39635584 | -0.37908131 | c | 6.000 | 0 |
| -0.94407800 | -0.58742944 | 0.34964603 | n | 7.000 | 0 |
| 0.96193921 | -2.12393314 | -0.55055623 | c | 6.000 | 0 |
| 3.20356657 | -0.70031324 | -0.82180829 | c | 6.000 | 0 |
| 5.39641844 | -1.85171749 | -1.70983133 | c | 6.000 | 0 |
| 5.33599845 | -4.39652294 | -2.31346124 | c | 6.000 | 0 |
| 3.10614729 | -5.78919487 | -2.03123853 | c | 6.000 | 0 |
| 0.90099167 | -4.68706622 | -1.14962159 | c | 6.000 | 0 |
| 2.60128865 | 1.82822912 | -0.03082159 | c | 6.000 | 0 |
| 0.02208076 | 1.81494032 | 0.68608739 | c | 6.000 | 0 |
| -1.10262795 | 3.99559023 | 1.64900211 | c | 6.000 | 0 |
| 0.34943834 | 6.16748327 | 1.81012401 | c | 6.000 | 0 |
| 2.88378910 | 6.20654410 | 1.06179176 | c | 6.000 | 0 |
| 4.02124153 | 4.03513534 | 0.15229297 | c | 6.000 | 0 |
| -2.72147424 | -3.76196182 | 3.88815906 | h | 1.000 | 0 |
| -3.96643132 | -0.74012775 | 4.61898030 | h | 1.000 | 0 |
| -5.97672524 | -3.13213048 | 3.42532216 | h | 1.000 | 0 |
| -3.65506266 | -3.11635725 | -0.61471723 | h | 1.000 | 0 |
| -5.87791100 | 1.93737841 | 0.93332158 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -4.92456978 | 1.19198504 | -2.19205242 | h | 1.000 | 0 |
| -7.27856566 | -0.61547487 | -0.65833662 | h | 1.000 | 0 |
| 7.12501576 | -0.77140750 | -1.92463485 | h | 1.000 | 0 |
| 7.02617232 | -5.32382620 | -3.00475399 | h | 1.000 | 0 |
| 3.09934852 | -7.78254950 | -2.50469665 | h | 1.000 | 0 |
| -0.79524466 | -5.81077493 | -0.92854317 | h | 1.000 | 0 |
| -3.04063694 | 4.02292913 | 2.28727175 | h | 1.000 | 0 |
| -0.50691897 | 7.87490055 | 2.55174690 | h | 1.000 | 0 |
| 3.96140389 | 7.94109269 | 1.21742026 | h | 1.000 | 0 |
| 5.99520133 | 4.04478149 | -0.39953233 | h | 1.000 | 0 |

(4-Methoxyphenyl)(*p*-tolyl)methylium (MAA* = 366.7 kJ/mol, E = 1.48):

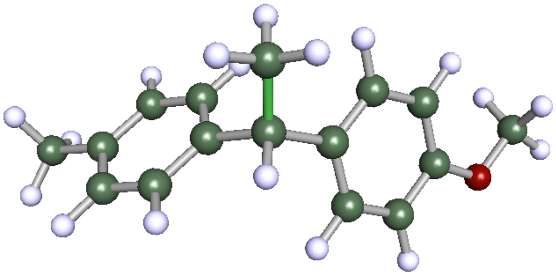


Total Energy = -655.15894225772 hartree
Enthalpy Correction = 0.276431 hartree
Entropy = 0.000188 hartree/K
LUMO Energy = -0.1366 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 11.14427282 | 1.58879426 | -0.39978064 | c | 6.000 | 0 |
| 8.85968580 | 1.80270412 | -1.82424004 | o | 8.000 | 0 |
| 6.72260549 | 1.00913090 | -0.83346293 | c | 6.000 | 0 |
| 6.51823622 | -0.06918790 | 1.58551823 | c | 6.000 | 0 |
| 4.19714185 | -0.84365979 | 2.41435671 | c | 6.000 | 0 |
| 1.98322739 | -0.51669715 | 0.93591585 | c | 6.000 | 0 |
| -0.29422817 | -1.27665413 | 2.01637150 | c | 6.000 | 0 |
| -2.82407087 | -0.86308889 | 1.25418685 | c | 6.000 | 0 |
| -4.68286468 | -2.43536119 | 2.34118184 | c | 6.000 | 0 |
| -7.17906156 | -2.22406066 | 1.65034947 | c | 6.000 | 0 |
| -7.94349126 | -0.38618170 | -0.08579725 | c | 6.000 | 0 |
| -10.63995200 | -0.16480827 | -0.85701583 | c | 6.000 | 0 |
| -6.12075268 | 1.25593136 | -1.08421524 | c | 6.000 | 0 |
| -3.61533097 | 1.03254500 | -0.44520076 | c | 6.000 | 0 |
| 2.26179594 | 0.50947583 | -1.53314810 | c | 6.000 | 0 |
| 4.56854521 | 1.24889269 | -2.39204485 | c | 6.000 | 0 |
| 12.61460248 | 2.37106714 | -1.59929570 | h | 1.000 | 0 |
| 11.00605684 | 2.67514124 | 1.34688157 | h | 1.000 | 0 |
| 11.54934040 | -0.38990369 | 0.01376032 | h | 1.000 | 0 |
| 8.16138571 | -0.30474176 | 2.77484426 | h | 1.000 | 0 |
| 4.01849026 | -1.68561629 | 4.27307806 | h | 1.000 | 0 |
| -0.09805598 | -2.38681172 | 3.73530835 | h | 1.000 | 0 |
| -4.10969595 | -3.85195659 | 3.70589245 | h | 1.000 | 0 |
| -8.57548119 | -3.47201534 | 2.47947383 | h | 1.000 | 0 |
| -11.14821857 | 1.79273127 | -1.25670497 | h | 1.000 | 0 |
| -10.95377955 | -1.24719366 | -2.59400586 | h | 1.000 | 0 |
| -11.90287865 | -0.92188778 | 0.58423443 | h | 1.000 | 0 |
| -6.70867432 | 2.75001199 | -2.35623109 | h | 1.000 | 0 |
| -2.27888167 | 2.40073124 | -1.16322615 | h | 1.000 | 0 |
| 0.65714892 | 0.61032432 | -2.79211428 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 4.81288275 | 1.99234513 | -4.28253202 | h | 1.000 | 0 |

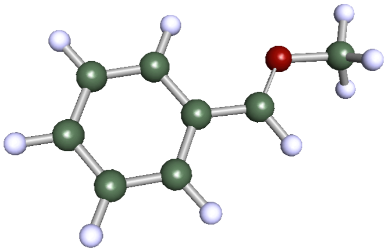
(4-Methoxyphenyl)(*p*-tolyl)methylium Product:



Total Energy = -695.23169711103 hartree
Enthalpy Correction = 0.316103 hartree
Entropy = 0.000203 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 10.32906886 | 1.91117934 | -1.41285418 | c | 6.000 | 0 |
| 8.38101520 | 1.42813292 | -3.18000024 | o | 8.000 | 0 |
| 6.24340407 | 0.31663696 | -2.31548613 | c | 6.000 | 0 |
| 4.35396795 | -0.12711645 | -4.10247110 | c | 6.000 | 0 |
| 2.11451447 | -1.25170350 | -3.38218491 | c | 6.000 | 0 |
| 1.66953197 | -1.97832107 | -0.88325889 | c | 6.000 | 0 |
| -0.85217426 | -3.14207630 | -0.19988383 | c | 6.000 | 0 |
| -0.82111437 | -4.63373342 | 2.26560449 | c | 6.000 | 0 |
| -2.91086936 | -1.15508093 | -0.15083362 | c | 6.000 | 0 |
| -5.06122340 | -1.39799630 | -1.63745898 | c | 6.000 | 0 |
| -6.96678145 | 0.40682270 | -1.56841142 | c | 6.000 | 0 |
| -6.78749709 | 2.51131329 | -0.00376068 | c | 6.000 | 0 |
| -8.86358414 | 4.43305647 | 0.11799572 | c | 6.000 | 0 |
| -4.62136813 | 2.75575286 | 1.47876469 | c | 6.000 | 0 |
| -2.71894268 | 0.95976147 | 1.40507957 | c | 6.000 | 0 |
| 3.57078013 | -1.53153702 | 0.86340432 | c | 6.000 | 0 |
| 5.84416491 | -0.39361534 | 0.17930885 | c | 6.000 | 0 |
| 9.68465440 | 3.18632708 | 0.08153612 | h | 1.000 | 0 |
| 11.02215587 | 0.15783688 | -0.56441207 | h | 1.000 | 0 |
| 11.84987494 | 2.80792299 | -2.46682003 | h | 1.000 | 0 |
| 4.68064283 | 0.41899223 | -6.05025298 | h | 1.000 | 0 |
| 0.66328016 | -1.57749009 | -4.79592721 | h | 1.000 | 0 |
| -1.33568024 | -4.45845299 | -1.72092518 | h | 1.000 | 0 |
| 0.65001357 | -6.08294335 | 2.23774634 | h | 1.000 | 0 |
| -2.64288196 | -5.55983692 | 2.54748594 | h | 1.000 | 0 |
| -0.48858622 | -3.40621958 | 3.89156712 | h | 1.000 | 0 |
| -5.24879785 | -3.02095465 | -2.87900496 | h | 1.000 | 0 |
| -8.62017840 | 0.17451533 | -2.76096499 | h | 1.000 | 0 |
| -8.11442550 | 6.32659423 | 0.45051184 | h | 1.000 | 0 |
| -10.16926185 | 4.00919879 | 1.66537674 | h | 1.000 | 0 |
| -9.96123050 | 4.46134668 | -1.62791403 | h | 1.000 | 0 |
| -4.41934759 | 4.39033610 | 2.70267027 | h | 1.000 | 0 |
| -1.04452631 | 1.21887662 | 2.56159551 | h | 1.000 | 0 |
| 3.31644037 | -2.07395637 | 2.82161800 | h | 1.000 | 0 |
| 7.27496160 | -0.08356864 | 1.60629148 | h | 1.000 | 0 |

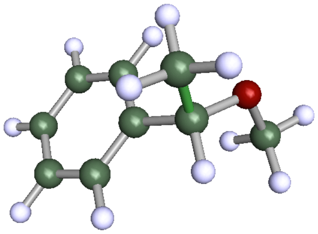
(*E*)-Benzylidene(methyl)oxonium (MAA* = 364.7 kJ/mol, E = 2.97):



Total Energy = -384.99888038822 hartree
Enthalpy Correction = 0.161581 hartree
Entropy = 0.00014 hartree/K
LUMO Energy = -0.1271 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 6.48578005 | -0.14089026 | -0.93144270 | c | 6.000 | 0 |
| 3.77622474 | -0.17769915 | -1.37281096 | o | 8.000 | 0 |
| 2.30938309 | 0.04924145 | 0.50123898 | c | 6.000 | 0 |
| -0.33747803 | 0.03400875 | 0.21251437 | c | 6.000 | 0 |
| -1.79568041 | 0.30405257 | 2.41461922 | c | 6.000 | 0 |
| -4.39607971 | 0.30698065 | 2.24027021 | c | 6.000 | 0 |
| -5.53196116 | 0.04156762 | -0.11397617 | c | 6.000 | 0 |
| -4.09243479 | -0.22904187 | -2.30966943 | c | 6.000 | 0 |
| -1.49896827 | -0.23481846 | -2.16442266 | c | 6.000 | 0 |
| 6.99027918 | 1.67440552 | -0.10928235 | h | 1.000 | 0 |
| 7.34014099 | -0.37962288 | -2.77870729 | h | 1.000 | 0 |
| 6.96823156 | -1.70057701 | 0.31761007 | h | 1.000 | 0 |
| 3.13768253 | 0.26172195 | 2.37675021 | h | 1.000 | 0 |
| -0.86301219 | 0.50850514 | 4.22677989 | h | 1.000 | 0 |
| -5.54314540 | 0.51439919 | 3.92093171 | h | 1.000 | 0 |
| -7.57566089 | 0.04444103 | -0.25093403 | h | 1.000 | 0 |
| -5.02176155 | -0.43406537 | -4.12074697 | h | 1.000 | 0 |
| -0.35153974 | -0.44260887 | -3.84580095 | h | 1.000 | 0 |

(*E*)-Benzylidene(methyl)oxonium Product:

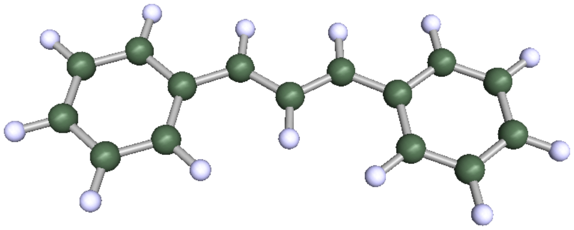


Total Energy = -425.07146073614 hartree
Enthalpy Correction = 0.200928 hartree
Entropy = 0.000152 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.48641899 | 1.70116123 | 1.58958452 | c | 6.000 | 0 |
| -3.94022649 | 0.76722526 | -0.84369488 | o | 8.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.16444356 | -1.23502028 | -0.82412508 | c | 6.000 | 0 |
| -2.12771623 | -2.35058861 | -3.46004075 | c | 6.000 | 0 |
| 0.43444409 | -0.36647609 | -0.01737945 | c | 6.000 | 0 |
| 1.86670970 | -1.81044677 | 1.64372019 | c | 6.000 | 0 |
| 4.28872438 | -1.06067509 | 2.32548207 | c | 6.000 | 0 |
| 5.29475892 | 1.16050977 | 1.35959322 | c | 6.000 | 0 |
| 3.86686212 | 2.62381491 | -0.28988250 | c | 6.000 | 0 |
| 1.45532173 | 1.86083855 | -0.97633714 | c | 6.000 | 0 |
| -2.81317719 | 2.53035510 | 2.48497817 | h | 1.000 | 0 |
| -5.92645033 | 3.15889313 | 1.37999137 | h | 1.000 | 0 |
| -5.21535060 | 0.19644168 | 2.81631780 | h | 1.000 | 0 |
| -2.80589848 | -2.68257329 | 0.52262931 | h | 1.000 | 0 |
| -1.50815080 | -0.93167909 | -4.82625763 | h | 1.000 | 0 |
| -0.82334934 | -3.94593066 | -3.54151361 | h | 1.000 | 0 |
| -4.01226011 | -3.00639397 | -3.98502081 | h | 1.000 | 0 |
| 1.07609477 | -3.53850269 | 2.41695881 | h | 1.000 | 0 |
| 5.38438295 | -2.20621578 | 3.62412966 | h | 1.000 | 0 |
| 7.17987109 | 1.75687352 | 1.89639122 | h | 1.000 | 0 |
| 4.63809948 | 4.36672054 | -1.04288365 | h | 1.000 | 0 |
| 0.33817287 | 3.01166863 | -2.25264084 | h | 1.000 | 0 |

(*E*)-1,3-Diphenylallylium (MAA* = 357.9 kJ/mol, E = 2.7):



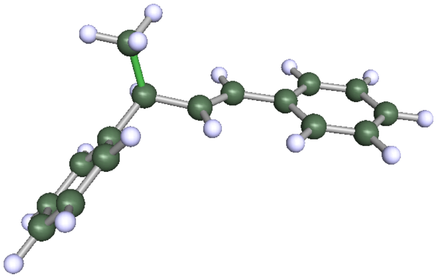
Total Energy = -578.76598352242 hartree
Enthalpy Correction = 0.248473 hartree
Entropy = 0.000173 hartree/K
LUMO Energy = -0.1481 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.41078833 | 3.32784802 | 0.00000000 | c | 6.000 | 0 |
| -0.81346329 | 2.65737665 | 0.00000000 | c | 6.000 | 0 |
| 0.18689685 | 0.24971071 | 0.00000000 | c | 6.000 | 0 |
| 2.77876380 | -0.02931791 | 0.00000000 | c | 6.000 | 0 |
| 4.15639104 | -2.33128029 | 0.00000000 | c | 6.000 | 0 |
| 6.81289259 | -2.19641960 | 0.00000000 | c | 6.000 | 0 |
| 8.24533950 | -4.37377872 | 0.00000000 | c | 6.000 | 0 |
| 7.04752153 | -6.71326225 | 0.00000000 | c | 6.000 | 0 |
| 4.41700025 | -6.88171083 | 0.00000000 | c | 6.000 | 0 |
| 2.97481424 | -4.71704129 | 0.00000000 | c | 6.000 | 0 |
| -5.36568969 | 1.52002903 | 0.00000000 | c | 6.000 | 0 |
| -7.84963529 | 2.29189081 | 0.00000000 | c | 6.000 | 0 |
| -8.43140786 | 4.86298566 | 0.00000000 | c | 6.000 | 0 |
| -6.52580882 | 6.67334617 | 0.00000000 | c | 6.000 | 0 |
| -4.03238619 | 5.91441924 | 0.00000000 | c | 6.000 | 0 |
| 0.52170872 | 4.21944019 | 0.00000000 | h | 1.000 | 0 |
| -1.03779449 | -1.38877973 | 0.00000000 | h | 1.000 | 0 |
| 3.89971682 | 1.69306186 | 0.00000000 | h | 1.000 | 0 |
| 7.71555567 | -0.35711062 | 0.00000000 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 10.28865293 | -4.26373627 | 0.00000000 | h | 1.000 | 0 |
| 8.16919933 | -8.42695844 | 0.00000000 | h | 1.000 | 0 |
| 3.51129044 | -8.71696985 | 0.00000000 | h | 1.000 | 0 |
| 0.93391102 | -4.85919779 | 0.00000000 | h | 1.000 | 0 |
| -4.92548497 | -0.47801887 | 0.00000000 | h | 1.000 | 0 |
| -9.35415407 | 0.90463624 | 0.00000000 | h | 1.000 | 0 |
| -10.39218620 | 5.45449275 | 0.00000000 | h | 1.000 | 0 |
| -6.99777841 | 8.66442757 | 0.00000000 | h | 1.000 | 0 |
| -2.52307713 | 7.29991756 | 0.00000000 | h | 1.000 | 0 |

(*E*)-1,3-Diphenylallylium Product:

The $CH_3$-CH-CH-C Torsion Angle was constrained to 270°.

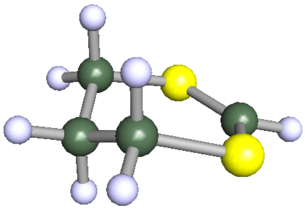


Total Energy = -618.83420375687 hartree
Enthalpy Correction = 0.287549 hartree
Entropy = 0.00019 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.67856178 | -4.62911266 | -0.73327660 | c | 6.000 | 0 |
| -2.47808052 | -2.48569935 | 1.20551286 | c | 6.000 | 0 |
| -4.25032312 | -0.33077951 | 0.60672923 | c | 6.000 | 0 |
| -4.07894179 | 0.98126669 | -1.67194525 | c | 6.000 | 0 |
| -5.70682696 | 2.96512462 | -2.20610107 | c | 6.000 | 0 |
| -7.54187470 | 3.67388353 | -0.46620605 | c | 6.000 | 0 |
| -7.73043216 | 2.38209655 | 1.80803134 | c | 6.000 | 0 |
| -6.09328589 | 0.39800818 | 2.33461275 | c | 6.000 | 0 |
| 0.20591799 | -1.59160038 | 1.42430607 | c | 6.000 | 0 |
| 1.87400548 | -2.55400900 | 3.04831608 | c | 6.000 | 0 |
| 4.54342686 | -1.87366780 | 3.28898660 | c | 6.000 | 0 |
| 6.00731154 | -3.10182318 | 5.11151204 | c | 6.000 | 0 |
| 8.54793595 | -2.53370136 | 5.42348333 | c | 6.000 | 0 |
| 9.68189217 | -0.71499354 | 3.91357631 | c | 6.000 | 0 |
| 8.24900923 | 0.52549968 | 2.09089090 | c | 6.000 | 0 |
| 5.71562388 | -0.04497574 | 1.77997495 | c | 6.000 | 0 |
| -2.04898390 | -4.01068627 | -2.60035754 | h | 1.000 | 0 |
| -1.49724622 | -6.21762572 | -0.15383729 | h | 1.000 | 0 |
| -4.63284692 | -5.27662170 | -0.89307953 | h | 1.000 | 0 |
| -3.03767573 | -3.26281409 | 3.03941505 | h | 1.000 | 0 |
| -2.65847500 | 0.45091421 | -3.05244575 | h | 1.000 | 0 |
| -5.54382937 | 3.96289890 | -3.98868592 | h | 1.000 | 0 |
| -8.81491512 | 5.22399092 | -0.88293131 | h | 1.000 | 0 |
| -9.15406953 | 2.91879703 | 3.18092766 | h | 1.000 | 0 |
| -6.24739652 | -0.60315674 | 4.11824771 | h | 1.000 | 0 |
| 0.79232845 | -0.16300766 | 0.06760542 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 1.22651205 | -3.99574466 | 4.36713782 | h | 1.000 | 0 |
| 5.12853044 | -4.52466154 | 6.29887673 | h | 1.000 | 0 |
| 9.64193361 | -3.51469587 | 6.85154211 | h | 1.000 | 0 |
| 11.66582863 | -0.26292429 | 4.14984133 | h | 1.000 | 0 |
| 9.11875139 | 1.95002098 | 0.90200382 | h | 1.000 | 0 |
| 4.63833633 | 0.94601480 | 0.34718611 | h | 1.000 | 0 |

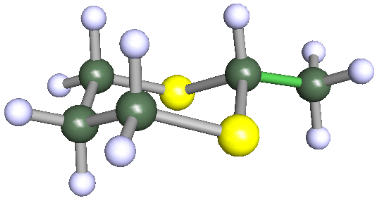
1,3-Dithian-2-ylium (MAA* = 357.6 kJ/mol, E = -2.14):



Total Energy = -952.47823997149 hartree
Enthalpy Correction = 0.1125 hartree
Entropy = 0.000123 hartree/K
LUMO Energy = -0. 1120 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.61259874 | -0.84836935 | -0.51073779 | c | 6.000 | 0 |
| 1.71177880 | -3.30325441 | -0.82650210 | s | 16.000 | 0 |
| -1.39142141 | -2.15397081 | -0.01276003 | c | 6.000 | 0 |
| -1.79641094 | 0.61164049 | -0.60898730 | c | 6.000 | 0 |
| -0.18987188 | 2.36195773 | 0.97878339 | c | 6.000 | 0 |
| 3.15193774 | 2.11242970 | 0.36141945 | s | 16.000 | 0 |
| 5.56616328 | -1.25976518 | -1.00491363 | h | 1.000 | 0 |
| -2.65065035 | -3.35427191 | -1.11774326 | h | 1.000 | 0 |
| -1.68494821 | -2.57321277 | 1.98408488 | h | 1.000 | 0 |
| -3.77185490 | 1.04632853 | -0.19616497 | h | 1.000 | 0 |
| -1.49813259 | 0.97357550 | -2.61801171 | h | 1.000 | 0 |
| -0.60465222 | 4.33931375 | 0.57265302 | h | 1.000 | 0 |
| -0.45453666 | 2.04759888 | 2.99887987 | h | 1.000 | 0 |

1,3-Dithian-2-ylium Product:

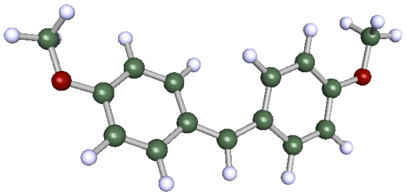


Total Energy = -992.54819860867 hartree
Enthalpy Correction = 0.152552 hartree
Entropy = 0.000137 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.07441534 | -0.44133071 | -0.62269262 | c | 6.000 | 0 |
| 2.33497399 | -0.04263591 | 0.10173413 | c | 6.000 | 0 |
| 0.99326136 | 2.37642270 | -1.90328757 | s | 16.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -2.17439988 | 2.50359913 | -0.63431937 | c | 6.000 | 0 |
| -3.59058550 | 0.01513434 | -0.77183023 | c | 6.000 | 0 |
| -2.43993767 | -2.04032636 | 0.86121112 | c | 6.000 | 0 |
| 0.67835803 | -3.02212507 | -0.12482414 | s | 16.000 | 0 |
| 6.12422723 | 1.32462312 | -0.43169051 | h | 1.000 | 0 |
| 5.23259490 | -1.09146795 | -2.57527450 | h | 1.000 | 0 |
| 5.93730569 | -1.85253535 | 0.61107216 | h | 1.000 | 0 |
| 2.19140874 | 0.60961267 | 2.05668650 | h | 1.000 | 0 |
| -3.13132310 | 3.95273809 | -1.74684212 | h | 1.000 | 0 |
| -2.07371294 | 3.17830752 | 1.31739003 | h | 1.000 | 0 |
| -3.70579537 | -0.62377621 | -2.73342643 | h | 1.000 | 0 |
| -5.52516542 | 0.34546122 | -0.11117850 | h | 1.000 | 0 |
| -3.58062604 | -3.75687012 | 0.78872268 | h | 1.000 | 0 |
| -2.34499938 | -1.43483110 | 2.83558328 | h | 1.000 | 0 |

Bis(4-methoxyphenyl)methylium (MAA* = 351.9 kJ/mol, E = 0):

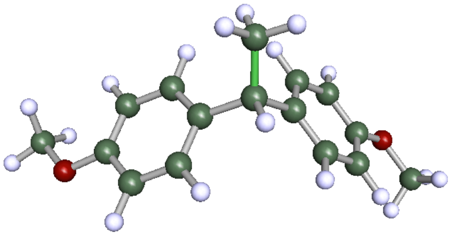


Total Energy = -730.32963714660 hartree
Enthalpy Correction = 0.282807 hartree
Entropy = 0.000193 hartree/K
LUMO Energy = -0.1316 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 10.45333570 | 2.17588733 | 1.64329526 | c | 6.000 | 0 |
| 9.74488459 | 0.01642884 | 0.19142664 | o | 8.000 | 0 |
| 7.32819136 | -0.57213826 | -0.02177400 | c | 6.000 | 0 |
| 6.77862520 | -2.72670852 | -1.47712555 | c | 6.000 | 0 |
| 4.32885231 | -3.47011112 | -1.78048123 | c | 6.000 | 0 |
| 2.30378507 | -2.06519060 | -0.72309201 | c | 6.000 | 0 |
| -0.15668900 | -2.91846641 | -1.21879750 | c | 6.000 | 0 |
| -2.50761942 | -1.73426150 | -0.90676176 | c | 6.000 | 0 |
| -4.69369253 | -3.28231875 | -1.04170447 | c | 6.000 | 0 |
| -7.05188096 | -2.30705295 | -0.67668341 | c | 6.000 | 0 |
| -7.34385238 | 0.29719529 | -0.23506982 | c | 6.000 | 0 |
| -9.68697713 | 1.09573307 | 0.08715197 | o | 8.000 | 0 |
| -10.13700445 | 3.71577020 | 0.54242648 | c | 6.000 | 0 |
| -5.22066983 | 1.89549902 | -0.21348018 | c | 6.000 | 0 |
| -2.85948763 | 0.88948539 | -0.54008104 | c | 6.000 | 0 |
| 2.91233701 | 0.04604849 | 0.79847045 | c | 6.000 | 0 |
| 5.36703921 | 0.78392128 | 1.15215555 | c | 6.000 | 0 |
| 9.60172365 | 3.88400750 | 0.86272023 | h | 1.000 | 0 |
| 9.89623419 | 1.93651420 | 3.61454987 | h | 1.000 | 0 |
| 12.49866281 | 2.28703514 | 1.50483103 | h | 1.000 | 0 |
| 8.32525181 | -3.76907170 | -2.31842664 | h | 1.000 | 0 |
| 3.89942834 | -5.13523217 | -2.89347743 | h | 1.000 | 0 |
| -0.25880958 | -4.82570352 | -1.97897670 | h | 1.000 | 0 |
| -4.46288212 | -5.28727396 | -1.39196668 | h | 1.000 | 0 |
| -8.72015264 | -3.49006957 | -0.73662420 | h | 1.000 | 0 |
| -9.16706257 | 4.32984230 | 2.25580621 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -9.52391375 | 4.84569121 | -1.07047392 | h | 1.000 | 0 |
| -12.16777331 | 3.89256922 | 0.78654419 | h | 1.000 | 0 |
| -5.43648458 | 3.91393169 | 0.01216683 | h | 1.000 | 0 |
| -1.26361823 | 2.16105911 | -0.63091612 | h | 1.000 | 0 |
| 1.44131651 | 1.04248188 | 1.80639855 | h | 1.000 | 0 |
| 5.77890236 | 2.37449786 | 2.36520254 | h | 1.000 | 0 |

Bis(4-methoxyphenyl)methylium Product:

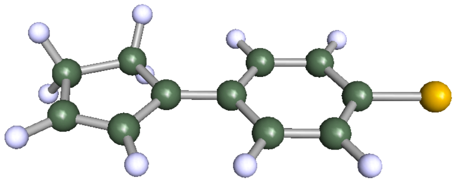


Total Energy = -770.3966298367 hartree
Enthalpy Correction = 0.322361 hartree
Entropy = 0.000208 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.74813976 | -5.48267099 | -1.54754895 | c | 6.000 | 0 |
| -0.11284164 | -2.72281203 | -2.08523399 | c | 6.000 | 0 |
| -2.32758578 | -0.96654347 | -1.62928255 | c | 6.000 | 0 |
| -3.78963436 | -1.08127293 | 0.54816084 | c | 6.000 | 0 |
| -5.76780966 | 0.59311146 | 0.97943912 | c | 6.000 | 0 |
| -6.32118556 | 2.44228943 | -0.80643625 | c | 6.000 | 0 |
| -8.20447528 | 4.15961948 | -0.56825024 | o | 8.000 | 0 |
| -9.69826385 | 4.06550110 | 1.64749731 | c | 6.000 | 0 |
| -4.88215272 | 2.57970558 | -3.00798074 | c | 6.000 | 0 |
| -2.92082034 | 0.89656078 | -3.39630238 | c | 6.000 | 0 |
| 2.19934115 | -1.82602061 | -0.65518509 | c | 6.000 | 0 |
| 2.49725449 | -2.24336139 | 1.93232893 | c | 6.000 | 0 |
| 4.58640396 | -1.35519226 | 3.22181626 | c | 6.000 | 0 |
| 6.45964173 | -0.00690725 | 1.94808981 | c | 6.000 | 0 |
| 8.44018221 | 0.79147290 | 3.35900109 | o | 8.000 | 0 |
| 10.36065751 | 2.18452242 | 2.12529883 | c | 6.000 | 0 |
| 6.20394712 | 0.42643508 | -0.62988208 | c | 6.000 | 0 |
| 4.08513972 | -0.48701730 | -1.89061017 | c | 6.000 | 0 |
| -2.35803430 | -6.08509632 | -2.69032811 | h | 1.000 | 0 |
| -1.23234222 | -5.79650429 | 0.43341929 | h | 1.000 | 0 |
| 0.86389156 | -6.69048074 | -1.99828616 | h | 1.000 | 0 |
| 0.34926128 | -2.57102681 | -4.09514464 | h | 1.000 | 0 |
| -3.40419310 | -2.50263249 | 1.97252782 | h | 1.000 | 0 |
| -6.85625440 | 0.43280785 | 2.70250038 | h | 1.000 | 0 |
| -11.07644954 | 5.58187172 | 1.47424933 | h | 1.000 | 0 |
| -8.54954579 | 4.37224943 | 3.33889342 | h | 1.000 | 0 |
| -10.68521923 | 2.25619029 | 1.80942565 | h | 1.000 | 0 |
| -5.32843550 | 4.01481803 | -4.40053409 | h | 1.000 | 0 |
| -1.82028177 | 1.03210719 | -5.12202570 | h | 1.000 | 0 |
| 1.07488398 | -3.28334174 | 2.97811486 | h | 1.000 | 0 |
| 4.80109907 | -1.69343395 | 5.23134144 | h | 1.000 | 0 |
| 11.74795324 | 2.65110573 | 3.56942340 | h | 1.000 | 0 |
| 11.26459152 | 1.06345589 | 0.64180298 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 9.61040364 | 3.92756613 | 1.30449956 | h | 1.000 | 0 |
| 7.62692005 | 1.45696883 | -1.67521796 | h | 1.000 | 0 |
| 3.91209255 | -0.13404477 | -3.90412346 | h | 1.000 | 0 |

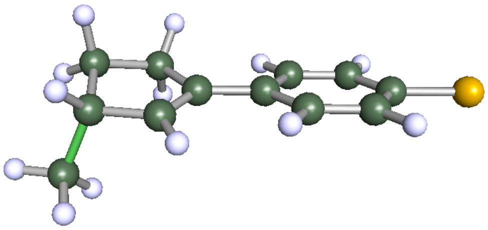
1-(4-Chlorophenyl)cyclopent-2-en-1-ylium (MAA* = 351.8 kJ/mol, E = 3.2):



Total Energy = -884.73051467320 hartree
Enthalpy Correction = 0.189128 hartree
Entropy = 0.000157 hartree/K
LUMO Energy = -0.1384 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 9.58899744 | 0.58906564 | -0.79208610 | cl | 17.000 | 0 |
| 6.37165814 | 0.32040729 | -0.53378790 | c | 6.000 | 0 |
| 5.27371789 | -2.06718896 | -0.64415997 | c | 6.000 | 0 |
| 2.69148595 | -2.27367577 | -0.43518816 | c | 6.000 | 0 |
| 4.92706091 | 2.49701850 | -0.21931392 | c | 6.000 | 0 |
| 2.34668351 | 2.27111218 | -0.01282288 | c | 6.000 | 0 |
| 1.17542432 | -0.11266253 | -0.11545118 | c | 6.000 | 0 |
| -1.49822381 | -0.31930958 | 0.10339040 | c | 6.000 | 0 |
| -3.23346956 | 1.85855893 | 0.43901681 | c | 6.000 | 0 |
| -5.86178948 | 0.70054127 | 0.57782719 | c | 6.000 | 0 |
| -5.40639276 | -2.02156619 | 0.30939580 | c | 6.000 | 0 |
| -2.90568314 | -2.57638570 | 0.03982347 | c | 6.000 | 0 |
| 6.44115785 | -3.72737219 | -0.89044789 | h | 1.000 | 0 |
| 1.84047861 | -4.13052181 | -0.52129134 | h | 1.000 | 0 |
| 5.82984103 | 4.32977391 | -0.14003069 | h | 1.000 | 0 |
| 1.22022368 | 3.96084584 | 0.23239272 | h | 1.000 | 0 |
| -3.03172261 | 3.18721584 | -1.13295095 | h | 1.000 | 0 |
| -2.74041485 | 2.91735293 | 2.14579430 | h | 1.000 | 0 |
| -6.84277065 | 1.09861345 | 2.35863110 | h | 1.000 | 0 |
| -7.13585574 | 1.37209065 | -0.91121297 | h | 1.000 | 0 |
| -6.90543184 | -3.41720405 | 0.32684370 | h | 1.000 | 0 |
| -2.14497488 | -4.45670963 | -0.18437153 | h | 1.000 | 0 |

1-(4-Chlorophenyl)cyclopent-2-en-1-ylium Product:

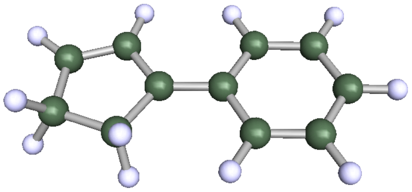


Total Energy = -924.79962187168 hartree

Enthalpy Correction = 0.230227 hartree
Entropy = 0.00017 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -10.77192264 | -0.62095034 | 0.72255638 | cl | 17.000 | 0 |
| -7.51671313 | -0.46475366 | 0.37895692 | c | 6.000 | 0 |
| -6.07849386 | -2.63219526 | 0.72451671 | c | 6.000 | 0 |
| -3.48566486 | -2.49965117 | 0.44408927 | c | 6.000 | 0 |
| -6.39052451 | 1.81064791 | -0.24473685 | c | 6.000 | 0 |
| -3.78621430 | 1.90945350 | -0.52366935 | c | 6.000 | 0 |
| -2.27796232 | -0.22942162 | -0.17813067 | c | 6.000 | 0 |
| 0.46669932 | -0.06759125 | -0.46726560 | c | 6.000 | 0 |
| 2.17214782 | -1.82329776 | 0.16924324 | c | 6.000 | 0 |
| 4.84187202 | -0.96211212 | -0.23271924 | c | 6.000 | 0 |
| 6.14753104 | -0.39040979 | 2.27763581 | c | 6.000 | 0 |
| 4.48734016 | 1.38924161 | -1.90925536 | c | 6.000 | 0 |
| 1.76327390 | 2.27016518 | -1.45904253 | c | 6.000 | 0 |
| -6.98412785 | -4.40479701 | 1.19964770 | h | 1.000 | 0 |
| -2.38331848 | -4.20607970 | 0.69920753 | h | 1.000 | 0 |
| -7.52935957 | 3.48936060 | -0.51415872 | h | 1.000 | 0 |
| -2.92044691 | 3.69916852 | -1.01062389 | h | 1.000 | 0 |
| 1.73790704 | -3.63415977 | 1.02668969 | h | 1.000 | 0 |
| 5.94999317 | -2.40945161 | -1.21442233 | h | 1.000 | 0 |
| 5.15126737 | 1.11082691 | 3.29058554 | h | 1.000 | 0 |
| 6.18906941 | -2.05954111 | 3.49384433 | h | 1.000 | 0 |
| 8.09514921 | 0.22368304 | 1.96524745 | h | 1.000 | 0 |
| 5.88102941 | 2.85591905 | -1.50478491 | h | 1.000 | 0 |
| 4.70742399 | 0.85564657 | -3.89211110 | h | 1.000 | 0 |
| 1.65210754 | 3.79581144 | -0.05965736 | h | 1.000 | 0 |
| 0.88193701 | 2.99448782 | -3.18164267 | h | 1.000 | 0 |

1-Phenylcyclopent-2-en-1-ylium (MAA* = 351.3 kJ/mol, E = 2.89):

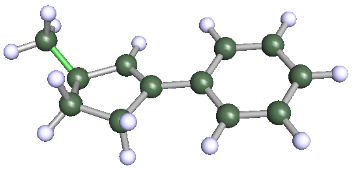


Total Energy = -425.26145697689 hartree
Enthalpy Correction = 0.197648 hartree
Entropy = 0.000146 hartree/K
LUMO Energy = -0.1366 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.22865874 | 0.09123348 | -0.15930672 | c | 6.000 | 0 |
| -1.42796239 | 0.33122618 | 0.21622123 | c | 6.000 | 0 |
| -2.75821605 | 2.60563076 | 0.58990183 | c | 6.000 | 0 |
| -5.26310456 | 2.08289135 | 0.88219381 | c | 6.000 | 0 |
| -5.80167049 | -0.63264593 | 0.72140561 | c | 6.000 | 0 |
| -3.22345180 | -1.82276514 | 0.27314256 | c | 6.000 | 0 |
| 2.31656679 | -2.31003555 | -0.50381293 | c | 6.000 | 0 |
| 4.88426868 | -2.55079674 | -0.86409511 | c | 6.000 | 0 |
| 6.40763020 | -0.40573196 | -0.88721509 | c | 6.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 5.36417508 | 1.98476907 | -0.55087234 | c | 6.000 | 0 |
| 2.79734672 | 2.23898331 | -0.18938961 | c | 6.000 | 0 |
| -1.94215094 | 4.47511664 | 0.64165320 | h | 1.000 | 0 |
| -6.71062040 | 3.49717553 | 1.19925153 | h | 1.000 | 0 |
| -7.15809788 | -1.01327068 | -0.79728886 | h | 1.000 | 0 |
| -6.72194517 | -1.29255076 | 2.45610135 | h | 1.000 | 0 |
| -2.69511810 | -3.15898508 | 1.76013648 | h | 1.000 | 0 |
| -3.13265365 | -2.88111546 | -1.50102823 | h | 1.000 | 0 |
| 1.13509194 | -3.98032773 | -0.48620639 | h | 1.000 | 0 |
| 5.71414677 | -4.40243725 | -1.12840381 | h | 1.000 | 0 |
| 8.42689349 | -0.59971585 | -1.17033489 | h | 1.000 | 0 |
| 6.56461264 | 3.64157295 | -0.57278989 | h | 1.000 | 0 |
| 1.99560040 | 4.10177885 | 0.07073627 | h | 1.000 | 0 |

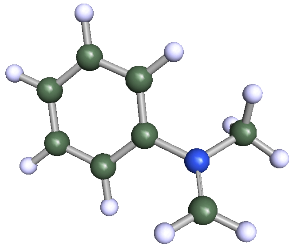
1-Phenylcyclopent-2-en-1-ylium Product:



Total Energy = -465.33000413003 hartree
Enthalpy Correction = 0.238391 hartree
Entropy = 0.000159 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 6.57779242 | -2.34025127 | 0.65247875 | c | 6.000 | 0 |
| 4.75040736 | -0.26743885 | -0.13404373 | c | 6.000 | 0 |
| 4.29466656 | 1.74611089 | 1.90917365 | c | 6.000 | 0 |
| 1.54524049 | 2.58614064 | 1.57840363 | c | 6.000 | 0 |
| 2.11953617 | -1.16353325 | -0.68965459 | c | 6.000 | 0 |
| 0.33901903 | 0.36803163 | 0.24949160 | c | 6.000 | 0 |
| -2.40190376 | 0.10835188 | -0.02333225 | c | 6.000 | 0 |
| -4.00341959 | 2.10319398 | 0.63307710 | c | 6.000 | 0 |
| -6.60574191 | 1.89495040 | 0.37012266 | c | 6.000 | 0 |
| -7.66706173 | -0.31866378 | -0.54671315 | c | 6.000 | 0 |
| -6.09879072 | -2.32701437 | -1.19697764 | c | 6.000 | 0 |
| -3.50590108 | -2.11716310 | -0.93593171 | c | 6.000 | 0 |
| 6.81086835 | -3.74601015 | -0.84305898 | h | 1.000 | 0 |
| 8.44007894 | -1.55433833 | 1.07958606 | h | 1.000 | 0 |
| 5.88973954 | -3.30992143 | 2.34405084 | h | 1.000 | 0 |
| 5.50827894 | 0.63345431 | -1.84890290 | h | 1.000 | 0 |
| 5.63868250 | 3.30764885 | 1.80883203 | h | 1.000 | 0 |
| 4.51376066 | 0.85492312 | 3.76350754 | h | 1.000 | 0 |
| 0.63019551 | 3.03745584 | 3.37540105 | h | 1.000 | 0 |
| 1.39758089 | 4.28427893 | 0.39744573 | h | 1.000 | 0 |
| 1.76183151 | -2.83191477 | -1.82637119 | h | 1.000 | 0 |
| -3.20552860 | 3.84831362 | 1.34823306 | h | 1.000 | 0 |
| -7.80618500 | 3.47286256 | 0.88804794 | h | 1.000 | 0 |
| -9.69872298 | -0.48777750 | -0.74715895 | h | 1.000 | 0 |
| -6.90862731 | -4.07181795 | -1.90372849 | h | 1.000 | 0 |
| -2.31579619 | -3.70987189 | -1.42860616 | h | 1.000 | 0 |

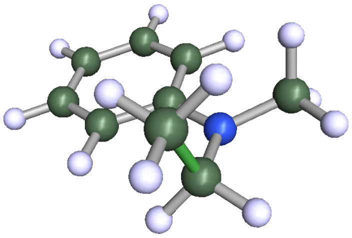
*N*-Methyl-*N*-methylenebenzenaminium (MAA* = 333.6 kJ/mol, E = -5.17):



Total Energy = -365.15118495198 hartree
Enthalpy Correction = 0.17401 hartree
Entropy = 0.000137 hartree/K
LUMO Energy = -0.0941 hartree

```
                  atomic coordinates              atom    charge  isotop
 -3.56176244    2.87927700   -0.04354779    c       6.000     0
 -2.56804010    0.78560802    0.60401550    n       7.000     0
 -4.00687200   -1.10731416    2.01311490    c       6.000     0
 -0.00963303    0.17583815   -0.06259712    c       6.000     0
  0.84803302    0.77339729   -2.46689699    c       6.000     0
  3.32216277    0.20896255   -3.10766761    c       6.000     0
  4.90427674   -0.94690991   -1.36356989    c       6.000     0
  4.00932993   -1.55189813    1.02729239    c       6.000     0
  1.53668649   -1.00556840    1.69305853    c       6.000     0
 -5.52603719    3.23520846    0.39986127    h       1.000     0
 -2.43080877    4.27674068   -1.01809256    h       1.000     0
 -5.95175441   -0.47356850    2.17902057    h       1.000     0
 -3.89864544   -2.89487584    1.00212941    h       1.000     0
 -3.18331238   -1.31722072    3.88652091    h       1.000     0
 -0.41682963    1.61118631   -3.84152549    h       1.000     0
  4.00134311    0.65259397   -4.98655127    h       1.000     0
  6.83600343   -1.39279452   -1.87430922    h       1.000     0
  5.23995686   -2.45214535    2.39250463    h       1.000     0
  0.85590304   -1.45651688    3.56723984    h       1.000     0
```

*N*-Methyl-*N*-methylenebenzenaminium Product:

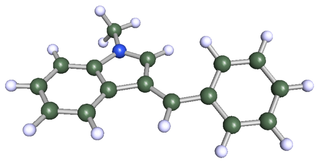


Total Energy = -405.21125966199 hartree
Enthalpy Correction = 0.213621 hartree
Entropy = 0.000152 hartree/K

```
                  atomic coordinates              atom    charge  isotop
  2.99697006   -2.84127709   -1.21640520    c       6.000     0
  1.72000151   -1.14415694    0.49439573    n       7.000     0
 -0.79471791   -0.62656701    0.11653296    c       6.000     0
```

| | | | | | |
|---|---|---|---|---|---|
| -2.22707107 | -2.01274677 | -1.64680056 | c | 6.000 | 0 |
| -4.78606551 | -1.55733217 | -1.96707625 | c | 6.000 | 0 |
| -6.02301478 | 0.29484143 | -0.58157075 | c | 6.000 | 0 |
| -4.62200537 | 1.70025399 | 1.13875748 | c | 6.000 | 0 |
| -2.06513481 | 1.27133245 | 1.48490397 | c | 6.000 | 0 |
| 3.29851104 | 0.56806827 | 1.93591825 | c | 6.000 | 0 |
| 4.06727844 | 2.93914027 | 0.50395480 | c | 6.000 | 0 |
| 2.15070995 | -4.72595529 | -1.17242914 | h | 1.000 | 0 |
| 4.95961209 | -3.02127659 | -0.62543626 | h | 1.000 | 0 |
| 2.96938967 | -2.17460146 | -3.18122200 | h | 1.000 | 0 |
| -1.33802039 | -3.46433403 | -2.77752432 | h | 1.000 | 0 |
| -5.82121889 | -2.67416708 | -3.34014190 | h | 1.000 | 0 |
| -8.02252100 | 0.64725575 | -0.84520321 | h | 1.000 | 0 |
| -5.52897575 | 3.17752256 | 2.23378020 | h | 1.000 | 0 |
| -1.05366800 | 2.43123347 | 2.82944923 | h | 1.000 | 0 |
| 4.98167144 | -0.48546592 | 2.49894989 | h | 1.000 | 0 |
| 2.33316481 | 1.06898693 | 3.69008236 | h | 1.000 | 0 |
| 2.41276804 | 4.03560529 | -0.06405312 | h | 1.000 | 0 |
| 5.25906981 | 4.13898231 | 1.68819995 | h | 1.000 | 0 |
| 5.13326663 | 2.45465761 | -1.19706211 | h | 1.000 | 0 |

(Z)-3-Benzylidene-1-methyl-3H-indol-1-ium (MAA* = 332.5 kJ/mol, E = -1.8):



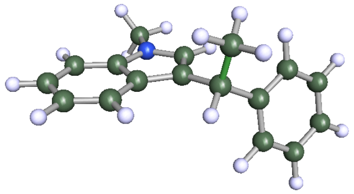
Total Energy = -672.19849447361 hartree
Enthalpy Correction = 0.273333 hartree
Entropy = 0.000182 hartree/K
LUMO Energy = -0.1254 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.92612957 | 4.58562346 | -0.00386269 | c | 6.000 | 0 |
| -3.51610118 | 2.24845637 | 0.12756749 | n | 7.000 | 0 |
| -1.04929923 | 2.03511391 | 0.08237089 | c | 6.000 | 0 |
| -0.34226114 | -0.57073631 | 0.17368766 | c | 6.000 | 0 |
| -2.72231460 | -1.95512854 | 0.25890562 | c | 6.000 | 0 |
| -4.64974507 | -0.14939530 | 0.25982721 | c | 6.000 | 0 |
| -7.18625272 | -0.75389496 | 0.35658328 | c | 6.000 | 0 |
| -7.77459602 | -3.30940272 | 0.45492328 | c | 6.000 | 0 |
| -5.88437172 | -5.14762183 | 0.45872876 | c | 6.000 | 0 |
| -3.34359002 | -4.49806594 | 0.36958511 | c | 6.000 | 0 |
| 2.02335599 | -1.58834731 | 0.06563634 | c | 6.000 | 0 |
| 4.43680127 | -0.36219834 | 0.18355729 | c | 6.000 | 0 |
| 6.51398575 | -1.66031564 | -0.83672300 | c | 6.000 | 0 |
| 8.88169340 | -0.56083222 | -0.86989488 | c | 6.000 | 0 |
| 9.22711235 | 1.82234516 | 0.17684356 | c | 6.000 | 0 |
| 7.20378187 | 3.09499010 | 1.27535286 | c | 6.000 | 0 |
| 4.82842210 | 2.01888550 | 1.28634972 | c | 6.000 | 0 |
| -6.08192384 | 4.77680452 | 1.69062475 | h | 1.000 | 0 |
| -6.14315246 | 4.55415495 | -1.66568483 | h | 1.000 | 0 |
| -3.60725548 | 6.15428485 | -0.12976408 | h | 1.000 | 0 |
| 0.12808832 | 3.68662930 | -0.12184984 | h | 1.000 | 0 |
| -8.64883339 | 0.67699713 | 0.35815090 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -9.73807701 | -3.88202000 | 0.53275862 | h | 1.000 | 0 |
| -6.41220721 | -7.12411244 | 0.53548361 | h | 1.000 | 0 |
| -1.89859224 | -5.94920237 | 0.38472230 | h | 1.000 | 0 |
| 2.10224672 | -3.62738562 | -0.18088412 | h | 1.000 | 0 |
| 6.23045976 | -3.52480849 | -1.63771549 | h | 1.000 | 0 |
| 10.46519071 | -1.56489101 | -1.69117492 | h | 1.000 | 0 |
| 11.08809443 | 2.67766984 | 0.17786815 | h | 1.000 | 0 |
| 7.49724933 | 4.92062610 | 2.15354063 | h | 1.000 | 0 |
| 3.29822091 | 2.97577786 | 2.24758784 | h | 1.000 | 0 |

(Z)-3-Benzylidene-1-methyl-3H-indol-1-ium Product:

The $CH_3$-C-C-C Torsion Angle was constrained to 90°.

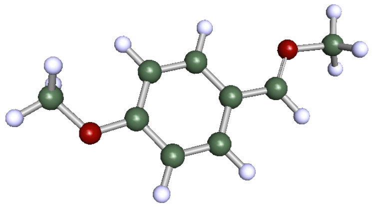


Total Energy = -712.25760865963 hartree
Enthalpy Correction = 0.312978 hartree
Entropy = 0.000199 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.94047656 | -3.07972137 | -4.85709755 | c | 6.000 | 0 |
| 1.54061821 | -2.12326576 | -2.19777993 | c | 6.000 | 0 |
| 3.09711346 | -3.96229312 | -0.66097538 | c | 6.000 | 0 |
| 2.75792111 | -6.56631722 | -0.82087334 | c | 6.000 | 0 |
| 4.15741657 | -8.20219889 | 0.68227862 | c | 6.000 | 0 |
| 5.93060199 | -7.25998777 | 2.36797837 | c | 6.000 | 0 |
| 6.29486896 | -4.66511513 | 2.53657485 | c | 6.000 | 0 |
| 4.88820258 | -3.04147650 | 1.03568313 | c | 6.000 | 0 |
| -0.82921742 | -1.39279849 | -0.81579397 | c | 6.000 | 0 |
| -2.32336751 | -2.88520495 | 0.68040192 | c | 6.000 | 0 |
| -4.42034162 | -1.58077155 | 1.47225939 | n | 7.000 | 0 |
| -6.36370064 | -2.53394278 | 3.12161784 | c | 6.000 | 0 |
| -4.32404241 | 0.80609275 | 0.49065103 | c | 6.000 | 0 |
| -2.08919550 | 0.99710141 | -0.97540391 | c | 6.000 | 0 |
| -1.55536286 | 3.27695015 | -2.20101429 | c | 6.000 | 0 |
| -3.21624736 | 5.27638640 | -1.93706729 | c | 6.000 | 0 |
| -5.41365057 | 5.04937477 | -0.46782908 | c | 6.000 | 0 |
| -5.99750672 | 2.81905477 | 0.76503535 | c | 6.000 | 0 |
| -0.27996411 | -4.74177984 | -4.79769709 | h | 1.000 | 0 |
| 2.66828943 | -3.56899932 | -5.87727621 | h | 1.000 | 0 |
| -0.05284284 | -1.61827612 | -5.92293095 | h | 1.000 | 0 |
| 2.68069606 | -0.40643167 | -2.39543861 | h | 1.000 | 0 |
| 1.38834518 | -7.34343898 | -2.13057644 | h | 1.000 | 0 |
| 3.86109148 | -10.22427417 | 0.52803068 | h | 1.000 | 0 |
| 7.02808811 | -8.53631710 | 3.53598227 | h | 1.000 | 0 |
| 7.68388213 | -3.90455424 | 3.83763438 | h | 1.000 | 0 |
| 5.18071528 | -1.01559666 | 1.17822456 | h | 1.000 | 0 |
| -2.04655054 | -4.81657520 | 1.27925960 | h | 1.000 | 0 |
| -5.96386851 | -4.50522836 | 3.55088935 | h | 1.000 | 0 |
| -8.21427366 | -2.41759865 | 2.21431333 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -6.42103746 | -1.46790275 | 4.88923105 | h | 1.000 | 0 |
| 0.13630824 | 3.47970847 | -3.34201061 | h | 1.000 | 0 |
| -2.82179612 | 7.05335214 | -2.87781194 | h | 1.000 | 0 |
| -6.67766721 | 6.65271478 | -0.29618304 | h | 1.000 | 0 |
| -7.69587720 | 2.65244965 | 1.89862044 | h | 1.000 | 0 |

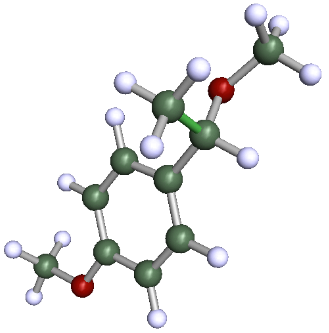
(*E*)-(4-Methoxybenzylidene)(methyl)oxonium (MAA* = 332.2 kJ/mol, E = 0.14):



Total Energy = -499.45945219773 hartree
Enthalpy Correction = 0.197016 hartree
Entropy = 0.000159 hartree/K
LUMO Energy = -0.1154hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 8.11829747 | 1.53236860 | -0.19476379 | c | 6.000 | 0 |
| 5.42797121 | 1.36361572 | 0.26804950 | o | 8.000 | 0 |
| 4.09463132 | 0.07039734 | -1.27226769 | c | 6.000 | 0 |
| 1.49362945 | -0.20705937 | -0.97268309 | c | 6.000 | 0 |
| 0.15677762 | 0.91267709 | 1.04575005 | c | 6.000 | 0 |
| -2.39578020 | 0.58576657 | 1.26418437 | c | 6.000 | 0 |
| -3.68645886 | -0.88177443 | -0.54608333 | c | 6.000 | 0 |
| -6.14208209 | -1.29810341 | -0.48376346 | o | 8.000 | 0 |
| -7.62195563 | -0.22559708 | 1.50226308 | c | 6.000 | 0 |
| -2.37377942 | -2.00631556 | -2.56686913 | c | 6.000 | 0 |
| 0.17406346 | -1.67330407 | -2.77456241 | c | 6.000 | 0 |
| 8.85961017 | 2.73026171 | 1.29468623 | h | 1.000 | 0 |
| 8.42834198 | 2.38255778 | -2.04195997 | h | 1.000 | 0 |
| 8.93240572 | -0.35373987 | -0.09165194 | h | 1.000 | 0 |
| 5.04888363 | -0.83226597 | -2.85892479 | h | 1.000 | 0 |
| 1.16309396 | 2.03653562 | 2.42848577 | h | 1.000 | 0 |
| -3.40271180 | 1.44946784 | 2.81663953 | h | 1.000 | 0 |
| -7.51317718 | 1.83276571 | 1.45264897 | h | 1.000 | 0 |
| -6.99355849 | -0.93300819 | 3.33413093 | h | 1.000 | 0 |
| -9.54911411 | -0.83339363 | 1.14078472 | h | 1.000 | 0 |
| -3.42325922 | -3.12058059 | -3.92367822 | h | 1.000 | 0 |
| 1.20417102 | -2.53127183 | -4.32341550 | h | 1.000 | 0 |

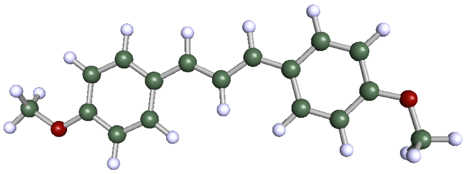
(*E*)-(4-Methoxybenzylidene)(methyl)oxonium Product:



Total Energy = -539.51909961677 hartree
Enthalpy Correction = 0.236132 hartree
Entropy = 0.000172 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -6.91246341 | -1.78023694 | 2.11350665 | c | 6.000 | 0 |
| -4.30497098 | -1.30581706 | 1.87102091 | o | 8.000 | 0 |
| -3.64263098 | -0.03623388 | -0.40247030 | c | 6.000 | 0 |
| -4.53091959 | 2.69812978 | -0.40627872 | c | 6.000 | 0 |
| -0.82358358 | -0.21539047 | -0.70333801 | c | 6.000 | 0 |
| 0.24061822 | -0.99849344 | -2.97834784 | c | 6.000 | 0 |
| 2.83296306 | -1.09831039 | -3.29883968 | c | 6.000 | 0 |
| 4.43268076 | -0.42171249 | -1.31926073 | c | 6.000 | 0 |
| 6.94258327 | -0.57773382 | -1.78626103 | o | 8.000 | 0 |
| 8.62040444 | 0.09964829 | 0.18372559 | c | 6.000 | 0 |
| 3.39987258 | 0.35218203 | 0.97452503 | c | 6.000 | 0 |
| 0.79210934 | 0.45401007 | 1.25355197 | c | 6.000 | 0 |
| -8.00686961 | -0.04405822 | 2.38287526 | h | 1.000 | 0 |
| -7.64775335 | -2.77328982 | 0.44757515 | h | 1.000 | 0 |
| -7.16178735 | -2.97811333 | 3.77120233 | h | 1.000 | 0 |
| -4.53326927 | -1.03314951 | -1.99349752 | h | 1.000 | 0 |
| -3.69421302 | 3.72044524 | 1.18092661 | h | 1.000 | 0 |
| -6.58551677 | 2.83199584 | -0.27741447 | h | 1.000 | 0 |
| -3.94483231 | 3.61973533 | -2.15701817 | h | 1.000 | 0 |
| -0.98201272 | -1.54278711 | -4.53266180 | h | 1.000 | 0 |
| 3.65200605 | -1.71013753 | -5.07416072 | h | 1.000 | 0 |
| 8.36070316 | 2.07308813 | 0.74239764 | h | 1.000 | 0 |
| 10.51733310 | -0.15276935 | -0.56846014 | h | 1.000 | 0 |
| 8.36830993 | -1.11907763 | 1.83417113 | h | 1.000 | 0 |
| 4.59852973 | 0.88020485 | 2.54400037 | h | 1.000 | 0 |
| 0.01270932 | 1.05787142 | 3.04996634 | h | 1.000 | 0 |

(*E*)-1,3-Bis(4-methoxyphenyl)allylium (MAA* = 315.5 kJ/mol, E = -1.45):

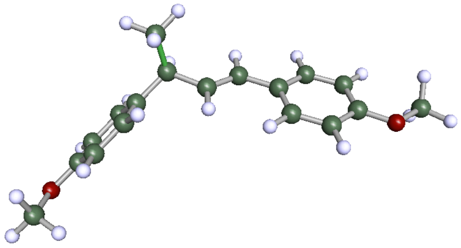


Total Energy = -807.68363941692 hartree
Enthalpy Correction = 0.319035 hartree
Entropy = 0.000209 hartree/K
LUMO Energy = -0.1320 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -11.77915526 | -3.64500082 | -2.13153169 | c | 6.000 | 0 |
| -11.23565226 | -1.37586796 | -0.78747001 | o | 8.000 | 0 |
| -8.84322125 | -0.71076265 | -0.44850891 | c | 6.000 | 0 |
| -6.77653688 | -2.10537895 | -1.33830644 | c | 6.000 | 0 |
| -4.37438488 | -1.23571093 | -0.87283873 | c | 6.000 | 0 |
| -3.93907515 | 1.01798241 | 0.47406296 | c | 6.000 | 0 |
| -1.41951695 | 1.79072641 | 0.88719585 | c | 6.000 | 0 |
| -0.61272241 | 3.92232301 | 2.15831612 | c | 6.000 | 0 |
| 1.94457920 | 4.38503352 | 2.39407658 | c | 6.000 | 0 |
| 3.10714224 | 6.44720246 | 3.62517335 | c | 6.000 | 0 |
| 1.73262971 | 8.39042866 | 4.82124578 | c | 6.000 | 0 |
| 2.93685924 | 10.35729174 | 6.00414679 | c | 6.000 | 0 |
| 5.58990795 | 10.44202478 | 6.02877591 | c | 6.000 | 0 |
| 6.91690701 | 12.26198957 | 7.12869963 | o | 8.000 | 0 |
| 5.61216118 | 14.26320177 | 8.37152555 | c | 6.000 | 0 |
| 6.99729264 | 8.52924399 | 4.84478679 | c | 6.000 | 0 |
| 5.77383714 | 6.57864631 | 3.67139737 | c | 6.000 | 0 |
| -6.05732421 | 2.39351768 | 1.35021133 | c | 6.000 | 0 |
| -8.45328012 | 1.55014793 | 0.89954951 | c | 6.000 | 0 |
| -13.82690616 | -3.79398322 | -2.16544690 | h | 1.000 | 0 |
| -10.97435020 | -5.27682365 | -1.15900338 | h | 1.000 | 0 |
| -11.05281684 | -3.53962093 | -4.05949339 | h | 1.000 | 0 |
| -7.04733127 | -3.84284492 | -2.37734787 | h | 1.000 | 0 |
| -2.76581358 | -2.30548517 | -1.55593450 | h | 1.000 | 0 |
| 0.03782696 | 0.56302396 | 0.11712597 | h | 1.000 | 0 |
| -1.97551089 | 5.21838672 | 2.96621867 | h | 1.000 | 0 |
| 3.21558925 | 3.01217758 | 1.54254091 | h | 1.000 | 0 |
| -0.31323152 | 8.35115167 | 4.82020514 | h | 1.000 | 0 |
| 1.83641961 | 11.82283697 | 6.90600281 | h | 1.000 | 0 |
| 4.43499526 | 15.30533701 | 7.03570991 | h | 1.000 | 0 |
| 7.07273961 | 15.49653650 | 9.12158217 | h | 1.000 | 0 |
| 4.45574345 | 13.53050055 | 9.91518523 | h | 1.000 | 0 |
| 9.04040487 | 8.63806066 | 4.88707263 | h | 1.000 | 0 |
| 6.85606763 | 5.09829194 | 2.75712823 | h | 1.000 | 0 |
| -5.79568996 | 4.13532012 | 2.39147897 | h | 1.000 | 0 |
| -10.08817287 | 2.58832358 | 1.56153776 | h | 1.000 | 0 |

(*E*)-1,3-Bis(4-methoxyphenyl)allylium Product:

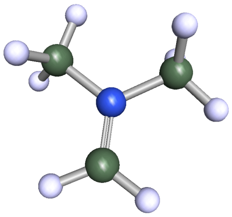
The $CH_3$-C-C-C Torsion Angle was constrained to 270°.



Total Energy = -847.73531040232 hartree
Enthalpy Correction = 0.357995 hartree
Entropy = 0.000227 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.05283840 | -5.11160773 | 3.59556154 | c | 6.000 | 0 |
| 2.31573975 | -4.35065090 | 0.81287810 | c | 6.000 | 0 |
| 4.43882935 | -2.48951409 | 0.39997860 | c | 6.000 | 0 |
| 4.45504560 | -0.13709541 | 1.56868377 | c | 6.000 | 0 |
| 6.39569029 | 1.58888083 | 1.18105668 | c | 6.000 | 0 |
| 8.39098055 | 0.96353858 | -0.41531579 | c | 6.000 | 0 |
| 10.37121832 | 2.50573116 | -0.91897388 | o | 8.000 | 0 |
| 10.40351359 | 4.90915775 | 0.25303977 | c | 6.000 | 0 |
| 8.40750692 | -1.38701339 | -1.60139514 | c | 6.000 | 0 |
| 6.45309953 | -3.07505803 | -1.19202596 | c | 6.000 | 0 |
| -0.14930367 | -3.36090499 | -0.18864606 | c | 6.000 | 0 |
| -1.91049800 | -4.80697702 | -1.26476372 | c | 6.000 | 0 |
| -4.39636559 | -4.01513629 | -2.17057984 | c | 6.000 | 0 |
| -5.33979372 | -1.55629905 | -1.88112261 | c | 6.000 | 0 |
| -7.69237164 | -0.89480788 | -2.77796121 | c | 6.000 | 0 |
| -9.20702077 | -2.67846601 | -4.00365571 | c | 6.000 | 0 |
| -11.48346301 | -1.85520463 | -4.81778745 | o | 8.000 | 0 |
| -13.07155577 | -3.61403326 | -6.06045367 | c | 6.000 | 0 |
| -8.31831627 | -5.13176659 | -4.30617508 | c | 6.000 | 0 |
| -5.94047471 | -5.76435189 | -3.39038935 | c | 6.000 | 0 |
| 0.60818087 | -6.57034809 | 3.79946079 | h | 1.000 | 0 |
| 1.50001873 | -3.49796679 | 4.76123106 | h | 1.000 | 0 |
| 3.84399859 | -5.84319386 | 4.31771821 | h | 1.000 | 0 |
| 2.78218929 | -6.06653095 | -0.24685525 | h | 1.000 | 0 |
| 2.92108588 | 0.39306794 | 2.82244021 | h | 1.000 | 0 |
| 6.33046941 | 3.39990915 | 2.12731874 | h | 1.000 | 0 |
| 12.12219039 | 5.83708244 | -0.38996486 | h | 1.000 | 0 |
| 8.76401264 | 6.03767766 | -0.30631399 | h | 1.000 | 0 |
| 10.44567272 | 4.73776416 | 2.31285083 | h | 1.000 | 0 |
| 9.96666144 | -1.86366263 | -2.84227846 | h | 1.000 | 0 |
| 6.49344419 | -4.89635197 | -2.13497970 | h | 1.000 | 0 |
| -0.50867813 | -1.36092026 | 0.12673728 | h | 1.000 | 0 |
| -1.48593321 | -6.80215066 | -1.54478917 | h | 1.000 | 0 |
| -4.21630447 | -0.13085264 | -0.93130142 | h | 1.000 | 0 |
| -8.40548551 | 1.01144723 | -2.54303551 | h | 1.000 | 0 |
| -14.78598292 | -2.59021356 | -6.55022174 | h | 1.000 | 0 |
| -12.18421820 | -4.33435986 | -7.78256508 | h | 1.000 | 0 |
| -13.54674966 | -5.19721817 | -4.81930543 | h | 1.000 | 0 |
| -9.44575160 | -6.55691032 | -5.24229698 | h | 1.000 | 0 |
| -5.26660619 | -7.68545454 | -3.63934647 | h | 1.000 | 0 |

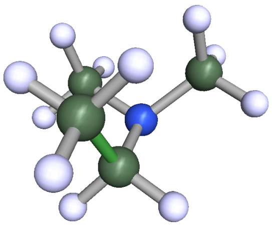
*N*-Methyl-*N*-methylenemethanaminium (MAA* = 295.0 kJ/mol, E = -6.69):



Total Energy = -173.56548862941 hartree
Enthalpy Correction = 0.116798 hartree
Entropy = 0.000107 hartree/K
LUMO Energy = -0.0804 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.49175403 | 2.33970533 | -0.09706876 | c | 6.000 | 0 |
| 0.21951911 | 0.31359820 | -0.01583132 | n | 7.000 | 0 |
| 1.38107744 | -2.15903920 | -0.32879200 | c | 6.000 | 0 |
| -2.52067213 | 0.34892239 | 0.40173238 | c | 6.000 | 0 |
| 0.53940672 | 4.13570170 | 0.14635241 | h | 1.000 | 0 |
| 3.51190936 | 2.25463559 | -0.40854570 | h | 1.000 | 0 |
| 1.00743029 | -3.26800823 | 1.36629021 | h | 1.000 | 0 |
| 3.40143936 | -1.94302192 | -0.62113296 | h | 1.000 | 0 |
| 0.50724810 | -3.08257320 | -1.94920001 | h | 1.000 | 0 |
| -3.41698366 | 1.40879927 | -1.11540733 | h | 1.000 | 0 |
| -3.21054146 | -1.58312667 | 0.40549101 | h | 1.000 | 0 |
| -2.91158717 | 1.23440676 | 2.21611207 | h | 1.000 | 0 |

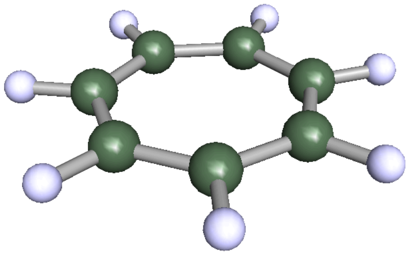
*N*-Methyl-*N*-methylenemethanaminium Product:



Total Energy = -213.61059106097 hartree
Enthalpy Correction = 0.156702 hartree
Entropy = 0.000124 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.17906186 | 1.47804084 | 1.24884502 | c | 6.000 | 0 |
| -0.96197623 | -0.13190031 | -0.59339911 | n | 7.000 | 0 |
| -2.54998087 | -2.24812578 | -1.27797787 | c | 6.000 | 0 |
| 1.58347926 | -0.87934998 | 0.13613929 | c | 6.000 | 0 |
| 1.83489761 | -2.51769627 | 2.49478928 | c | 6.000 | 0 |
| -2.64666251 | 0.50268500 | 3.03003721 | h | 1.000 | 0 |
| -3.94274019 | 2.21400629 | 0.46492671 | h | 1.000 | 0 |
| -0.95407853 | 3.07872707 | 1.69887165 | h | 1.000 | 0 |
| -4.31407065 | -1.55122709 | -2.09625936 | h | 1.000 | 0 |
| -1.59576112 | -3.41097844 | -2.69295370 | h | 1.000 | 0 |
| -3.04856003 | -3.47254161 | 0.33254881 | h | 1.000 | 0 |
| 2.68329240 | 0.85423940 | 0.39609702 | h | 1.000 | 0 |
| 2.41755734 | -1.87810830 | -1.47290412 | h | 1.000 | 0 |
| 0.84286915 | -4.31633974 | 2.28921567 | h | 1.000 | 0 |
| 3.82760691 | -2.93738150 | 2.83635611 | h | 1.000 | 0 |
| 1.09907849 | -1.56563375 | 4.17205287 | h | 1.000 | 0 |

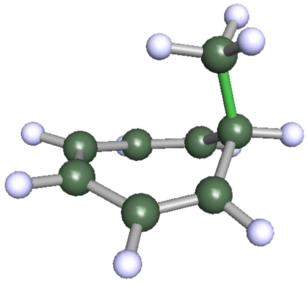
Cyclohepta-2,4,6-trien-1-ylium (MAA* = 291.9 kJ/mol, E = -3.72):



Total Energy = -270.52683931791 hartree
Enthalpy Correction = 0.126613 hartree
Entropy = 0.000119 hartree/K
LUMO Energy = -0.1182 hartree

```
               atomic coordinates              atom    charge  isotop
  -1.65258992    2.53025967   -0.01783135     c       6.000     0
   0.94705299    2.86855797   -0.08934966     c       6.000     0
   2.83361777    1.04684221   -0.09343380     c       6.000     0
   2.58646204   -1.56321583   -0.02683770     c       6.000     0
   0.39164279   -2.99625616    0.05959910     c       6.000     0
  -2.09824462   -2.17299571    0.10134065     c       6.000     0
  -3.00800853    0.28666487    0.06684873     c       6.000     0
  -2.77297184    4.24613048   -0.02965930     h       1.000     0
   1.58937431    4.81364483   -0.15011265     h       1.000     0
   4.75505270    1.75670465   -0.15689268     h       1.000     0
   4.34029609   -2.62325272   -0.04516087     h       1.000     0
   0.65707173   -5.02797344    0.09967762     h       1.000     0
  -3.52100445   -3.64631280    0.16967055     h       1.000     0
  -5.04775106    0.48120198    0.11214136     h       1.000     0
```

Cyclohepta-2,4,6-trien-1-ylium Product:

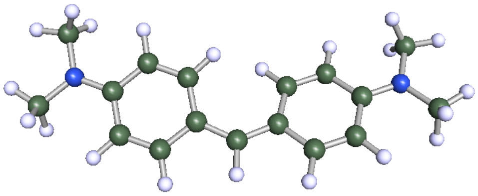


Total Energy = -310.57018122791 hartree
Enthalpy Correction = 0.164746 hartree
Entropy = 0.000132 hartree/K

```
               atomic coordinates              atom    charge  isotop
  -3.47865847   -0.30342970    0.94511364     h       1.000     0
  -1.42602424   -0.09098205    0.97887469     c       6.000     0
  -0.77376991    2.23524840   -0.51188099     c       6.000     0
   1.59187990    3.04470459   -0.97708009     c       6.000     0
   3.90074887    1.70141853   -0.49584469     c       6.000     0
   4.16288135   -0.84574204   -0.42094207     c       6.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 2.17848647 | -2.65607431 | -0.80924179 | c | 6.000 | 0 |
| -0.30501259 | -2.31836380 | -0.37819343 | c | 6.000 | 0 |
| -0.61184022 | 0.07421852 | 3.74399235 | c | 6.000 | 0 |
| -2.33849416 | 3.37437922 | -1.19848107 | h | 1.000 | 0 |
| 1.80282786 | 4.88592665 | -1.86566084 | h | 1.000 | 0 |
| 5.61470251 | 2.82915266 | -0.42299488 | h | 1.000 | 0 |
| 6.07006493 | -1.59504905 | -0.29262466 | h | 1.000 | 0 |
| 2.76465613 | -4.46446134 | -1.59032668 | h | 1.000 | 0 |
| -1.60143250 | -3.78956097 | -0.98836920 | h | 1.000 | 0 |
| 1.43176732 | 0.28894893 | 3.90879599 | h | 1.000 | 0 |
| -1.51294701 | 1.69313955 | 4.65612695 | h | 1.000 | 0 |
| -1.17009809 | -1.63816682 | 4.75467596 | h | 1.000 | 0 |

Bis(4-(dimethylamino)phenyl)methylium (MAA* = 287.6 kJ/mol, E = -7.02):

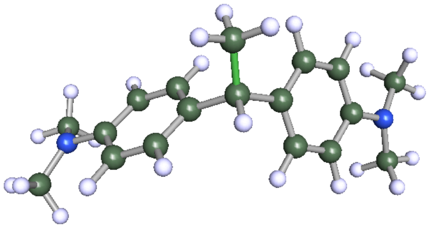


Total Energy = -769.18852229257 hartree
Enthalpy Correction = 0.367588 hartree
Entropy = 0.000221 hartree/K
LUMO Energy = -0.1110 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -11.92847137 | -0.43457495 | -0.97953426 | c | 6.000 | 0 |
| -9.83395001 | 1.02814810 | 0.00978595 | n | 7.000 | 0 |
| -10.35405443 | 3.45141961 | 1.17777054 | c | 6.000 | 0 |
| -7.47568337 | 0.13367936 | -0.10957797 | c | 6.000 | 0 |
| -5.41333591 | 1.50958196 | 0.93801610 | c | 6.000 | 0 |
| -3.00119599 | 0.62781313 | 0.76571361 | c | 6.000 | 0 |
| -2.43284714 | -1.69653405 | -0.44495802 | c | 6.000 | 0 |
| -0.01871904 | -2.73820727 | -0.75478846 | c | 6.000 | 0 |
| 2.40850506 | -1.72748474 | -0.44361544 | c | 6.000 | 0 |
| 4.47604890 | -3.43693432 | -0.48125140 | c | 6.000 | 0 |
| 6.90847390 | -2.67206955 | -0.12049570 | c | 6.000 | 0 |
| 7.47563561 | -0.07389939 | 0.25607872 | c | 6.000 | 0 |
| 9.84629472 | 0.71101294 | 0.63117114 | n | 7.000 | 0 |
| 10.39984809 | 3.37099965 | 0.98911489 | c | 6.000 | 0 |
| 11.92081940 | -1.07804291 | 0.62961472 | c | 6.000 | 0 |
| 5.43117921 | 1.67419146 | 0.16612905 | c | 6.000 | 0 |
| 3.00749748 | 0.87128175 | -0.16165719 | c | 6.000 | 0 |
| -4.51902022 | -3.11253338 | -1.36196995 | c | 6.000 | 0 |
| -6.94023821 | -2.24481032 | -1.23675743 | c | 6.000 | 0 |
| -13.66281771 | 0.63265792 | -0.72311765 | h | 1.000 | 0 |
| -12.11459486 | -2.23715087 | 0.01250806 | h | 1.000 | 0 |
| -11.68484696 | -0.81060372 | -2.99568520 | h | 1.000 | 0 |
| -9.27222932 | 4.95769577 | 0.27110327 | h | 1.000 | 0 |
| -12.35206765 | 3.87173942 | 0.96878268 | h | 1.000 | 0 |
| -9.89707665 | 3.42693073 | 3.19300203 | h | 1.000 | 0 |
| -5.75712768 | 3.26182523 | 1.92909903 | h | 1.000 | 0 |
| -1.52004708 | 1.69953757 | 1.67685073 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -0.03108471 | -4.70574938 | -1.35281760 | h | 1.000 | 0 |
| 4.08856135 | -5.42952320 | -0.76653435 | h | 1.000 | 0 |
| 8.40617837 | -4.05980826 | -0.13358047 | h | 1.000 | 0 |
| 12.40540948 | 3.58421340 | 1.37006988 | h | 1.000 | 0 |
| 9.34636804 | 4.13810204 | 2.59012569 | h | 1.000 | 0 |
| 9.93426217 | 4.46795496 | -0.69918029 | h | 1.000 | 0 |
| 11.66906707 | -2.50726444 | 2.09915428 | h | 1.000 | 0 |
| 12.08620928 | -2.02889631 | -1.19721042 | h | 1.000 | 0 |
| 13.66878148 | -0.06780184 | 0.99865990 | h | 1.000 | 0 |
| 5.79744112 | 3.67784154 | 0.31369216 | h | 1.000 | 0 |
| 1.54049889 | 2.28484552 | -0.31131303 | h | 1.000 | 0 |
| -4.15479836 | -4.93271941 | -2.23177615 | h | 1.000 | 0 |
| -8.45287292 | -3.38686378 | -1.99631859 | h | 1.000 | 0 |

Bis(4-(dimethylamino)phenyl)methylium Product:

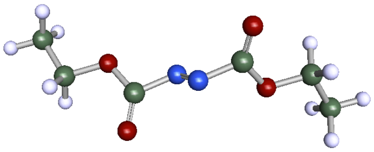


Total Energy = -809.23126420363 hartree
Enthalpy Correction = 0.406493 hartree
Entropy = 0.000233 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 9.97656085 | -1.21618966 | -3.74073749 | c | 6.000 | 0 |
| 8.88288199 | -1.84946118 | -1.32440618 | n | 7.000 | 0 |
| 9.25950841 | -4.39822856 | -0.42910058 | c | 6.000 | 0 |
| 6.77956818 | -0.53962197 | -0.52594320 | c | 6.000 | 0 |
| 5.32204649 | -1.37602603 | 1.53586160 | c | 6.000 | 0 |
| 3.25978098 | -0.00618145 | 2.36627386 | c | 6.000 | 0 |
| 2.50563860 | 2.24045297 | 1.21733802 | c | 6.000 | 0 |
| 0.18421367 | 3.60583745 | 2.18010358 | c | 6.000 | 0 |
| -0.00694303 | 6.34026487 | 1.28828514 | c | 6.000 | 0 |
| -2.20254184 | 2.16517731 | 1.54209030 | c | 6.000 | 0 |
| -2.76130172 | 1.45493121 | -0.92842312 | c | 6.000 | 0 |
| -4.95842382 | 0.17626986 | -1.53882060 | c | 6.000 | 0 |
| -6.74483573 | -0.45187302 | 0.32914488 | c | 6.000 | 0 |
| -8.97160505 | -1.66219035 | -0.27069286 | n | 7.000 | 0 |
| -9.22244848 | -2.80289821 | -2.73564876 | c | 6.000 | 0 |
| -10.45198311 | -2.74942514 | 1.74549570 | c | 6.000 | 0 |
| -6.15876161 | 0.22397344 | 2.82773459 | c | 6.000 | 0 |
| -3.94582621 | 1.51043757 | 3.39209553 | c | 6.000 | 0 |
| 3.92844387 | 3.05043470 | -0.83406371 | c | 6.000 | 0 |
| 6.00372678 | 1.70454508 | -1.70681225 | c | 6.000 | 0 |
| 8.65967217 | -1.51263206 | -5.32012881 | h | 1.000 | 0 |
| 10.59136250 | 0.75400834 | -3.78343162 | h | 1.000 | 0 |
| 11.63636325 | -2.39204327 | -4.04964349 | h | 1.000 | 0 |
| 9.42050788 | -4.44798976 | 1.62830205 | h | 1.000 | 0 |
| 7.72166590 | -5.68032386 | -0.98489811 | h | 1.000 | 0 |
| 11.02054094 | -5.12193090 | -1.20708506 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 5.80356704 | -3.11002081 | 2.50614709 | h | 1.000 | 0 |
| 2.18419616 | -0.72356496 | 3.96138139 | h | 1.000 | 0 |
| 0.31732965 | 3.63614061 | 4.24644274 | h | 1.000 | 0 |
| -1.62454441 | 7.25777205 | 2.18170577 | h | 1.000 | 0 |
| 1.69558725 | 7.40687062 | 1.76854146 | h | 1.000 | 0 |
| -0.28065922 | 6.44969948 | -0.75596763 | h | 1.000 | 0 |
| -1.42751977 | 1.88401285 | -2.42786265 | h | 1.000 | 0 |
| -5.27920755 | -0.34503806 | -3.48914023 | h | 1.000 | 0 |
| -11.10363734 | -3.61898959 | -2.90178918 | h | 1.000 | 0 |
| -7.82504617 | -4.30303879 | -3.07277914 | h | 1.000 | 0 |
| -9.02037884 | -1.39402583 | -4.23049638 | h | 1.000 | 0 |
| -12.15432738 | -3.58336592 | 0.94632768 | h | 1.000 | 0 |
| -11.04047416 | -1.30444347 | 3.09717475 | h | 1.000 | 0 |
| -9.42622236 | -4.22540448 | 2.78801861 | h | 1.000 | 0 |
| -7.43040165 | -0.25539126 | 4.35439193 | h | 1.000 | 0 |
| -3.56653122 | 2.00271929 | 5.34872968 | h | 1.000 | 0 |
| 3.42549167 | 4.77903762 | -1.81284099 | h | 1.000 | 0 |
| 7.02496642 | 2.42771328 | -3.32293200 | h | 1.000 | 0 |

Diethyl (E)-diazene-1,2-dicarboxylate (MAA* = 281.9 kJ/mol, E = -10.55):

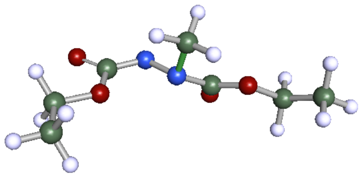


Total Energy = -644.58901949964 hartree
Enthalpy Correction = 0.186167 hartree
Entropy = 0.000186 hartree/K
LUMO Energy = -0.0985 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.41353304 | -0.42894445 | 3.33920973 | o | 8.000 | 0 |
| 3.28298201 | -2.18708378 | 2.46404783 | c | 6.000 | 0 |
| 4.16495531 | -4.32983246 | 1.62760059 | o | 8.000 | 0 |
| 6.88638210 | -4.67675019 | 1.78728479 | c | 6.000 | 0 |
| 7.46974624 | -7.27480747 | 0.81199599 | c | 6.000 | 0 |
| 0.56441650 | -2.17922068 | 2.40234606 | n | 7.000 | 0 |
| -0.29518844 | -1.77538696 | 0.28814150 | n | 7.000 | 0 |
| -3.03295840 | -1.77538350 | 0.26728378 | c | 6.000 | 0 |
| -3.80070361 | 0.30943448 | -0.80401572 | o | 8.000 | 0 |
| -6.51506470 | 0.61219615 | -1.06616585 | c | 6.000 | 0 |
| -6.97568001 | 3.06083127 | -2.42049400 | c | 6.000 | 0 |
| -4.27325787 | -3.52058659 | 1.00522291 | o | 8.000 | 0 |
| 7.43691621 | -4.43480165 | 3.75890813 | h | 1.000 | 0 |
| 7.77421700 | -3.19897997 | 0.65802394 | h | 1.000 | 0 |
| 6.86722056 | -7.48168860 | -1.14954744 | h | 1.000 | 0 |
| 9.50812803 | -7.57829113 | 0.90088872 | h | 1.000 | 0 |
| 6.54671380 | -8.72105241 | 1.95611214 | h | 1.000 | 0 |
| -7.33746472 | 0.59694073 | 0.82424277 | h | 1.000 | 0 |
| -7.22958829 | -1.01105099 | -2.11666730 | h | 1.000 | 0 |
| -6.21579567 | 4.65391863 | -1.35371965 | h | 1.000 | 0 |
| -9.00930902 | 3.33300449 | -2.63366245 | h | 1.000 | 0 |
| -6.12267039 | 3.04012354 | -4.29781252 | h | 1.000 | 0 |

Diethyl (E)-diazene-1,2-dicarboxylate Product:

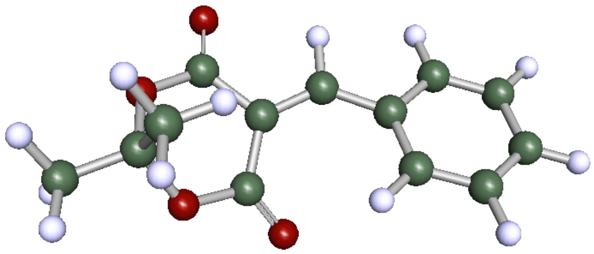
The $CH_3$-N-N-C Torsion Angle was constrained to 270°. The O=C-N-N-C=O Torsion Angle was constrained to 141.75°.



Total Energy = -684.63331789674 hartree
Enthalpy Correction = 0.226984 hartree
Entropy = 0.000192 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.49281164 | -2.01964540 | 0.03843142 | o | 8.000 | 0 |
| -3.26562892 | -0.16132580 | 0.60128739 | c | 6.000 | 0 |
| -4.24470067 | 1.75995714 | 1.92966106 | o | 8.000 | 0 |
| -6.86267517 | 1.53530976 | 2.58353098 | c | 6.000 | 0 |
| -7.57749675 | 3.85528742 | 4.06298551 | c | 6.000 | 0 |
| -0.80784846 | 0.29967039 | -0.15149617 | n | 7.000 | 0 |
| 0.57022275 | 1.75707939 | 1.78036663 | c | 6.000 | 0 |
| 0.46630867 | -2.02402864 | -0.60386445 | n | 7.000 | 0 |
| 2.17735766 | -1.88503909 | -2.40887483 | c | 6.000 | 0 |
| 2.44701287 | 0.39502765 | -3.61038566 | o | 8.000 | 0 |
| 4.35631356 | 0.52565861 | -5.49647734 | c | 6.000 | 0 |
| 4.41684393 | 3.19640519 | -6.48391688 | c | 6.000 | 0 |
| 3.55264535 | -3.68787230 | -3.03991133 | o | 8.000 | 0 |
| -7.13278996 | -0.18539772 | 3.69021768 | h | 1.000 | 0 |
| -7.97342205 | 1.36346832 | 0.85201734 | h | 1.000 | 0 |
| -6.45238776 | 4.00800756 | 5.78574031 | h | 1.000 | 0 |
| -9.56759581 | 3.74217778 | 4.59610773 | h | 1.000 | 0 |
| -7.30331561 | 5.56427711 | 2.93953164 | h | 1.000 | 0 |
| 0.70782501 | 0.68649151 | 3.54441091 | h | 1.000 | 0 |
| -0.34336543 | 3.56295195 | 2.13099487 | h | 1.000 | 0 |
| 2.46374779 | 2.10974039 | 1.05514260 | h | 1.000 | 0 |
| 3.93807434 | -0.81828013 | -7.01066807 | h | 1.000 | 0 |
| 6.17888765 | -0.00763726 | -4.68177508 | h | 1.000 | 0 |
| 4.85827823 | 4.53100038 | -4.97221318 | h | 1.000 | 0 |
| 2.59877489 | 3.72196775 | -7.30898373 | h | 1.000 | 0 |
| 5.86427922 | 3.37121060 | -7.94534680 | h | 1.000 | 0 |

5-Benzylidene-2,2-dimethyl-1,3-dioxane-4,6-dione (MAA* = 273.0 kJ/mol, E = -9.15):

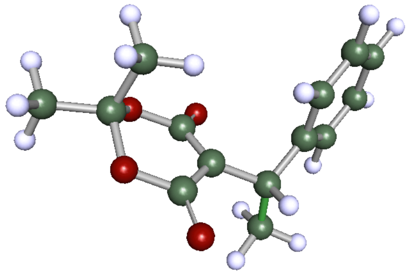


Total Energy = -802.96472014913 hartree
Enthalpy Correction = 0.243144 hartree
Entropy = 0.000191 hartree/K
LUMO Energy = -0.1005 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.01880802 | 2.59784297 | -5.27612547 | o | 8.000 | 0 |
| -2.50767005 | 1.20371022 | -3.54123716 | c | 6.000 | 0 |
| -4.92867579 | 0.62025162 | -3.08148646 | o | 8.000 | 0 |
| -5.56396860 | -0.55002200 | -0.72994581 | c | 6.000 | 0 |
| -8.16870770 | -1.63526257 | -1.05349840 | c | 6.000 | 0 |
| -5.37813163 | 1.33176836 | 1.41025788 | c | 6.000 | 0 |
| -3.91437829 | -2.64472950 | -0.30078729 | o | 8.000 | 0 |
| -0.61706228 | -0.00905739 | -1.87734055 | c | 6.000 | 0 |
| -1.41273170 | -2.33600109 | -0.57685041 | c | 6.000 | 0 |
| -0.03240785 | -4.02283833 | 0.08181150 | o | 8.000 | 0 |
| 1.72373165 | 1.02209758 | -1.88881928 | c | 6.000 | 0 |
| 3.99493739 | 0.53889947 | -0.45470273 | c | 6.000 | 0 |
| 4.08549989 | -0.71742741 | 1.87414353 | c | 6.000 | 0 |
| 6.35995041 | -1.00981481 | 3.12172127 | c | 6.000 | 0 |
| 8.58597720 | -0.09128719 | 2.06462254 | c | 6.000 | 0 |
| 8.52445662 | 1.17921155 | -0.22972214 | c | 6.000 | 0 |
| 6.24187302 | 1.52625958 | -1.45554260 | c | 6.000 | 0 |
| -8.18284154 | -2.97080642 | -2.62197139 | h | 1.000 | 0 |
| -9.50527273 | -0.11596513 | -1.43477117 | h | 1.000 | 0 |
| -8.72953861 | -2.60318207 | 0.67547256 | h | 1.000 | 0 |
| -5.89498489 | 0.40732726 | 3.17675612 | h | 1.000 | 0 |
| -6.67887573 | 2.89065909 | 1.06375881 | h | 1.000 | 0 |
| -3.46872335 | 2.08861527 | 1.59052666 | h | 1.000 | 0 |
| 1.91622859 | 2.56560304 | -3.23198539 | h | 1.000 | 0 |
| 2.37525555 | -1.43940279 | 2.72057787 | h | 1.000 | 0 |
| 6.40537303 | -1.96175074 | 4.93405676 | h | 1.000 | 0 |
| 10.36505639 | -0.34689267 | 3.04706976 | h | 1.000 | 0 |
| 10.24847067 | 1.92311015 | -1.04584029 | h | 1.000 | 0 |
| 6.17596835 | 2.55908396 | -3.22455056 | h | 1.000 | 0 |

5-Benzylidene-2,2-dimethyl-1,3-dioxane-4,6-dione Product:

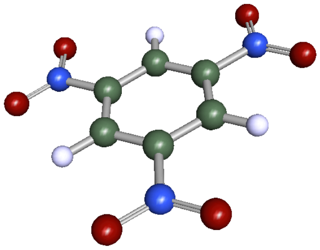
The $CH_3$-CH-C-C(=O) Torsion Angle was constrained to 90°.



Total Energy = -843.00331700391 hartree
Enthalpy Correction = 0.282846 hartree
Entropy = 0.000201 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.13596216 | 1.90292180 | 4.80595511 | o | 8.000 | 0 |
| -2.46677238 | 1.13277766 | 2.63250799 | c | 6.000 | 0 |
| -4.80593315 | 1.65430721 | 1.61394719 | o | 8.000 | 0 |
| -5.02568343 | 1.52359980 | -1.05432244 | c | 6.000 | 0 |
| -3.71582032 | 3.75984441 | -2.28795388 | c | 6.000 | 0 |
| -7.81375745 | 1.45355941 | -1.64056947 | c | 6.000 | 0 |
| -3.99403160 | -0.78137786 | -1.94872128 | o | 8.000 | 0 |
| -0.76965534 | -0.25746110 | 1.14072943 | c | 6.000 | 0 |
| -1.63057709 | -1.44878307 | -1.07363642 | c | 6.000 | 0 |
| -0.54474990 | -3.09305198 | -2.30191918 | o | 8.000 | 0 |
| 1.78386628 | -0.91539686 | 2.22015978 | c | 6.000 | 0 |
| 1.75627831 | -3.43809978 | 3.61127596 | c | 6.000 | 0 |
| 3.87898333 | -0.63225012 | 0.29376754 | c | 6.000 | 0 |
| 5.55154770 | -2.56453919 | -0.31446695 | c | 6.000 | 0 |
| 7.47647716 | -2.19125835 | -2.06457064 | c | 6.000 | 0 |
| 7.76856139 | 0.13313626 | -3.23857028 | c | 6.000 | 0 |
| 6.11289417 | 2.08575807 | -2.64276171 | c | 6.000 | 0 |
| 4.19784670 | 1.69695637 | -0.90043505 | c | 6.000 | 0 |
| -1.70453098 | 3.76743845 | -1.84422545 | h | 1.000 | 0 |
| -4.56088444 | 5.51466314 | -1.61349464 | h | 1.000 | 0 |
| -3.95166152 | 3.65259797 | -4.33307637 | h | 1.000 | 0 |
| -8.71626558 | 3.17655204 | -0.96028104 | h | 1.000 | 0 |
| -8.67951127 | -0.17532666 | -0.72090369 | h | 1.000 | 0 |
| -8.09755170 | 1.31314590 | -3.67679339 | h | 1.000 | 0 |
| 2.14498376 | 0.53831660 | 3.65182409 | h | 1.000 | 0 |
| 0.29408749 | -3.39159199 | 5.06632607 | h | 1.000 | 0 |
| 1.32889782 | -4.99167316 | 2.32029173 | h | 1.000 | 0 |
| 3.56404234 | -3.83508438 | 4.53208523 | h | 1.000 | 0 |
| 5.35273617 | -4.40098953 | 0.56837783 | h | 1.000 | 0 |
| 8.75191068 | -3.73305126 | -2.51165718 | h | 1.000 | 0 |
| 9.26992597 | 0.42710918 | -4.60175840 | h | 1.000 | 0 |
| 6.32100422 | 3.91817828 | -3.53840935 | h | 1.000 | 0 |
| 2.90493699 | 3.22464515 | -0.44960927 | h | 1.000 | 0 |

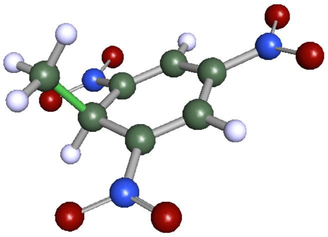
1,3,5-Trinitrobenzene (MAA* = 271.8 kJ/mol, E = -13.19):



Total Energy = -845.22685615130 hartree
Enthalpy Correction = 0.122116 hartree
Entropy = 0.000175 hartree/K
LUMO Energy = -0.1183 hartree

```
                  atomic coordinates                atom    charge  isotop
   4.20668172   -5.14659335   -0.92890011    o       8.000     0
   4.44370425   -2.93939450   -0.37858016    n       7.000     0
   2.14026222   -1.41603525   -0.18178511    c       6.000     0
  -0.15991896   -2.56359421   -0.62948306    c       6.000     0
  -2.29566024   -1.07797354   -0.42984651    c       6.000     0
  -4.76609981   -2.23772383   -0.89510754    n       7.000     0
  -6.61239090   -0.90027124   -0.71152483    o       8.000     0
  -4.80516129   -4.45990796   -1.43479368    o       8.000     0
  -2.19997898    1.45515336    0.18866510    c       6.000     0
   0.15559583    2.49372180    0.61414285    c       6.000     0
   0.32241104    5.17751010    1.27301204    n       7.000     0
   2.40590950    6.04825223    1.63668610    o       8.000     0
  -1.63326028    6.35509950    1.41184802    o       8.000     0
   2.35991346    1.10779161    0.44336023    c       6.000     0
   6.43858740   -1.89464592    0.02143039    o       8.000     0
  -0.28451368   -4.54202233   -1.11670563    h       1.000     0
  -3.89823313    2.57847624    0.33337784    h       1.000     0
   4.18215185    1.96215730    0.78420404    h       1.000     0
```

1,3,5-Trinitrobenzene Product:

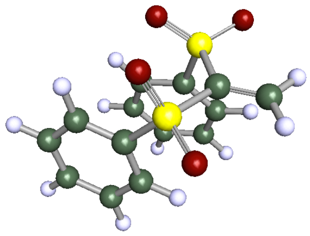


Total Energy = -885.26550198642 hartree
Enthalpy Correction = 0.162018 hartree
Entropy = 0.000184 hartree/K

```
                  atomic coordinates                atom    charge  isotop
  -3.74544171   -1.69482467    0.45138823    c       6.000     0
  -1.73381215   -0.40637338   -1.19815564    c       6.000     0
  -1.07954269    2.16629754   -0.18872893    c       6.000     0
```

| | | | | | |
|---|---|---|---|---|---|
| -2.82049157 | 4.14371450 | -0.63705104 | n | 7.000 | 0 |
| -4.68410210 | 3.66700487 | -1.94120409 | o | 8.000 | 0 |
| -2.44763514 | 6.25608419 | 0.25786151 | o | 8.000 | 0 |
| 1.01719228 | 2.67654709 | 1.19271709 | c | 6.000 | 0 |
| 2.88572059 | 0.81316015 | 1.48530602 | c | 6.000 | 0 |
| 5.02028458 | 1.31107480 | 2.96663820 | n | 7.000 | 0 |
| 5.17765201 | 3.35384227 | 4.07843185 | o | 8.000 | 0 |
| 6.68635858 | -0.31112709 | 3.13314865 | o | 8.000 | 0 |
| 2.74403587 | -1.44134510 | 0.09042310 | c | 6.000 | 0 |
| 0.64836156 | -1.94856743 | -1.29407270 | c | 6.000 | 0 |
| 0.65104745 | -4.11330011 | -2.86063311 | n | 7.000 | 0 |
| -1.24447669 | -4.52077702 | -4.14282426 | o | 8.000 | 0 |
| 2.50472389 | -5.51378896 | -2.91862137 | o | 8.000 | 0 |
| -4.20646636 | -3.55686559 | -0.30253529 | h | 1.000 | 0 |
| -5.46827308 | -0.56515369 | 0.49617848 | h | 1.000 | 0 |
| -3.04504410 | -1.91525039 | 2.38019085 | h | 1.000 | 0 |
| -2.48595759 | -0.20995459 | -3.10903633 | h | 1.000 | 0 |
| 1.29170146 | 4.53102696 | 2.00110733 | h | 1.000 | 0 |
| 4.33416490 | -2.72142435 | 0.05947146 | h | 1.000 | 0 |

(Ethene-1,1-diyldisulfonyl)dibenzene (MAA* = 271.0 kJ/mol, E = -7.5):

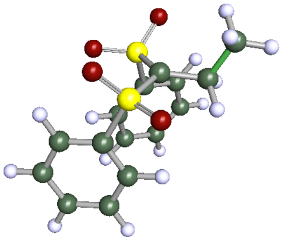


Total Energy = -1637.11226542889 hartree
Enthalpy Correction = 0.256055 hartree
Entropy = 0.000214 hartree/K
LUMO Energy = -0.0786 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.77969302 | -6.01573822 | 2.77676696 | c | 6.000 | 0 |
| -0.36043065 | -4.66194261 | 0.71208884 | c | 6.000 | 0 |
| -2.94816660 | -3.36754474 | -0.99245125 | s | 16.000 | 0 |
| -2.35667860 | -3.44164804 | -3.64335427 | o | 8.000 | 0 |
| -3.07203515 | -0.20175329 | -0.00498883 | c | 6.000 | 0 |
| -2.70269793 | 1.69805367 | -1.77037118 | c | 6.000 | 0 |
| -2.86174822 | 4.19275768 | -0.98606721 | c | 6.000 | 0 |
| -3.36163208 | 4.75140179 | 1.52545717 | c | 6.000 | 0 |
| -3.72263997 | 2.82474940 | 3.27569201 | c | 6.000 | 0 |
| -3.58792350 | 0.32719859 | 2.51669252 | c | 6.000 | 0 |
| -5.17292626 | -4.64554743 | -0.08316241 | o | 8.000 | 0 |
| 2.79008494 | -4.29753055 | -0.40977894 | s | 16.000 | 0 |
| 4.40515399 | -5.09043886 | 1.63346173 | o | 8.000 | 0 |
| 3.16414346 | -1.04492018 | -0.88119956 | c | 6.000 | 0 |
| 3.26239309 | 0.53288234 | 1.21863725 | c | 6.000 | 0 |
| 3.58642563 | 3.09892287 | 0.84497070 | c | 6.000 | 0 |
| 3.82796202 | 4.05113971 | -1.59178055 | c | 6.000 | 0 |
| 3.73141643 | 2.45213902 | -3.66789800 | c | 6.000 | 0 |
| 3.38097160 | -0.12126050 | -3.32503214 | c | 6.000 | 0 |
| 2.98858948 | -5.57459449 | -2.80090140 | o | 8.000 | 0 |
| 0.78211291 | -6.79754393 | 3.84578766 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.69075222 | -6.37810401 | 3.41694090 | h | 1.000 | 0 |
| -2.29424909 | 1.22385545 | -3.71642092 | h | 1.000 | 0 |
| -2.57619813 | 5.69998030 | -2.34090510 | h | 1.000 | 0 |
| -3.46525616 | 6.70467582 | 2.13149731 | h | 1.000 | 0 |
| -4.11173191 | 3.27073346 | 5.23509720 | h | 1.000 | 0 |
| -3.87602559 | -1.18445470 | 3.86742255 | h | 1.000 | 0 |
| 3.09164685 | -0.23591046 | 3.10829424 | h | 1.000 | 0 |
| 3.65429147 | 4.35957467 | 2.45544712 | h | 1.000 | 0 |
| 4.08421829 | 6.06356292 | -1.87161704 | h | 1.000 | 0 |
| 3.91472891 | 3.20767108 | -5.56131815 | h | 1.000 | 0 |
| 3.27664600 | -1.40036675 | -4.91700721 | h | 1.000 | 0 |

(Ethene-1,1-diyldisulfonyl)dibenzene Product:

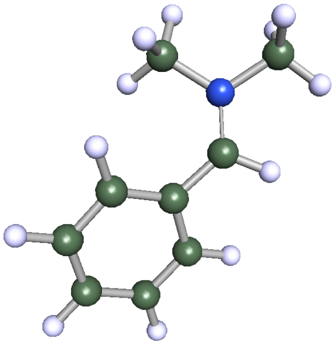


Total Energy = -1677.14969404506 hartree
Enthalpy Correction = 0.296543 hartree
Entropy = 0.000228 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.34363294 | 8.42409116 | -0.41214353 | c | 6.000 | 0 |
| 0.21955220 | 6.36233206 | 1.25050234 | c | 6.000 | 0 |
| 0.56220156 | 3.72559905 | 0.22313284 | c | 6.000 | 0 |
| -1.81016249 | 2.29541041 | -1.34144850 | s | 16.000 | 0 |
| -0.97072585 | 0.88070215 | -3.53562747 | o | 8.000 | 0 |
| -3.25436814 | 0.02339586 | 0.66133891 | c | 6.000 | 0 |
| -2.95843309 | -2.53946621 | 0.19943586 | c | 6.000 | 0 |
| -4.01960803 | -4.27844605 | 1.85402894 | c | 6.000 | 0 |
| -5.36706831 | -3.45325332 | 3.94747635 | c | 6.000 | 0 |
| -5.65927349 | -0.88051632 | 4.39396224 | c | 6.000 | 0 |
| -4.59746520 | 0.86347021 | 2.75805593 | c | 6.000 | 0 |
| -3.72205789 | 4.21991690 | -1.80180488 | o | 8.000 | 0 |
| 3.01858918 | 2.03798042 | 1.30334799 | s | 16.000 | 0 |
| 5.30605404 | 3.55911339 | 1.19958797 | o | 8.000 | 0 |
| 2.51748520 | 1.50800539 | 4.58358414 | c | 6.000 | 0 |
| 1.12025036 | -0.57761475 | 5.35849314 | c | 6.000 | 0 |
| 0.63306142 | -0.93297101 | 7.90645239 | c | 6.000 | 0 |
| 1.53055035 | 0.78584011 | 9.67662236 | c | 6.000 | 0 |
| 2.93537238 | 2.85999854 | 8.89492707 | c | 6.000 | 0 |
| 3.43815868 | 3.22497002 | 6.34721098 | c | 6.000 | 0 |
| 3.09903578 | -0.43882128 | 0.12943798 | o | 8.000 | 0 |
| 3.36625936 | 8.11129836 | -0.67930845 | h | 1.000 | 0 |
| 1.08048921 | 10.29342599 | 0.43295024 | h | 1.000 | 0 |
| 0.44279534 | 8.42101999 | -2.26996812 | h | 1.000 | 0 |
| 1.05863461 | 6.47338112 | 3.14100047 | h | 1.000 | 0 |
| -1.79723942 | 6.71566985 | 1.51335373 | h | 1.000 | 0 |
| -1.88935336 | -3.14946292 | -1.43318256 | h | 1.000 | 0 |
| -3.78881553 | -6.28375854 | 1.50492833 | h | 1.000 | 0 |
| -6.19015118 | -4.81484481 | 5.23738624 | h | 1.000 | 0 |

```
-6.70598181   -0.23337601    6.03104584     h       1.000      0
-4.79955267    2.87127336    3.10773084     h       1.000      0
 0.42687440   -1.91194213    3.97232184     h       1.000      0
-0.45424238   -2.56011968    8.51126238     h       1.000      0
 1.14424003    0.50216195   11.66826252     h       1.000      0
 3.65539053    4.19390072   10.27275086     h       1.000      0
 4.56800702    4.81342571    5.72538555     h       1.000      0
```

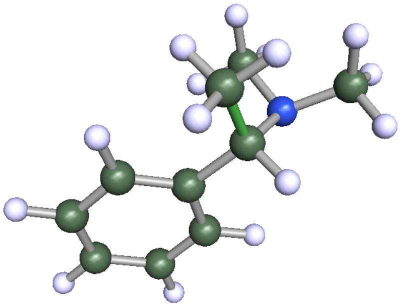
*N*-Benzylidene-*N*-methylmethanaminium (MAA* = 265.1 kJ/mol, E = -9.27):



Total Energy = -404.44857561165 hartree
Enthalpy Correction = 0.204506 hartree
Entropy = 0.000147 hartree/K
LUMO Energy = -0.0942 hartree

```
               atomic coordinates              atom    charge  isotop
-5.94489074   -0.39331037   -1.10309536     c       6.000      0
-3.42768290   -0.19339890   -0.00811293     n       7.000      0
-3.38451234    0.01295958    2.73226832     c       6.000      0
-1.46249752   -0.24694195   -1.43797139     c       6.000      0
 1.16371198    0.01857190   -0.76404949     c       6.000      0
 2.88191543   -1.08811140   -2.44886310     c       6.000      0
 5.44849932   -0.97219880   -1.98417828     c       6.000      0
 6.33179184    0.32082608    0.12246683     c       6.000      0
 4.64766768    1.50207823    1.75624184     c       6.000      0
 2.07457867    1.34969025    1.33548235     c       6.000      0
-7.03666190    1.26259648   -0.54272947     h       1.000      0
-5.81259069   -0.48617359   -3.15003839     h       1.000      0
-6.85714942   -2.08627305   -0.36411405     h       1.000      0
-5.00837357   -1.01466311    3.46336630     h       1.000      0
-3.53862469    1.99045564    3.29148728     h       1.000      0
-1.65572067   -0.80621573    3.47862562     h       1.000      0
-1.85523797   -0.57956938   -3.42372371     h       1.000      0
 2.17836087   -2.05942091   -4.10986121     h       1.000      0
 6.76238306   -1.86392129   -3.27529377     h       1.000      0
 8.34531586    0.43801933    0.47791418     h       1.000      0
 5.34728012    2.55752812    3.36424303     h       1.000      0
 0.80243758    2.33747288    2.58993539     h       1.000      0
```

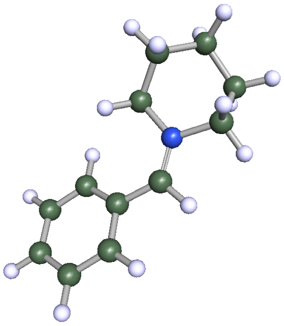
*N*-Benzylidene-*N*-methylmethanaminium Product:



Total Energy = -444.48180844006 hartree
Enthalpy Correction = 0.242743 hartree
Entropy = 0.00016 hartree/K

```
                atomic coordinates            atom    charge  isotop
   -3.12503067   -1.04209236   -2.72230666    c      6.000     0
   -3.29592035    0.06304200   -0.22932271    n      7.000     0
   -5.86945670    0.09019924    0.67987389    c      6.000     0
   -1.50966901   -1.00519444    1.59503615    c      6.000     0
   -1.82423534   -3.82774646    2.08076825    c      6.000     0
    1.15483152   -0.24568696    0.86342929    c      6.000     0
    3.08450898   -1.97854279    0.45046089    c      6.000     0
    5.49961288   -1.17609392   -0.21147950    c      6.000     0
    6.01911513    1.37816827   -0.46201426    c      6.000     0
    4.10418895    3.13083700   -0.04631541    c      6.000     0
    1.70270600    2.31965320    0.60551629    c      6.000     0
   -1.16777818   -1.01420814   -3.37506820    h      1.000     0
   -3.80977306   -3.00739429   -2.80857230    h      1.000     0
   -4.25988057    0.07076861   -4.04079298    h      1.000     0
   -5.94587893    0.98286848    2.54008793    h      1.000     0
   -6.72683529   -1.80323340    0.83461038    h      1.000     0
   -7.04132999    1.19264529   -0.61577414    h      1.000     0
   -1.92214032   -0.03042271    3.37821186    h      1.000     0
   -3.76043921   -4.24266633    2.65694324    h      1.000     0
   -1.40001705   -4.95964304    0.40808792    h      1.000     0
   -0.57476377   -4.44674650    3.60165254    h      1.000     0
    2.72320317   -3.98485159    0.63683554    h      1.000     0
    6.97539589   -2.56167738   -0.53171105    h      1.000     0
    7.90092934    2.00593618   -0.97446206    h      1.000     0
    4.49088077    5.13544330   -0.22852258    h      1.000     0
    0.20306898    3.68357418    0.90905908    h      1.000     0
```

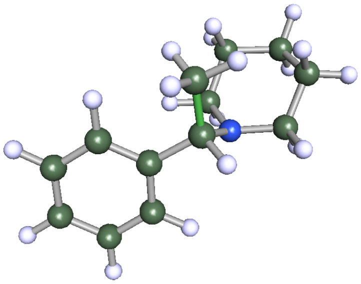
1-Benzylidenepiperidin-1-ium (MAA* = 262.5 kJ/mol, E = -9.6):



Total Energy = -521.09582350882 hartree
Enthalpy Correction = 0.272661 hartree
Entropy = 0.000163 hartree/K
LUMO Energy = -0.0940 hartree

```
                 atomic coordinates              atom    charge  isotop
  -1.45211433   -0.53265352   -0.58318642    n      7.000     0
  -1.64336195    0.39456634    2.02832126    c      6.000     0
  -4.36933162    0.92948871    2.70584361    c      6.000     0
  -5.99806578   -1.44869887    2.53959737    c      6.000     0
  -5.15669057   -3.12485419    0.32920926    c      6.000     0
  -3.79150110   -1.59004611   -1.66153480    c      6.000     0
   0.55611262   -0.43076700   -1.94843435    c      6.000     0
   3.04784985    0.48294695   -1.33652762    c      6.000     0
   4.54830273    1.09514073   -3.43467590    c      6.000     0
   6.96483129    2.02761857   -3.11334783    c      6.000     0
   7.94400482    2.29269403   -0.69269490    c      6.000     0
   6.50515312    1.61737897    1.39836632    c      6.000     0
   4.06781833    0.72872245    1.09637755    c      6.000     0
  -0.85763589   -1.05101246    3.27861504    h      1.000     0
  -0.48536142    2.08971452    2.18240892    h      1.000     0
  -4.39789409    1.71572294    4.61145344    h      1.000     0
  -5.09361605    2.40226610    1.45194719    h      1.000     0
  -5.86979594   -2.51569905    4.30111728    h      1.000     0
  -7.97362741   -0.89926649    2.31137847    h      1.000     0
  -3.89434435   -4.62496422    0.98060365    h      1.000     0
  -6.76784873   -4.04924326   -0.56408791    h      1.000     0
  -4.95464235   -0.00954514   -2.30620873    h      1.000     0
  -3.27156978   -2.72280992   -3.29648243    h      1.000     0
   0.30925296   -1.09457432   -3.87449691    h      1.000     0
   3.78422097    0.84981603   -5.31962064    h      1.000     0
   8.09428373    2.52491545   -4.74598066    h      1.000     0
   9.84755798    3.00219649   -0.43259416    h      1.000     0
   7.29295421    1.77851746    3.28056065    h      1.000     0
   3.01505877    0.16242878    2.74891192    h      1.000     0
```

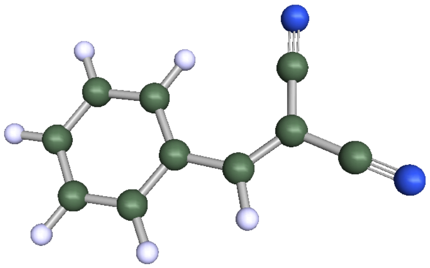
1-Benzylidenepiperidin-1-ium Product:



Total Energy = -561.12817880347 hartree
Enthalpy Correction = 0.310734 hartree
Entropy = 0.000175 hartree/K

```
              atomic coordinates              atom    charge  isotop
    1.61227330   -4.26983805   -2.98921287    c      6.000     0
    1.01230394   -2.14345259   -1.13153675    c      6.000     0
    3.28627878   -0.49123792   -0.54195297    c      6.000     0
    3.08994251    1.24983234    1.42719194    c      6.000     0
    5.09339112    2.80862898    2.06178743    c      6.000     0
    7.34854936    2.66830404    0.71572191    c      6.000     0
    7.56684528    0.95163362   -1.24898585    c      6.000     0
    5.55026486   -0.62080540   -1.86598049    c      6.000     0
   -1.12513555   -0.52833448   -1.74233430    n      7.000     0
   -3.63388627   -1.52826553   -1.30660674    c      6.000     0
   -4.86555823   -2.79763059   -3.58763909    c      6.000     0
   -4.79565959   -1.03323777   -5.85814358    c      6.000     0
   -2.10013240   -0.16846501   -6.36923589    c      6.000     0
   -0.95745791    1.01582673   -3.99723719    c      6.000     0
    3.16978531   -5.43012013   -2.28487773    h      1.000     0
   -0.02860513   -5.49267644   -3.22447330    h      1.000     0
    2.14518738   -3.54916669   -4.84736616    h      1.000     0
    0.49323702   -3.05136849    0.65879187    h      1.000     0
    1.32088873    1.37702849    2.45552394    h      1.000     0
    4.90305222    4.13926116    3.60907077    h      1.000     0
    8.91999929    3.88983928    1.20240303    h      1.000     0
    9.31261769    0.82641818   -2.31540174    h      1.000     0
    5.76659766   -1.95106644   -3.40663888    h      1.000     0
   -4.86006015    0.05331266   -0.73852157    h      1.000     0
   -3.55067148   -2.82577264    0.29873594    h      1.000     0
   -3.88289843   -4.55950577   -4.04643175    h      1.000     0
   -6.81520955   -3.29987373   -3.11264476    h      1.000     0
   -5.59996539   -1.95049616   -7.52635313    h      1.000     0
   -5.97557701    0.62667139   -5.45984512    h      1.000     0
   -2.05789982    1.21711765   -7.90510929    h      1.000     0
   -0.96189880   -1.78393369   -6.97952237    h      1.000     0
    1.02147632    1.51546678   -4.30891007    h      1.000     0
   -1.96870738    2.79598564   -3.63206393    h      1.000     0
```

2-(4-Methylbenzylidene)malononitrile (MAA* = 260.1 kJ/mol, E = -9.42):

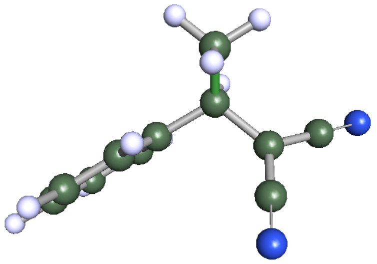


Total Energy = -493.74847882247 hartree
Enthalpy Correction = 0.143647 hartree
Entropy = 0.000157 hartree/K
LUMO Energy = -0.1043 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.16321337 | 4.58687226 | 0.81149350 | n | 7.000 | 0 |
| 4.84209157 | 2.43570928 | 0.70303598 | c | 6.000 | 0 |
| 4.54004350 | -0.22973899 | 0.57645473 | c | 6.000 | 0 |
| 6.81957159 | -1.63854571 | 0.81609821 | c | 6.000 | 0 |
| 8.67007258 | -2.76953871 | 1.01075423 | n | 7.000 | 0 |
| 2.32289156 | -1.48457481 | 0.24688639 | c | 6.000 | 0 |
| -0.21905279 | -0.56758345 | -0.04250928 | c | 6.000 | 0 |
| -2.09149087 | -2.40794708 | -0.41716424 | c | 6.000 | 0 |
| -4.59472459 | -1.72728906 | -0.72280654 | c | 6.000 | 0 |
| -5.27045436 | 0.80711597 | -0.65245184 | c | 6.000 | 0 |
| -3.43644847 | 2.65418945 | -0.27621659 | c | 6.000 | 0 |
| -0.93244977 | 1.98559187 | 0.02600529 | c | 6.000 | 0 |
| 2.50339947 | -3.52761048 | 0.18755931 | h | 1.000 | 0 |
| -1.55112855 | -4.38380425 | -0.46747126 | h | 1.000 | 0 |
| -6.01916687 | -3.16852088 | -1.01340105 | h | 1.000 | 0 |
| -7.23089673 | 1.35076054 | -0.88850084 | h | 1.000 | 0 |
| -3.97041552 | 4.62950169 | -0.21772776 | h | 1.000 | 0 |
| 0.45494488 | 3.45541236 | 0.31996174 | h | 1.000 | 0 |

2-(4-Methylbenzylidene)malononitrile Product:

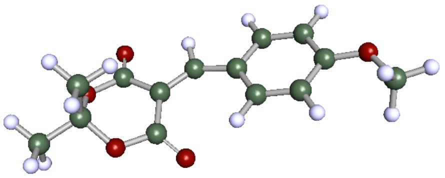
The $CH_3$-C-C-CN Torsion Angle was constrained to 90°.



Total Energy = -533.78081750262 hartree
Enthalpy Correction = 0.183516 hartree
Entropy = 0.000172 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.67957051 | -1.56497521 | -3.16406904 | c | 6.000 | 0 |
| -2.05300539 | 0.42707897 | -1.17316259 | c | 6.000 | 0 |
| -3.81812953 | 0.29486382 | 1.10287344 | c | 6.000 | 0 |
| -6.02697100 | 1.69238414 | 1.11416482 | c | 6.000 | 0 |
| -7.86526727 | 2.91832787 | 1.07778969 | n | 7.000 | 0 |
| -3.44693682 | -1.45871659 | 3.00880018 | c | 6.000 | 0 |
| -3.08655471 | -2.93479851 | 4.61054738 | n | 7.000 | 0 |
| 0.68237436 | 0.38898693 | -0.35495007 | c | 6.000 | 0 |
| 1.97561884 | -1.85990393 | 0.08834321 | c | 6.000 | 0 |
| 4.47513387 | -1.84080342 | 0.89033794 | c | 6.000 | 0 |
| 5.72995252 | 0.43277964 | 1.25845388 | c | 6.000 | 0 |
| 4.46142081 | 2.68959110 | 0.82028007 | c | 6.000 | 0 |
| 1.96362230 | 2.65821230 | 0.02476770 | c | 6.000 | 0 |
| -2.52144450 | -3.47452753 | -2.39539230 | h | 1.000 | 0 |
| -1.41952374 | -1.41750731 | -4.79619494 | h | 1.000 | 0 |
| -4.62198022 | -1.31332216 | -3.81418184 | h | 1.000 | 0 |
| -2.37781072 | 2.28224736 | -2.02750234 | h | 1.000 | 0 |
| 1.03104750 | -3.65520748 | -0.19282687 | h | 1.000 | 0 |
| 5.44716122 | -3.61421888 | 1.22369141 | h | 1.000 | 0 |
| 7.68379199 | 0.44777993 | 1.87475116 | h | 1.000 | 0 |
| 5.42321820 | 4.47925302 | 1.09020154 | h | 1.000 | 0 |
| 0.98249448 | 4.42808693 | -0.31491600 | h | 1.000 | 0 |

5-(4-Methoxybenzylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione (MAA* = 257.9 kJ/mol, E = -10.28):



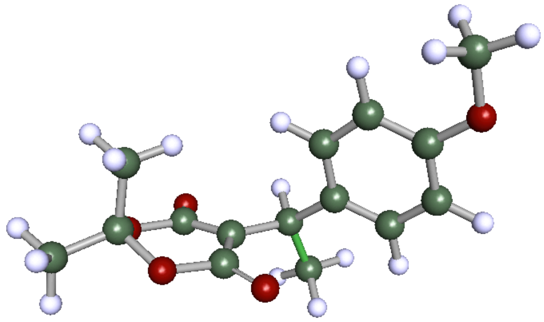
Total Energy = -917.42011011499 hartree
Enthalpy Correction = 0.278533 hartree
Entropy = 0.000209 hartree/K
LUMO Energy = -0.0955 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.07576325 | -4.43358064 | -2.52357989 | o | 8.000 | 0 |
| -4.99627085 | -2.54168244 | -1.24851025 | c | 6.000 | 0 |
| -7.16826678 | -1.32729115 | -0.75417959 | o | 8.000 | 0 |
| -7.05235886 | 1.19102830 | 0.20792425 | c | 6.000 | 0 |
| -9.62804481 | 1.77136214 | 1.25638056 | c | 6.000 | 0 |
| -6.22785381 | 3.01001295 | -1.83569100 | c | 6.000 | 0 |
| -5.34383004 | 1.26829400 | 2.29394166 | o | 8.000 | 0 |
| -2.69087027 | -1.47397849 | -0.10279962 | c | 6.000 | 0 |
| -3.03892360 | 0.22652004 | 2.05260167 | c | 6.000 | 0 |
| -1.50873163 | 0.63946190 | 3.69535243 | o | 8.000 | 0 |
| -0.46869050 | -2.35166828 | -1.07055150 | c | 6.000 | 0 |
| 2.15477966 | -1.79594973 | -0.72731827 | c | 6.000 | 0 |
| 3.18430266 | 0.16555300 | 0.73331311 | c | 6.000 | 0 |
| 5.75388828 | 0.56893077 | 0.84022640 | c | 6.000 | 0 |
| 7.39756755 | -1.01074130 | -0.50013147 | c | 6.000 | 0 |
| 9.90843275 | -0.77279257 | -0.48783132 | o | 8.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 11.00540558 | 1.21328162 | 0.95242160 | c | 6.000 | 0 |
| 6.41759981 | -2.97624609 | -1.97329730 | c | 6.000 | 0 |
| 3.85380627 | -3.33408855 | -2.09199454 | c | 6.000 | 0 |
| -10.11461073 | 0.40389994 | 2.71823206 | h | 1.000 | 0 |
| -9.63280819 | 3.66646914 | 2.06202155 | h | 1.000 | 0 |
| -11.02357155 | 1.68309674 | -0.25571839 | h | 1.000 | 0 |
| -4.35582741 | 2.53660921 | -2.55899032 | h | 1.000 | 0 |
| -7.57518672 | 2.94566709 | -3.39269076 | h | 1.000 | 0 |
| -6.18039133 | 4.92087051 | -1.06897493 | h | 1.000 | 0 |
| -0.78405452 | -3.78062245 | -2.51363283 | h | 1.000 | 0 |
| 1.95197465 | 1.38912807 | 1.80129209 | h | 1.000 | 0 |
| 6.47623273 | 2.10782299 | 1.97388888 | h | 1.000 | 0 |
| 10.55185598 | 1.00619023 | 2.95555868 | h | 1.000 | 0 |
| 13.03511582 | 1.04634637 | 0.68216958 | h | 1.000 | 0 |
| 10.36276191 | 3.05386237 | 0.27440702 | h | 1.000 | 0 |
| 7.70704742 | -4.17599544 | -3.01643329 | h | 1.000 | 0 |
| 3.10528379 | -4.83977024 | -3.26375471 | h | 1.000 | 0 |

5-(4-Methoxybenzylidene)-2,2-dimethyl-1,3-dioxane-4,6-dione Product:

The $CH_3$-C-C-C(=O) Torsion Angle was constrained to 90°.

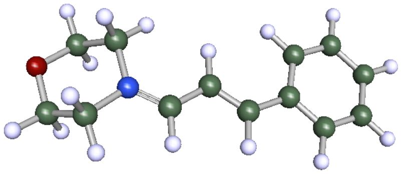


Total Energy = -957.45177737785 hartree
Enthalpy Correction = 0.317962 hartree
Entropy = 0.000222 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.98449866 | -2.39292604 | -3.25370293 | o | 8.000 | 0 |
| -2.43891022 | -1.37953228 | -1.75558170 | c | 6.000 | 0 |
| -4.47571229 | -2.84129041 | -1.02727296 | o | 8.000 | 0 |
| -5.77927972 | -2.11441087 | 1.19614093 | c | 6.000 | 0 |
| -4.22218820 | -2.74248756 | 3.52418485 | c | 6.000 | 0 |
| -8.27608698 | -3.48831879 | 1.16903763 | c | 6.000 | 0 |
| -6.34146994 | 0.50457790 | 1.11979700 | o | 8.000 | 0 |
| -2.32317320 | 1.10056101 | -0.80774966 | c | 6.000 | 0 |
| -4.36888406 | 2.10738966 | 0.54833333 | c | 6.000 | 0 |
| -4.64995604 | 4.31574494 | 1.23554745 | o | 8.000 | 0 |
| -0.07456480 | 2.78245749 | -1.31436488 | c | 6.000 | 0 |
| -0.39813388 | 4.32438813 | -3.72801304 | c | 6.000 | 0 |
| 2.42351527 | 1.41209883 | -1.09434187 | c | 6.000 | 0 |
| 4.18038825 | 1.27391762 | -3.04529033 | c | 6.000 | 0 |
| 6.46416195 | 0.02945197 | -2.74632068 | c | 6.000 | 0 |
| 7.05755772 | -1.12344784 | -0.45870078 | c | 6.000 | 0 |
| 9.33284094 | -2.30438530 | -0.32541490 | o | 8.000 | 0 |
| 9.98018971 | -3.48438301 | 1.98253489 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 5.33313381 | -1.00189597 | 1.52403100 | c | 6.000 | 0 |
| 3.05879771 | 0.25924815 | 1.17846846 | c | 6.000 | 0 |
| -2.42813377 | -1.73159423 | 3.49888150 | h | 1.000 | 0 |
| -5.26810167 | -2.21471358 | 5.22023520 | h | 1.000 | 0 |
| -3.84834499 | -4.76886342 | 3.57791712 | h | 1.000 | 0 |
| -7.95458226 | -5.52323960 | 1.19130098 | h | 1.000 | 0 |
| -9.37949420 | -2.97038509 | 2.83054451 | h | 1.000 | 0 |
| -9.33102327 | -2.98664002 | -0.52948916 | h | 1.000 | 0 |
| -0.09473640 | 4.15829144 | 0.23728056 | h | 1.000 | 0 |
| -0.48563630 | 3.10204029 | -5.39176937 | h | 1.000 | 0 |
| -2.16542772 | 5.38161139 | -3.61873078 | h | 1.000 | 0 |
| 1.14618740 | 5.67261901 | -3.99881159 | h | 1.000 | 0 |
| 3.76854187 | 2.13754661 | -4.85553297 | h | 1.000 | 0 |
| 7.81441962 | -0.06724141 | -4.28545160 | h | 1.000 | 0 |
| 11.84559552 | -4.30503129 | 1.70556774 | h | 1.000 | 0 |
| 10.05752194 | -2.11609345 | 3.53108335 | h | 1.000 | 0 |
| 8.63744179 | -4.98138862 | 2.46406675 | h | 1.000 | 0 |
| 5.73818131 | -1.86961119 | 3.33100452 | h | 1.000 | 0 |
| 1.72842189 | 0.33620895 | 2.73880392 | h | 1.000 | 0 |

(*E*)-4-(3-Phenylallylidene)morpholin-4-ium (MAA* = 256.1 kJ/mol, E = -8.6):



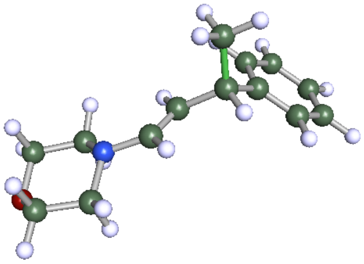
Total Energy = -634.33242128055 hartree
Enthalpy Correction = 0.284378 hartree
Entropy = 0.000179 hartree/K
LUMO Energy = -0.1057 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.86241711 | 0.11230916 | 1.92768176 | n | 7.000 | 0 |
| -6.01130489 | -1.12584933 | 3.13039891 | c | 6.000 | 0 |
| -8.22499368 | -1.16198633 | 1.30759808 | c | 6.000 | 0 |
| -8.82817895 | 1.30379004 | 0.49324862 | o | 8.000 | 0 |
| -6.76106299 | 2.41359811 | -0.76915618 | c | 6.000 | 0 |
| -4.47251993 | 2.61396467 | 0.95280390 | c | 6.000 | 0 |
| -1.69166369 | -1.00012049 | 1.72654701 | c | 6.000 | 0 |
| 0.52039199 | -0.01666589 | 0.59740700 | c | 6.000 | 0 |
| 2.61615189 | -1.48461666 | 0.58171269 | c | 6.000 | 0 |
| 5.05392224 | -0.84996259 | -0.45532618 | c | 6.000 | 0 |
| 5.55648299 | 1.46918735 | -1.63379236 | c | 6.000 | 0 |
| 7.93169590 | 1.96933248 | -2.58982513 | c | 6.000 | 0 |
| 9.84406721 | 0.17253824 | -2.38930053 | c | 6.000 | 0 |
| 9.37302511 | -2.13225289 | -1.22769432 | c | 6.000 | 0 |
| 6.99395874 | -2.63972098 | -0.26811455 | c | 6.000 | 0 |
| -5.47428132 | -3.03411500 | 3.67968160 | h | 1.000 | 0 |
| -6.50170955 | -0.03922713 | 4.81692101 | h | 1.000 | 0 |
| -7.77321708 | -2.36351325 | -0.32245275 | h | 1.000 | 0 |
| -9.88179708 | -1.92557436 | 2.26248240 | h | 1.000 | 0 |
| -6.27201275 | 1.30549069 | -2.45384542 | h | 1.000 | 0 |
| -7.33138777 | 4.30305580 | -1.35551875 | h | 1.000 | 0 |
| -4.90181182 | 3.82342704 | 2.57034321 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.87727040 | 3.40438739 | -0.06773249 | h | 1.000 | 0 |
| -1.59745526 | -2.88487430 | 2.53354258 | h | 1.000 | 0 |
| 0.52542916 | 1.85680909 | -0.21858943 | h | 1.000 | 0 |
| 2.47934489 | -3.34806483 | 1.43708128 | h | 1.000 | 0 |
| 4.08596943 | 2.88369999 | -1.80299641 | h | 1.000 | 0 |
| 8.30685384 | 3.76540172 | -3.49838293 | h | 1.000 | 0 |
| 11.70494996 | 0.57656997 | -3.14368273 | h | 1.000 | 0 |
| 10.85997836 | -3.53096113 | -1.07175894 | h | 1.000 | 0 |
| 6.61086255 | -4.43605657 | 0.64149857 | h | 1.000 | 0 |

(*E*)-4-(3-Phenylallylidene)morpholin-4-ium Product:

The $CH_3$-CH-CH-CHN Torsion Angle was constrained to 270°.

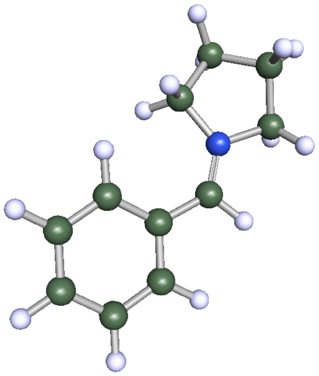


Total Energy = -674.36181835520 hartree
Enthalpy Correction = 0.322819 hartree
Entropy = 0.000194 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.74414015 | -0.92465662 | -0.98654731 | c | 6.000 | 0 |
| -2.72979904 | -1.88954142 | -2.82936374 | c | 6.000 | 0 |
| -3.44941538 | -4.41160275 | -3.95436735 | c | 6.000 | 0 |
| -3.81718091 | -6.52737513 | -2.42673320 | c | 6.000 | 0 |
| -4.46593671 | -8.84420577 | -3.46756109 | c | 6.000 | 0 |
| -4.76416125 | -9.08962369 | -6.06528989 | c | 6.000 | 0 |
| -4.40596490 | -6.99809556 | -7.60589896 | c | 6.000 | 0 |
| -3.75350688 | -4.68314138 | -6.55234961 | c | 6.000 | 0 |
| -0.15999670 | -1.99390161 | -1.61435435 | c | 6.000 | 0 |
| 1.43793217 | -0.03565912 | -1.67345474 | c | 6.000 | 0 |
| 3.69764443 | 0.22866090 | -0.39718867 | n | 7.000 | 0 |
| 4.65413065 | -1.93234724 | 0.97170697 | c | 6.000 | 0 |
| 6.84598696 | -1.15272381 | 2.63482886 | c | 6.000 | 0 |
| 8.76726257 | 0.07865238 | 1.24289607 | o | 8.000 | 0 |
| 7.78489637 | 2.26735745 | 0.05988341 | c | 6.000 | 0 |
| 5.66607932 | 1.59978247 | -1.73265103 | c | 6.000 | 0 |
| -6.59973042 | -0.84769457 | -1.89306081 | h | 1.000 | 0 |
| -4.24778980 | 0.96838545 | -0.33307837 | h | 1.000 | 0 |
| -4.88734813 | -2.15113813 | 0.66948828 | h | 1.000 | 0 |
| -2.63464124 | -0.53157920 | -4.38987733 | h | 1.000 | 0 |
| -3.59379699 | -6.36779309 | -0.39464767 | h | 1.000 | 0 |
| -4.74143254 | -10.46682047 | -2.24619623 | h | 1.000 | 0 |
| -5.27266526 | -10.89946390 | -6.87978529 | h | 1.000 | 0 |
| -4.63378391 | -7.16517385 | -9.63585961 | h | 1.000 | 0 |
| -3.47345061 | -3.05516922 | -7.76900061 | h | 1.000 | 0 |
| 0.27245317 | -3.66654567 | -0.50830780 | h | 1.000 | 0 |
| 0.96532523 | 1.61204985 | -2.81174954 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 5.24991816 | -3.43873410 | -0.33849949 | h | 1.000 | 0 |
| 3.15828270 | -2.69901563 | 2.17002423 | h | 1.000 | 0 |
| 6.16167057 | 0.11186439 | 4.13416608 | h | 1.000 | 0 |
| 7.69851573 | -2.81409044 | 3.50740920 | h | 1.000 | 0 |
| 7.09431657 | 3.58852610 | 1.50658894 | h | 1.000 | 0 |
| 9.33826650 | 3.15348651 | -0.96506700 | h | 1.000 | 0 |
| 4.86165737 | 3.32441478 | -2.53333811 | h | 1.000 | 0 |
| 6.43013029 | 0.46140000 | -3.29988679 | h | 1.000 | 0 |

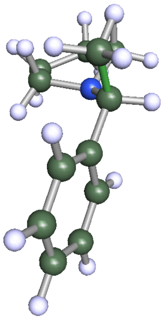
1-Benzylidenepyrrolidin-1-ium (MAA* = 251.8 kJ/mol, E = -9.35):



Total Energy = -481.81775913484 hartree
Enthalpy Correction = 0.242314 hartree
Entropy = 0.000155 hartree/K
LUMO Energy = -0.0962 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.16035080 | -0.35744026 | -0.39624763 | n | 7.000 | 0 |
| 2.34914680 | 2.20274201 | 0.66413461 | c | 6.000 | 0 |
| 5.08321848 | 2.94870454 | 0.20469794 | c | 6.000 | 0 |
| 6.47744323 | 0.43188548 | 0.29992145 | c | 6.000 | 0 |
| 4.69144743 | -1.31928438 | -1.09015480 | c | 6.000 | 0 |
| 0.15922403 | -1.67929938 | -0.76667996 | c | 6.000 | 0 |
| -2.44644913 | -1.11172381 | -0.23588956 | c | 6.000 | 0 |
| -3.34762578 | 0.94283756 | 1.17702380 | c | 6.000 | 0 |
| -5.91511681 | 1.23866864 | 1.54444543 | c | 6.000 | 0 |
| -7.61578021 | -0.47790235 | 0.51186876 | c | 6.000 | 0 |
| -6.74759619 | -2.52706340 | -0.87850325 | c | 6.000 | 0 |
| -4.18232166 | -2.85088269 | -1.23385614 | c | 6.000 | 0 |
| 0.98077769 | 3.43579154 | -0.25512957 | h | 1.000 | 0 |
| 1.92474293 | 2.09823388 | 2.68149817 | h | 1.000 | 0 |
| 5.27675068 | 3.80691311 | -1.66254698 | h | 1.000 | 0 |
| 5.73697995 | 4.29974129 | 1.61195875 | h | 1.000 | 0 |
| 6.71547301 | -0.19328928 | 2.25313260 | h | 1.000 | 0 |
| 8.32769283 | 0.49495702 | -0.59809364 | h | 1.000 | 0 |
| 4.83546018 | -3.30366959 | -0.57118121 | h | 1.000 | 0 |
| 4.89335105 | -1.13078040 | -3.13590162 | h | 1.000 | 0 |
| 0.50179197 | -3.50635275 | -1.63797338 | h | 1.000 | 0 |
| -2.07645151 | 2.28853777 | 2.03009747 | h | 1.000 | 0 |
| -6.59935961 | 2.81975177 | 2.64940678 | h | 1.000 | 0 |
| -9.62610611 | -0.22119423 | 0.80688393 | h | 1.000 | 0 |
| -8.06853680 | -3.87409557 | -1.67145278 | h | 1.000 | 0 |
| -3.48850726 | -4.45578650 | -2.30145916 | h | 1.000 | 0 |

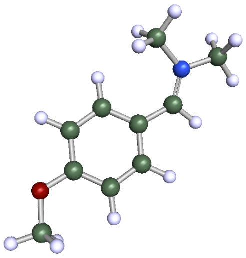
1-Benzylidenepyrrolidin-1-ium Product:



Total Energy = -521.84524231799 hartree
Enthalpy Correction = 0.280779 hartree
Entropy = 0.000171 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.68216610 | -4.76214106 | 1.89791190 | c | 6.000 | 0 |
| 0.90986996 | -1.99209810 | 1.70099781 | c | 6.000 | 0 |
| 2.86143922 | -0.33929873 | 0.40150388 | c | 6.000 | 0 |
| 5.15235341 | -1.25521088 | -0.49954804 | c | 6.000 | 0 |
| 6.88320798 | 0.34862831 | -1.66091193 | c | 6.000 | 0 |
| 6.34761404 | 2.89770583 | -1.93072164 | c | 6.000 | 0 |
| 4.06219381 | 3.83615555 | -1.03165627 | c | 6.000 | 0 |
| 2.34406586 | 2.22973847 | 0.11591086 | c | 6.000 | 0 |
| -1.54517132 | -1.54847406 | 0.54581176 | n | 7.000 | 0 |
| -1.90699769 | -2.46451878 | -2.01080724 | c | 6.000 | 0 |
| -4.68846549 | -1.89000658 | -2.51677422 | c | 6.000 | 0 |
| -5.92388050 | -1.91636642 | 0.12749465 | c | 6.000 | 0 |
| -3.73161017 | -2.42494610 | 1.93988978 | c | 6.000 | 0 |
| 0.20398361 | -5.85256871 | 2.83469934 | h | 1.000 | 0 |
| 3.40263722 | -4.95666235 | 3.01972657 | h | 1.000 | 0 |
| 2.02778048 | -5.60885945 | 0.04778050 | h | 1.000 | 0 |
| 0.73301552 | -1.27287328 | 3.63942524 | h | 1.000 | 0 |
| 5.61352210 | -3.24028730 | -0.31187877 | h | 1.000 | 0 |
| 8.65547357 | -0.40867684 | -2.35807319 | h | 1.000 | 0 |
| 7.69536717 | 4.14872503 | -2.83455001 | h | 1.000 | 0 |
| 3.62283474 | 5.82847418 | -1.22933916 | h | 1.000 | 0 |
| 0.54601785 | 2.94461455 | 0.78855076 | h | 1.000 | 0 |
| -1.56908517 | -4.51637366 | -2.16386580 | h | 1.000 | 0 |
| -0.62012973 | -1.51716673 | -3.31793227 | h | 1.000 | 0 |
| -4.88722197 | -0.03072375 | -3.38713747 | h | 1.000 | 0 |
| -5.52928135 | -3.26979344 | -3.79766821 | h | 1.000 | 0 |
| -7.38976545 | -3.35638236 | 0.29755016 | h | 1.000 | 0 |
| -6.79603208 | -0.09312782 | 0.53737430 | h | 1.000 | 0 |
| -3.63246715 | -4.46352916 | 2.36836105 | h | 1.000 | 0 |
| -3.89740756 | -1.41824079 | 3.73643056 | h | 1.000 | 0 |

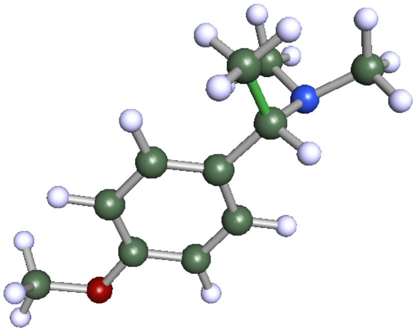
*N*-(4-Methoxybenzylidene)-*N*-methylmethanaminium (MAA* = 251.3 kJ/mol, E = -10.69):



Total Energy = -518.90460684980 hartree
Enthalpy Correction = 0.239862 hartree
Entropy = 0.000167 hartree/K
LUMO Energy = -0.0866 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.46522327 | -2.23360994 | -0.94620578 | c | 6.000 | 0 |
| -5.04503047 | 0.47446346 | -1.13092101 | n | 7.000 | 0 |
| -7.29197268 | 1.96273864 | -1.67911300 | c | 6.000 | 0 |
| -2.88715875 | 1.57840980 | -0.82933793 | c | 6.000 | 0 |
| -0.43535275 | 0.53604504 | -0.39452728 | c | 6.000 | 0 |
| 0.32820185 | -1.98221697 | -0.80690797 | c | 6.000 | 0 |
| 2.76555213 | -2.71061685 | -0.32154380 | c | 6.000 | 0 |
| 4.53274657 | -0.97013214 | 0.61256941 | c | 6.000 | 0 |
| 6.84096686 | -1.87096613 | 1.05031387 | o | 8.000 | 0 |
| 8.71829525 | -0.19401399 | 1.99683412 | c | 6.000 | 0 |
| 3.82487940 | 1.54497592 | 0.99637509 | c | 6.000 | 0 |
| 1.38250520 | 2.26765397 | 0.46376870 | c | 6.000 | 0 |
| -4.29425988 | -3.02972103 | 0.54388045 | h | 1.000 | 0 |
| -7.44507748 | -2.53954011 | -0.48897015 | h | 1.000 | 0 |
| -5.04807191 | -3.14889994 | -2.74620609 | h | 1.000 | 0 |
| -6.79888781 | 3.95191910 | -1.81136672 | h | 1.000 | 0 |
| -8.67317898 | 1.67018444 | -0.17809275 | h | 1.000 | 0 |
| -8.09383942 | 1.32212531 | -3.46684968 | h | 1.000 | 0 |
| -2.97569819 | 3.62677083 | -0.89018853 | h | 1.000 | 0 |
| -0.95387622 | -3.36710709 | -1.58010329 | h | 1.000 | 0 |
| 3.36774860 | -4.63653276 | -0.66251521 | h | 1.000 | 0 |
| 8.15066092 | 0.58347842 | 3.82246091 | h | 1.000 | 0 |
| 9.07453539 | 1.33641665 | 0.65907111 | h | 1.000 | 0 |
| 10.41690254 | -1.32652260 | 2.22284321 | h | 1.000 | 0 |
| 5.16162219 | 2.92941696 | 1.68029302 | h | 1.000 | 0 |
| 0.84301092 | 4.22528101 | 0.73587519 | h | 1.000 | 0 |

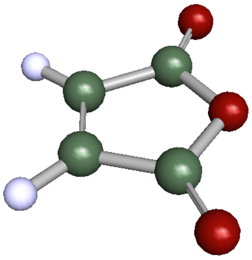
*N*-(4-Methoxybenzylidene)-*N*-methylmethanaminium Product:



Total Energy = -558.93248478807 hartree
Enthalpy Correction = 0.278003 hartree
Entropy = 0.00018 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.93483973 | -1.91459286 | 3.13791199 | c | 6.000 | 0 |
| -4.32386573 | -0.38589732 | 0.90686063 | n | 7.000 | 0 |
| -6.96138538 | 0.22766911 | 0.56351344 | c | 6.000 | 0 |
| -2.66394842 | 1.82720302 | 0.75726955 | c | 6.000 | 0 |
| -2.96584701 | 3.70755292 | 2.91958206 | c | 6.000 | 0 |
| 0.03334772 | 0.96154657 | 0.35453374 | c | 6.000 | 0 |
| 0.58652363 | -0.52611300 | -1.75531312 | c | 6.000 | 0 |
| 3.00435510 | -1.37445211 | -2.23206903 | c | 6.000 | 0 |
| 4.97079071 | -0.75658445 | -0.58272449 | c | 6.000 | 0 |
| 7.28427428 | -1.66800220 | -1.18858663 | o | 8.000 | 0 |
| 9.31612600 | -1.07772415 | 0.44696071 | c | 6.000 | 0 |
| 4.46432434 | 0.71999495 | 1.52570954 | c | 6.000 | 0 |
| 2.00755293 | 1.56118472 | 1.96580514 | c | 6.000 | 0 |
| -1.93201923 | -2.36713774 | 3.34125001 | h | 1.000 | 0 |
| -4.98033325 | -3.68496794 | 2.94383212 | h | 1.000 | 0 |
| -4.57590842 | -0.99796287 | 4.89569420 | h | 1.000 | 0 |
| -8.05062297 | -1.51635235 | 0.36524229 | h | 1.000 | 0 |
| -7.78838042 | 1.29900849 | 2.14875505 | h | 1.000 | 0 |
| -7.20386603 | 1.34215901 | -1.15787912 | h | 1.000 | 0 |
| -3.23848767 | 2.80175356 | -0.98063875 | h | 1.000 | 0 |
| -1.81824444 | 5.38919772 | 2.58326428 | h | 1.000 | 0 |
| -2.40075614 | 2.90520134 | 4.73514965 | h | 1.000 | 0 |
| -4.93105837 | 4.31318825 | 3.07508568 | h | 1.000 | 0 |
| -0.93202793 | -1.03332124 | -3.03535158 | h | 1.000 | 0 |
| 3.41620634 | -2.52032896 | -3.88033966 | h | 1.000 | 0 |
| 9.61819639 | 0.96432447 | 0.55877722 | h | 1.000 | 0 |
| 8.98893865 | -1.82492542 | 2.34678737 | h | 1.000 | 0 |
| 10.98175745 | -1.97201480 | -0.36167386 | h | 1.000 | 0 |
| 5.94589658 | 1.22994749 | 2.83879020 | h | 1.000 | 0 |
| 1.66852215 | 2.71012480 | 3.62587248 | h | 1.000 | 0 |

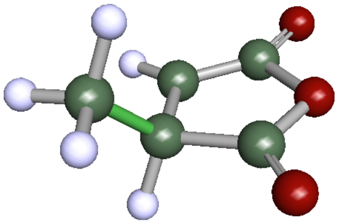
Furan-2,5-dione (MAA* = 246.6 kJ/mol, E = -11.31):



Total Energy = -379.05559693714 hartree
Enthalpy Correction = 0.062503 hartree
Entropy = 0.000115 hartree/K
LUMO Energy = -0.1100 hartree

```
               atomic coordinates                atom    charge  isotop
 -4.17039244   -2.05816569   -0.21977637     o      8.000     0
 -2.10047868   -1.17975683   -0.11083190     c      6.000     0
 -1.26235844    1.48199647   -0.05147045     c      6.000     0
  1.24441982    1.49625233    0.07094228     c      6.000     0
  0.01620588   -2.69568017   -0.01700436     o      8.000     0
  2.11444349   -1.15580391    0.09597593     c      6.000     0
  4.19491868   -2.01046037    0.19282272     o      8.000     0
 -2.57116184    3.04630358   -0.10454759     h      1.000     0
  2.53440354    3.07531459    0.14388973     h      1.000     0
```

Furan-2,5-dione Product:

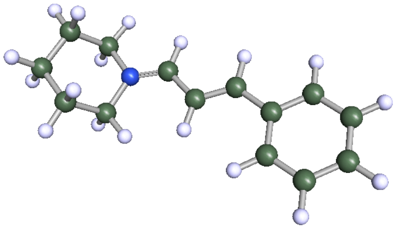


Total Energy = -419.08081603180 hartree
Enthalpy Correction = 0.101869 hartree
Entropy = 0.000135 hartree/K

```
               atomic coordinates                atom    charge  isotop
  5.95246277   -0.17217419   -0.68351152     o      8.000     0
  3.67912357    0.03199465   -0.18879571     c      6.000     0
  1.78440947   -1.38661756    0.80285493     c      6.000     0
 -0.63592374    0.05322217    0.87955277     c      6.000     0
 -2.85395126   -1.07624012   -0.58454132     c      6.000     0
  0.14831825    2.56666346   -0.22962980     c      6.000     0
  2.58273663    2.54969713   -0.82926227     o      8.000     0
 -1.17473330    4.40368907   -0.58361085     o      8.000     0
  2.03084468   -3.30871161    1.44567788     h      1.000     0
 -1.29704273    0.45212616    2.81084391     h      1.000     0
```

```
   -4.49180869    0.18007268   -0.53641443    h       1.000      0
   -2.32742504   -1.41064842   -2.55335309    h       1.000      0
   -3.39701062   -2.88307340    0.25018949    h       1.000      0
```

(*E*)-1-(3-Phenylallylidene)piperidin-1-ium (MAA* = 245.7 kJ/mol, E = -10.3):

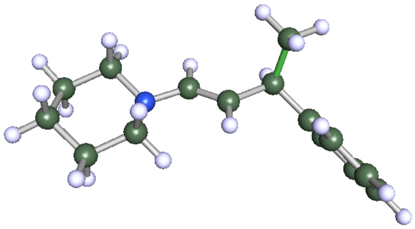


Total Energy = -598.45342092170 hartree
Enthalpy Correction = 0.308659 hartree
Entropy = 0.00018 hartree/K
LUMO Energy = -0.1031 hartree

```
                 atomic coordinates              atom    charge  isotop
    3.51237506   -0.63437091   -1.23358932    n       7.000      0
    5.70166665   -2.28598580   -1.57624815    c       6.000      0
    7.55216769   -1.94633655    0.59212611    c       6.000      0
    8.29827145    0.81311713    0.88319337    c       6.000      0
    5.96343218    2.46661510    1.14708962    c       6.000      0
    4.14444329    2.04504239   -1.03723127    c       6.000      0
    1.25651576   -1.55998204   -1.06219054    c       6.000      0
   -1.02455718   -0.20917641   -0.69886177    c       6.000      0
   -3.20629094   -1.53679402   -0.58668917    c       6.000      0
   -5.71794202   -0.53441834   -0.23853877    c       6.000      0
   -6.20491470    2.05256630    0.05785799    c       6.000      0
   -8.65104729    2.90183024    0.37949229    c       6.000      0
  -10.65212437    1.19291990    0.41080158    c       6.000      0
  -10.19754065   -1.37453965    0.12056726    c       6.000      0
   -7.74730438   -2.23158898   -0.20070249    c       6.000      0
    5.03000245   -4.22481561   -1.72263214    h       1.000      0
    6.58553109   -1.75586067   -3.36868088    h       1.000      0
    6.67853162   -2.63782866    2.33498045    h       1.000      0
    9.20189087   -3.12861659    0.21840107    h       1.000      0
    9.38059793    1.41250709   -0.77770443    h       1.000      0
    9.52674472    1.05037086    2.52406766    h       1.000      0
    4.98708680    2.04851165    2.92254057    h       1.000      0
    6.46714515    4.46730963    1.17845066    h       1.000      0
    5.02964375    2.57714845   -2.82784416    h       1.000      0
    2.43002656    3.14971572   -0.81858580    h       1.000      0
    1.13321177   -3.60268262   -1.22472132    h       1.000      0
   -1.00853151    1.82669374   -0.52374339    h       1.000      0
   -3.09068523   -3.57976566   -0.78078389    h       1.000      0
   -4.66662809    3.40331413    0.03678201    h       1.000      0
   -9.01239831    4.90440651    0.60750300    h       1.000      0
  -12.56828518    1.87117155    0.66258923    h       1.000      0
  -11.75298755   -2.70562213    0.14456496    h       1.000      0
   -7.37804741   -4.23485574   -0.42860878    h       1.000      0
```

(*E*)-1-(3-Phenylallylidene)piperidin-1-ium Product:

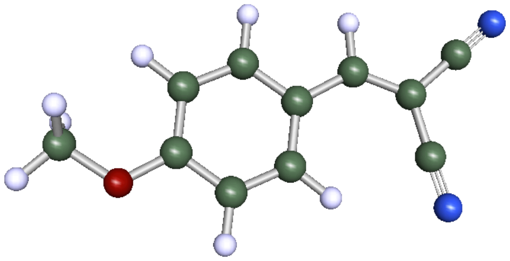
The $CH_3$-CH-CH-CHN Torsion Angle was constrained to 270°.



Total Energy = -638.47828307863 hartree
Enthalpy Correction = 0.346813 hartree
Entropy = 0.000196 hartree/K

```
                 atomic coordinates               atom    charge  isotop
   -5.05212615   -0.71468982   -0.31142535    c       6.000     0
   -3.22183331   -2.18967802   -2.00055031    c       6.000     0
   -4.35944736   -2.77980203   -4.55033246    c       6.000     0
   -4.54685919   -5.26436652   -5.39221158    c       6.000     0
   -5.56225291   -5.82489183   -7.74765813    c       6.000     0
   -6.41048126   -3.89482402   -9.30707226    c       6.000     0
   -6.23469673   -1.40541952   -8.48955200    c       6.000     0
   -5.22052166   -0.85804480   -6.13505402    c       6.000     0
   -0.73067452   -0.83842218   -2.27708697    c       6.000     0
    1.20180707   -1.23117057   -0.69179802    c       6.000     0
    3.57956133   -0.16401624   -0.74124409    n       7.000     0
    4.02271487    1.86417179   -2.52166802    c       6.000     0
    6.82455420    2.41305095   -2.81220861    c       6.000     0
    8.07757934    2.88046111   -0.27088318    c       6.000     0
    7.56603523    0.66667694    1.48708532    c       6.000     0
    4.74928657    0.20203571    1.72049121    c       6.000     0
   -5.42906444    1.16537638   -1.08065049    h       1.000     0
   -6.85507125   -1.70784855   -0.12572961    h       1.000     0
   -4.23090222   -0.47580164    1.56626869    h       1.000     0
   -2.86196143   -4.00240369   -1.06789338    h       1.000     0
   -3.88430426   -6.78345516   -4.18293328    h       1.000     0
   -5.69068516   -7.77556951   -8.36337593    h       1.000     0
   -7.20456943   -4.32439495  -11.14623830    h       1.000     0
   -6.89283890    0.11752953   -9.69294931    h       1.000     0
   -5.09711800    1.09610410   -5.52595445    h       1.000     0
   -0.61260727    0.58207606   -3.75234474    h       1.000     0
    0.97865319   -2.60708315    0.82237810    h       1.000     0
    3.23302696    1.30995472   -4.34562991    h       1.000     0
    3.01507110    3.58997888   -1.91970757    h       1.000     0
    7.72909032    0.79619122   -3.73623447    h       1.000     0
    7.05732120    4.04075416   -4.06287716    h       1.000     0
   10.10916267    3.17283920   -0.50662863    h       1.000     0
    7.30992883    4.61323461    0.56888236    h       1.000     0
    8.47593729   -1.03750448    0.74279662    h       1.000     0
    8.34861646    1.01618022    3.36718749    h       1.000     0
    4.37721733   -1.47925832    2.85952164    h       1.000     0
    3.86915652    1.81774775    2.70287416    h       1.000     0
```

2-(4-Methoxybenzylidene)malononitrile (MAA* = 245.4 kJ/mol, E = -10.8):

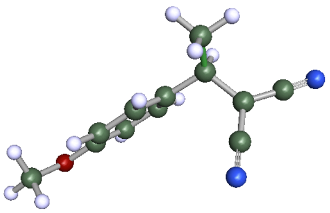


Total Energy = -608.20435634771 hartree
Enthalpy Correction = 0.000176 hartree
Entropy = 0.178895 hartree/K
LUMO Energy = -0.0968 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -7.64754147 | -0.98422101 | 1.17029983 | c | 6.000 | 0 |
| -5.40416003 | -2.46247208 | 1.08939122 | o | 8.000 | 0 |
| -3.23102506 | -1.32058551 | 0.52342492 | c | 6.000 | 0 |
| -3.00126759 | 1.25559728 | -0.00324654 | c | 6.000 | 0 |
| -0.65223508 | 2.22962091 | -0.56590682 | c | 6.000 | 0 |
| 1.52133802 | 0.70894254 | -0.62650295 | c | 6.000 | 0 |
| 3.84230142 | 1.93683119 | -1.23503034 | c | 6.000 | 0 |
| 6.24519457 | 1.01866262 | -1.45351700 | c | 6.000 | 0 |
| 8.23623418 | 2.70225709 | -2.09607584 | c | 6.000 | 0 |
| 9.85857966 | 4.06072300 | -2.61746336 | n | 7.000 | 0 |
| 6.98907691 | -1.53214775 | -1.09530072 | c | 6.000 | 0 |
| 7.65486319 | -3.58853006 | -0.81808663 | n | 7.000 | 0 |
| 1.24195676 | -1.88493960 | -0.08798081 | c | 6.000 | 0 |
| -1.08258381 | -2.87546411 | 0.47399104 | c | 6.000 | 0 |
| -8.03170503 | -0.13336752 | -0.67085793 | h | 1.000 | 0 |
| -9.15920261 | -2.28549982 | 1.66080658 | h | 1.000 | 0 |
| -7.50273203 | 0.48932289 | 2.60896723 | h | 1.000 | 0 |
| -4.62838387 | 2.48974148 | 0.02317834 | h | 1.000 | 0 |
| -0.47502893 | 4.22966509 | -0.97491754 | h | 1.000 | 0 |
| 3.67475496 | 3.95155486 | -1.58801150 | h | 1.000 | 0 |
| 2.85488049 | -3.13771928 | -0.10821218 | h | 1.000 | 0 |
| -1.30331465 | -4.86797219 | 0.88805081 | h | 1.000 | 0 |

2-(4-Methoxybenzylidene)malononitrile Product:

The $CH_3$-C-C-CN Torsion Angle was constrained to 90°.

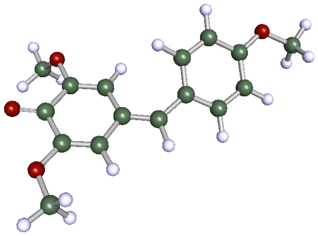


Total Energy = -648.23076547955 hartree
Enthalpy Correction = 0.218719 hartree

Entropy = 0.000192 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.77111567 | 1.97012534 | -2.46777313 | c | 6.000 | 0 |
| 3.39475244 | -0.54231985 | -2.13227820 | c | 6.000 | 0 |
| 4.88261143 | -2.38116638 | -0.48061747 | c | 6.000 | 0 |
| 6.69427887 | -3.92467244 | -1.55954440 | c | 6.000 | 0 |
| 8.19909606 | -5.21412665 | -2.53848055 | n | 7.000 | 0 |
| 4.56808728 | -2.45285355 | 2.11424776 | c | 6.000 | 0 |
| 4.27225484 | -2.49969469 | 4.30220630 | n | 7.000 | 0 |
| 0.71405078 | -0.25775564 | -1.19445168 | c | 6.000 | 0 |
| -1.14827714 | -1.93145818 | -2.02388700 | c | 6.000 | 0 |
| -3.61036695 | -1.77198522 | -1.17323811 | c | 6.000 | 0 |
| -4.28715437 | 0.09129947 | 0.56512856 | c | 6.000 | 0 |
| -6.74159362 | 0.12160532 | 1.29664813 | o | 8.000 | 0 |
| -7.48670326 | 1.99022951 | 3.05742493 | c | 6.000 | 0 |
| -2.46328260 | 1.77459353 | 1.42202041 | c | 6.000 | 0 |
| 0.00545629 | 1.58128035 | 0.53414187 | c | 6.000 | 0 |
| 3.70869989 | 3.25219724 | -3.69290360 | h | 1.000 | 0 |
| 6.62351089 | 1.64336576 | -3.31754712 | h | 1.000 | 0 |
| 5.07676838 | 2.90909116 | -0.65470234 | h | 1.000 | 0 |
| 3.26612752 | -1.42840027 | -3.99796965 | h | 1.000 | 0 |
| -0.65173782 | -3.39347265 | -3.37518206 | h | 1.000 | 0 |
| -5.04459313 | -3.07241140 | -1.84472224 | h | 1.000 | 0 |
| -6.45625443 | 1.79448447 | 4.83908567 | h | 1.000 | 0 |
| -7.19045706 | 3.89206961 | 2.30225387 | h | 1.000 | 0 |
| -9.49385088 | 1.69461882 | 3.39325691 | h | 1.000 | 0 |
| -2.93075642 | 3.24079393 | 2.76781260 | h | 1.000 | 0 |
| 1.38997317 | 2.92004135 | 1.23114225 | h | 1.000 | 0 |

2,6-Dimethoxy-4-(4-methoxybenzylidene)cyclohexa-2,5-dien-1-one (MAA* = 244.8 kJ/mol, E = -16.38):



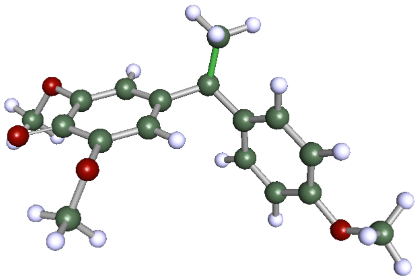
Total Energy = -919.51448184073 hartree
Enthalpy Correction = 0.309964 hartree
Entropy = 0.000221 hartree/K
LUMO Energy = -0.0988 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -9.10986279 | 1.54083425 | 1.65271886 | o | 8.000 | 0 |
| -6.98503435 | 0.81191269 | 1.05146854 | c | 6.000 | 0 |
| -6.55048328 | -1.70545628 | -0.02450195 | c | 6.000 | 0 |
| -8.69584480 | -3.02266718 | -0.35499277 | o | 8.000 | 0 |
| -8.46446011 | -5.49243170 | -1.35790880 | c | 6.000 | 0 |
| -4.18937382 | -2.53220175 | -0.55727485 | c | 6.000 | 0 |
| -4.73959103 | 2.40196097 | 1.33714222 | c | 6.000 | 0 |
| -5.05117924 | 4.78030071 | 2.25355823 | o | 8.000 | 0 |
| -6.33781358 | 6.47974249 | 0.60201660 | c | 6.000 | 0 |
| -2.39667278 | 1.52793991 | 0.83203792 | c | 6.000 | 0 |
| -2.00045725 | -0.99620413 | -0.06751081 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 0.32860117 | -2.01257935 | -0.56437113 | c | 6.000 | 0 |
| 2.82135735 | -1.05820761 | -0.04806635 | c | 6.000 | 0 |
| 3.42009029 | 0.64486786 | 1.90481748 | c | 6.000 | 0 |
| 5.85710269 | 1.46698585 | 2.26750048 | c | 6.000 | 0 |
| 7.80486765 | 0.62074867 | 0.69163273 | c | 6.000 | 0 |
| 10.11588337 | 1.54182523 | 1.17818146 | o | 8.000 | 0 |
| 12.16041051 | 0.70317802 | -0.34289780 | c | 6.000 | 0 |
| 7.27276961 | -1.12036638 | -1.21522741 | c | 6.000 | 0 |
| 4.81994580 | -1.95506792 | -1.53740259 | c | 6.000 | 0 |
| -7.33385211 | -6.69331913 | -0.11138388 | h | 1.000 | 0 |
| -7.60185736 | -5.45136338 | -3.23634729 | h | 1.000 | 0 |
| -10.37457455 | -6.23992229 | -1.49132348 | h | 1.000 | 0 |
| -3.87578416 | -4.40857791 | -1.31042585 | h | 1.000 | 0 |
| -6.50919644 | 8.26111588 | 1.61691116 | h | 1.000 | 0 |
| -5.22961926 | 6.77084004 | -1.11894733 | h | 1.000 | 0 |
| -8.21214485 | 5.77109684 | 0.12008399 | h | 1.000 | 0 |
| -0.81906669 | 2.81145044 | 1.03502361 | h | 1.000 | 0 |
| 0.30634709 | -3.82753108 | -1.52896420 | h | 1.000 | 0 |
| 1.97565659 | 1.25485255 | 3.21634974 | h | 1.000 | 0 |
| 6.31286839 | 2.75108076 | 3.79608028 | h | 1.000 | 0 |
| 12.42405017 | -1.33781501 | -0.16720614 | h | 1.000 | 0 |
| 11.85845546 | 1.19716647 | -2.32531887 | h | 1.000 | 0 |
| 13.82673236 | 1.67604211 | 0.36400118 | h | 1.000 | 0 |
| 8.74940398 | -1.83956031 | -2.43068454 | h | 1.000 | 0 |
| 4.42232598 | -3.32067033 | -3.01331071 | h | 1.000 | 0 |

2,6-Dimethoxy-4-(4-methoxybenzylidene)cyclohexa-2,5-dien-1-one Product:

The $CH_3$-C-C=C Torsion Angle was constrained to 90°.

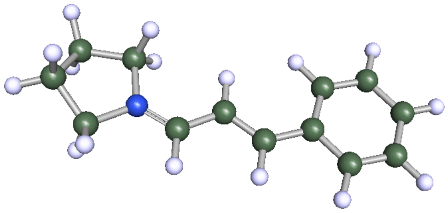


Total Energy = -959.54020663808 hartree
Enthalpy Correction = 0.34902 hartree
Entropy = 0.000236 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -8.74908721 | 1.47295577 | 0.62307142 | o | 8.000 | 0 |
| -6.57697631 | 0.67232654 | -0.08737393 | c | 6.000 | 0 |
| -6.20468319 | -1.68105891 | -1.35245589 | c | 6.000 | 0 |
| -8.26915605 | -3.19382938 | -1.85468465 | o | 8.000 | 0 |
| -9.45467326 | -4.15805028 | 0.34841548 | c | 6.000 | 0 |
| -3.87359933 | -2.46932511 | -2.24334019 | c | 6.000 | 0 |
| -1.70724452 | -1.01209597 | -1.91964989 | c | 6.000 | 0 |
| 0.79239768 | -1.84574443 | -3.04061047 | c | 6.000 | 0 |
| 1.07568408 | -0.87973687 | -5.74427036 | c | 6.000 | 0 |
| 2.98959460 | -1.17133641 | -1.34554035 | c | 6.000 | 0 |
| 4.68018147 | 0.75988696 | -1.86919957 | c | 6.000 | 0 |
| 6.64027642 | 1.38045022 | -0.22120117 | c | 6.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 6.93250596 | 0.03617916 | 2.01232928 | c | 6.000 | 0 |
| 8.76947867 | 0.48101695 | 3.74228592 | o | 8.000 | 0 |
| 10.49010884 | 2.46397949 | 3.23695440 | c | 6.000 | 0 |
| 5.25597510 | -1.92467487 | 2.56830354 | c | 6.000 | 0 |
| 3.32624643 | -2.49933521 | 0.91235659 | c | 6.000 | 0 |
| -1.96825274 | 1.25239921 | -0.60708092 | c | 6.000 | 0 |
| -4.29148101 | 2.05526352 | 0.28755061 | c | 6.000 | 0 |
| -4.39703997 | 4.37780766 | 1.47169647 | o | 8.000 | 0 |
| -5.14078554 | 4.23734619 | 4.04300061 | c | 6.000 | 0 |
| -8.16795955 | -5.42042354 | 1.36968376 | h | 1.000 | 0 |
| -11.10239874 | -5.23160938 | -0.26961424 | h | 1.000 | 0 |
| -10.04445418 | -2.61321726 | 1.58281299 | h | 1.000 | 0 |
| -3.77370283 | -4.27148027 | -3.22484406 | h | 1.000 | 0 |
| 0.73619267 | -3.91534116 | -3.13807306 | h | 1.000 | 0 |
| 1.01387757 | 1.18391984 | -5.81240068 | h | 1.000 | 0 |
| 2.85281576 | -1.50616368 | -6.59350036 | h | 1.000 | 0 |
| -0.48101647 | -1.58486502 | -6.90017839 | h | 1.000 | 0 |
| 4.50000465 | 1.83990890 | -3.59947274 | h | 1.000 | 0 |
| 7.91191039 | 2.90547904 | -0.70925025 | h | 1.000 | 0 |
| 9.51546570 | 4.28112656 | 3.08638064 | h | 1.000 | 0 |
| 11.54991225 | 2.11190209 | 1.49691173 | h | 1.000 | 0 |
| 11.79014608 | 2.51607871 | 4.82951176 | h | 1.000 | 0 |
| 5.50004561 | -2.97559088 | 4.31055243 | h | 1.000 | 0 |
| 2.02865107 | -4.01852028 | 1.37932096 | h | 1.000 | 0 |
| -0.33494427 | 2.44283078 | -0.25208209 | h | 1.000 | 0 |
| -3.73040556 | 3.19802284 | 5.14892637 | h | 1.000 | 0 |
| -6.97951932 | 3.31541682 | 4.21133432 | h | 1.000 | 0 |
| -5.25896608 | 6.17083749 | 4.74818973 | h | 1.000 | 0 |

(*E*)-1-(3-Phenylallylidene)pyrrolidin-1-ium (MAA* = 242.1 kJ/mol, E = -9.80):



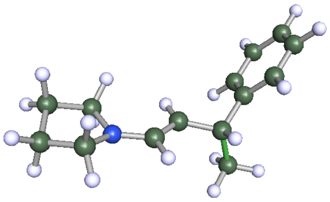
Total Energy = -559.16787269887 hartree
Enthalpy Correction = 0.277983 hartree
Entropy = 0.000175 hartree/K
LUMO Energy = -0.1047 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.22850072 | -0.67576075 | 0.08407246 | n | 7.000 | 0 |
| -6.60664758 | -2.10890692 | 0.01311929 | c | 6.000 | 0 |
| -8.57454807 | -0.14426040 | 0.70663894 | c | 6.000 | 0 |
| -7.52905886 | 2.24996678 | -0.50987230 | c | 6.000 | 0 |
| -4.70057545 | 2.06017601 | -0.03512531 | c | 6.000 | 0 |
| -2.03236079 | -1.71303432 | 0.27887484 | c | 6.000 | 0 |
| 0.28526666 | -0.38136854 | 0.37665896 | c | 6.000 | 0 |
| 2.45943880 | -1.71069167 | 0.58200719 | c | 6.000 | 0 |
| 4.99014868 | -0.70676335 | 0.71212230 | c | 6.000 | 0 |
| 5.51002659 | 1.89047211 | 0.65274272 | c | 6.000 | 0 |
| 7.97298109 | 2.74153957 | 0.78485406 | c | 6.000 | 0 |
| 9.95799979 | 1.02422231 | 0.97655577 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 9.47102133 | -1.55312851 | 1.03661518 | c | 6.000 | 0 |
| 7.00400403 | -2.41199530 | 0.90609043 | c | 6.000 | 0 |
| -6.48948504 | -3.71435718 | 1.29395790 | h | 1.000 | 0 |
| -6.88496323 | -2.79932692 | -1.91383386 | h | 1.000 | 0 |
| -8.67291941 | 0.06837239 | 2.75806719 | h | 1.000 | 0 |
| -10.44223815 | -0.65739101 | 0.01179877 | h | 1.000 | 0 |
| -8.31321247 | 3.97718588 | 0.28741328 | h | 1.000 | 0 |
| -7.90639643 | 2.24207440 | -2.53894314 | h | 1.000 | 0 |
| -3.54831384 | 2.90785587 | -1.51664247 | h | 1.000 | 0 |
| -4.16529840 | 2.88640920 | 1.77994798 | h | 1.000 | 0 |
| -2.00066841 | -3.76286449 | 0.37956345 | h | 1.000 | 0 |
| 0.27341442 | 1.66244251 | 0.28997460 | h | 1.000 | 0 |
| 2.31641000 | -3.75982592 | 0.65795481 | h | 1.000 | 0 |
| 3.98350183 | 3.24651832 | 0.50407610 | h | 1.000 | 0 |
| 8.36030255 | 4.75166012 | 0.73899033 | h | 1.000 | 0 |
| 11.88745474 | 1.70371503 | 1.07920923 | h | 1.000 | 0 |
| 11.01441836 | -2.89020914 | 1.18501476 | h | 1.000 | 0 |
| 6.60879797 | -4.42272606 | 0.95240193 | h | 1.000 | 0 |

(*E*)-1-(3-Phenylallylidene)pyrrolidin-1-ium Product:

The $CH_3$-CH-CH-CHN Torsion Angle was constrained to 90°.

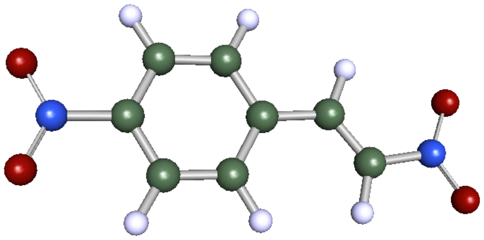


Total Energy = -599.19173807999 hartree
Enthalpy Correction = 0.316526 hartree
Entropy = 0.000191 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 12.45202646 | -1.45546776 | 5.53792853 | c | 6.000 | 0 |
| 12.43419826 | -1.33201945 | 2.64381222 | c | 6.000 | 0 |
| 14.20709544 | -3.25768990 | 1.50592095 | c | 6.000 | 0 |
| 16.24416557 | -2.50153195 | 0.02421739 | c | 6.000 | 0 |
| 17.87600618 | -4.26245349 | -1.03967097 | c | 6.000 | 0 |
| 17.49164827 | -6.82446189 | -0.63450863 | c | 6.000 | 0 |
| 15.46559779 | -7.60577346 | 0.84296127 | c | 6.000 | 0 |
| 13.84490434 | -5.83836553 | 1.90154540 | c | 6.000 | 0 |
| 9.80863571 | -1.58617949 | 1.58167238 | c | 6.000 | 0 |
| 8.30929691 | 0.42250486 | 1.16603555 | c | 6.000 | 0 |
| 5.84710964 | 0.38811037 | 0.44002216 | n | 7.000 | 0 |
| 4.55727091 | -1.93089826 | -0.22703623 | c | 6.000 | 0 |
| 2.14618853 | -1.04925085 | -1.55648455 | c | 6.000 | 0 |
| 1.83063882 | 1.68845914 | -0.69751194 | c | 6.000 | 0 |
| 4.54655222 | 2.59982439 | -0.52045582 | c | 6.000 | 0 |
| 14.37113727 | -1.25841288 | 6.28130310 | h | 1.000 | 0 |
| 11.28492530 | 0.06100443 | 6.31036356 | h | 1.000 | 0 |
| 11.68415391 | -3.25221054 | 6.20964423 | h | 1.000 | 0 |
| 13.15197344 | 0.53706331 | 2.11421780 | h | 1.000 | 0 |
| 16.55597504 | -0.50003293 | -0.30259013 | h | 1.000 | 0 |
| 19.45095720 | -3.62804497 | -2.18774238 | h | 1.000 | 0 |

```
 18.75966859    -8.20479502    -1.46178030     h       1.000      0
 15.14757693    -9.60367746     1.17236751     h       1.000      0
 12.27246022    -6.48054273     3.05056780     h       1.000      0
  9.06964756    -3.48803402     1.35590385     h       1.000      0
  9.06482747     2.31560647     1.44448669     h       1.000      0
  4.16027148    -3.04879330     1.47415003     h       1.000      0
  5.73406340    -3.10885373    -1.46563244     h       1.000      0
  0.52235332    -2.23369972    -1.10304709     h       1.000      0
  2.41636849    -1.10822595    -3.60336656     h       1.000      0
  0.69477514     2.81597888    -1.99577984     h       1.000      0
  0.94910569     1.76114230     1.17022503     h       1.000      0
  5.25318572     3.15929815    -2.39525566     h       1.000      0
  4.79318718     4.20253900     0.75788045     h       1.000      0
```

(*E*)-1-Nitro-4-(2-nitrovinyl)benzene (MAA* = 241.5 kJ/mol, E = -12.37):

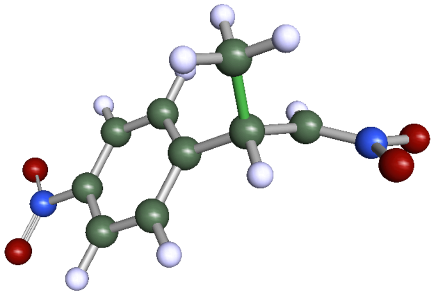


Total Energy = -718.18810844336 hartree
Enthalpy Correction = 0.153386 hartree
Entropy = 0.000172 hartree/K
LUMO Energy = -0.1225 hartree

```
                   atomic coordinates                atom    charge  isotop
  8.33847135    -1.79243506    -1.50126134     o       8.000      0
  7.55294892    -1.85348511     0.65794411     n       7.000      0
  4.95021984    -1.28059511     1.17711361     c       6.000      0
  3.37832521    -0.71973262    -0.70627269     c       6.000      0
  0.71609271    -0.11682152    -0.43307794     c       6.000      0
 -0.49419245    -0.00557291     1.91699437     c       6.000      0
 -3.02863977     0.57231796     2.07132128     c       6.000      0
 -4.35041288     1.03841714    -0.14506633     c       6.000      0
 -7.03441068     1.64943122     0.01417001     n       7.000      0
 -7.99622839     1.74378289     2.09533758     o       8.000      0
 -8.17092573     2.03313017    -1.94172691     o       8.000      0
 -3.21629250     0.94581635    -2.49909590     c       6.000      0
 -0.67338167     0.36753856    -2.62660984     c       6.000      0
  8.85822400    -2.38502769     2.48254007     o       8.000      0
  4.51931108    -1.38201383     3.16710375     h       1.000      0
  4.13582737    -0.71593300    -2.61173721     h       1.000      0
  0.54193101    -0.36893691     3.64281014     h       1.000      0
 -3.98066917     0.66376962     3.87602694     h       1.000      0
 -4.30255060     1.32000312    -4.18774183     h       1.000      0
  0.25635238     0.28634673    -4.44877187     h       1.000      0
```

(*E*)-1-Nitro-4-(2-nitrovinyl)benzene Product:

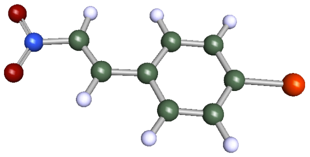
The $CH_3$-C-C-N Torsion Angle was constrained to 90°.



Total Energy = -758.21392049092 hartree
Enthalpy Correction = 0.192918 hartree
Entropy = 0.000184 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.91178181 | -2.07301654 | 3.96126556 | c | 6.000 | 0 |
| -2.63347941 | 0.10771501 | 2.07185070 | c | 6.000 | 0 |
| -4.64594497 | 0.08753480 | 0.09340235 | c | 6.000 | 0 |
| -6.78878662 | 1.29613302 | 0.41024029 | n | 7.000 | 0 |
| -7.25641351 | 2.52522286 | 2.43845462 | o | 8.000 | 0 |
| -8.49289159 | 1.27359389 | -1.32246303 | o | 8.000 | 0 |
| -0.06748535 | 0.08485813 | 0.83588465 | c | 6.000 | 0 |
| 1.56925301 | 2.12989261 | 1.11742463 | c | 6.000 | 0 |
| 3.92509005 | 2.14482584 | -0.01400795 | c | 6.000 | 0 |
| 4.63709547 | 0.07527141 | -1.45163088 | c | 6.000 | 0 |
| 7.10222204 | 0.07096797 | -2.65431050 | n | 7.000 | 0 |
| 8.47087521 | 1.89235058 | -2.34301148 | o | 8.000 | 0 |
| 7.69205693 | -1.75364449 | -3.92309877 | o | 8.000 | 0 |
| 3.05848439 | -1.99360436 | -1.77348420 | c | 6.000 | 0 |
| 0.71808585 | -1.97266674 | -0.61953955 | c | 6.000 | 0 |
| -2.78241536 | -3.90054549 | 3.01031116 | h | 1.000 | 0 |
| -1.44498229 | -1.98989759 | 5.41489411 | h | 1.000 | 0 |
| -4.75489639 | -1.95179535 | 4.88035127 | h | 1.000 | 0 |
| -2.82329689 | 1.87760490 | 3.11810104 | h | 1.000 | 0 |
| -4.44303891 | -0.91325125 | -1.67376830 | h | 1.000 | 0 |
| 0.98700681 | 3.73877963 | 2.24364144 | h | 1.000 | 0 |
| 5.19506464 | 3.73001852 | 0.20765861 | h | 1.000 | 0 |
| 3.66496895 | -3.58214447 | -2.90617702 | h | 1.000 | 0 |
| -0.51891468 | -3.58662461 | -0.86243320 | h | 1.000 | 0 |

(E)-1-Bromo-4-(2-nitrovinyl)benzene (MAA* = 230.4 kJ/mol, E = -13.37):



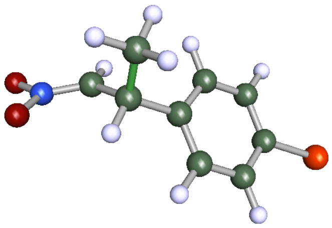
Total Energy = -3087.06022161445 hartree

Enthalpy Correction = 0.13918 hartree
Entropy = 0.000166 hartree/K
LUMO Energy = -0.1067 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -8.93138389 | 0.16188046 | -0.37153336 | br | 35.000 | 0 |
| -5.37382509 | -0.07420303 | -0.34955947 | c | 6.000 | 0 |
| -4.23185787 | -2.30016534 | -1.12110597 | c | 6.000 | 0 |
| -1.62128208 | -2.44676523 | -1.09629957 | c | 6.000 | 0 |
| -0.14688625 | -0.40025204 | -0.31276977 | c | 6.000 | 0 |
| 2.57252621 | -0.68263149 | -0.33646319 | c | 6.000 | 0 |
| 4.25047603 | 1.07464951 | 0.34211777 | c | 6.000 | 0 |
| 6.89880772 | 0.54845183 | 0.22477867 | n | 7.000 | 0 |
| 7.64465010 | -1.50711822 | -0.49742082 | o | 8.000 | 0 |
| 8.31127196 | 2.25503684 | 0.87930333 | o | 8.000 | 0 |
| -1.35934694 | 1.82221565 | 0.45587492 | c | 6.000 | 0 |
| -3.96115237 | 1.99430265 | 0.44161138 | c | 6.000 | 0 |
| -5.35630631 | -3.89541504 | -1.73190470 | h | 1.000 | 0 |
| -0.70505264 | -4.17844931 | -1.69560430 | h | 1.000 | 0 |
| 3.30433478 | -2.49205193 | -0.96655796 | h | 1.000 | 0 |
| 3.86387811 | 2.96160624 | 1.01006729 | h | 1.000 | 0 |
| -0.27128069 | 3.44181335 | 1.07425615 | h | 1.000 | 0 |
| -4.88757078 | 3.71709509 | 1.03881854 | h | 1.000 | 0 |

(E)-1-Bromo-4-(2-nitrovinyl)benzene Product:

The $CH_3$-C-C-N Torsion Angle was constrained to 270°.

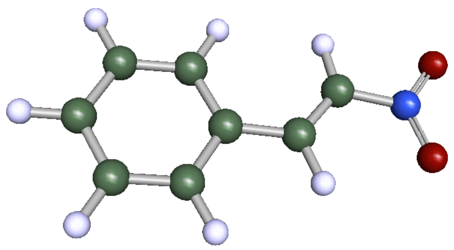


Total Energy = -3127.08190913370 hartree
Enthalpy Correction = 0.178787 hartree
Entropy = 0.000178 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 8.27624300 | 2.75076001 | -2.76285816 | br | 35.000 | 0 |
| 5.17992796 | 1.43416326 | -1.52615691 | c | 6.000 | 0 |
| 2.97426868 | 2.80280897 | -1.87358868 | c | 6.000 | 0 |
| 0.72143257 | 1.82699423 | -0.96006412 | c | 6.000 | 0 |
| 0.63433120 | -0.49429704 | 0.28282673 | c | 6.000 | 0 |
| -1.82456394 | -1.54927143 | 1.27181829 | c | 6.000 | 0 |
| -2.92574049 | 0.14770520 | 3.34916235 | c | 6.000 | 0 |
| -3.64577665 | -1.95948289 | -0.84383254 | c | 6.000 | 0 |
| -5.24783238 | -3.85061904 | -0.83305834 | n | 7.000 | 0 |
| -6.78061487 | -4.19423542 | -2.69168836 | o | 8.000 | 0 |
| -5.34959580 | -5.41025363 | 1.01379573 | o | 8.000 | 0 |
| 2.88481504 | -1.81568492 | 0.59838932 | c | 6.000 | 0 |
| 5.16522998 | -0.87190624 | -0.29360126 | c | 6.000 | 0 |
| 3.00775828 | 4.60549889 | -2.84125210 | h | 1.000 | 0 |
| -0.99779693 | 2.90946785 | -1.23336419 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -1.43685077 | -3.39757196 | 2.10887297 | h | 1.000 | 0 |
| -3.37408931 | 2.02231137 | 2.60842157 | h | 1.000 | 0 |
| -1.59100588 | 0.37018431 | 4.91118062 | h | 1.000 | 0 |
| -4.66296348 | -0.69091370 | 4.08215136 | h | 1.000 | 0 |
| -3.72458832 | -0.74232020 | -2.48027496 | h | 1.000 | 0 |
| 2.86749793 | -3.62492199 | 1.56251808 | h | 1.000 | 0 |
| 6.89911382 | -1.92573904 | -0.02811659 | h | 1.000 | 0 |

(*E*)-(2-Nitrovinyl)benzene (MAA* = 227.7 kJ/mol, E = -13.85):

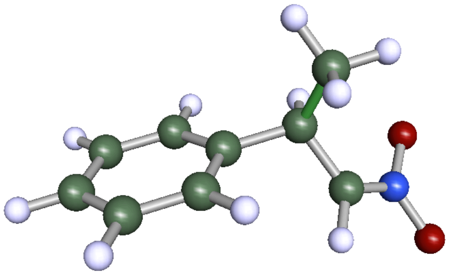


Total Energy = -513.79664615819 hartree
Enthalpy Correction = 0.14795 hartree
Entropy = 0.00015 hartree/K
LUMO Energy = -0.1043 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 8.25659958 | 2.41278734 | 0.00000000 | o | 8.000 | 0 |
| 6.82453397 | 0.59907711 | 0.00000000 | n | 7.000 | 0 |
| 4.18189210 | 1.15892341 | 0.00000000 | c | 6.000 | 0 |
| 2.48390469 | -0.70829303 | 0.00000000 | c | 6.000 | 0 |
| -0.23507695 | -0.41478457 | 0.00000000 | c | 6.000 | 0 |
| -1.72112400 | -2.60050643 | 0.00000000 | c | 6.000 | 0 |
| -4.33313757 | -2.43791163 | 0.00000000 | c | 6.000 | 0 |
| -5.49320376 | -0.08591636 | 0.00000000 | c | 6.000 | 0 |
| -4.03474400 | 2.10417562 | 0.00000000 | c | 6.000 | 0 |
| -1.42939282 | 1.94765036 | 0.00000000 | c | 6.000 | 0 |
| 7.55191470 | -1.58654475 | 0.00000000 | o | 8.000 | 0 |
| 3.81393157 | 3.16384000 | 0.00000000 | h | 1.000 | 0 |
| 3.20111227 | -2.63018888 | 0.00000000 | h | 1.000 | 0 |
| -0.80359032 | -4.43318514 | 0.00000000 | h | 1.000 | 0 |
| -5.46383092 | -4.14486022 | 0.00000000 | h | 1.000 | 0 |
| -7.53703908 | 0.04881068 | 0.00000000 | h | 1.000 | 0 |
| -4.94393176 | 3.93912123 | 0.00000000 | h | 1.000 | 0 |
| -0.31881770 | 3.66780527 | 0.00000000 | h | 1.000 | 0 |

(*E*)-(2-Nitrovinyl)benzene Product:

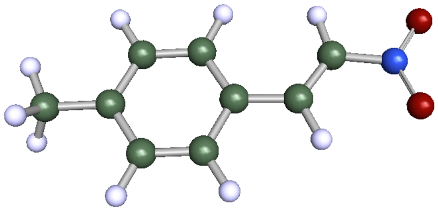
The $CH_3$-C-C-N Torsion Angle was constrained to 270°.



Total Energy = -553.81689700091 hartree
Enthalpy Correction = 0.187443 hartree
Entropy = 0.000163 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.90006630 | 2.54817351 | -1.82174600 | c | 6.000 | 0 |
| -1.94364248 | 0.80046070 | 0.28432760 | c | 6.000 | 0 |
| -3.43407124 | -1.59042067 | 0.43737319 | c | 6.000 | 0 |
| -5.44860105 | -1.78413764 | 1.86729832 | n | 7.000 | 0 |
| -6.26044013 | 0.08764624 | 3.17010779 | o | 8.000 | 0 |
| -6.68409576 | -3.87801392 | 2.00325892 | o | 8.000 | 0 |
| 0.83494054 | 0.22781778 | -0.03115320 | c | 6.000 | 0 |
| 1.73079468 | -1.06717621 | -2.14500740 | c | 6.000 | 0 |
| 4.28418168 | -1.59169710 | -2.42328811 | c | 6.000 | 0 |
| 5.99926702 | -0.81955485 | -0.59046853 | c | 6.000 | 0 |
| 5.13372500 | 0.47638114 | 1.51870939 | c | 6.000 | 0 |
| 2.57311511 | 0.98986830 | 1.79018181 | c | 6.000 | 0 |
| -4.89069022 | 2.99490264 | -1.50765649 | h | 1.000 | 0 |
| -2.72452664 | 1.64177455 | -3.66865821 | h | 1.000 | 0 |
| -1.82794128 | 4.31450085 | -1.86256919 | h | 1.000 | 0 |
| -2.19259126 | 1.78799225 | 2.08137345 | h | 1.000 | 0 |
| -2.91884759 | -3.27284009 | -0.59710192 | h | 1.000 | 0 |
| 0.41718765 | -1.67953959 | -3.59599737 | h | 1.000 | 0 |
| 4.94003487 | -2.60664147 | -4.07872649 | h | 1.000 | 0 |
| 7.99564664 | -1.22564755 | -0.80782301 | h | 1.000 | 0 |
| 6.45404873 | 1.09113332 | 2.96075148 | h | 1.000 | 0 |
| 1.90928560 | 2.00211439 | 3.44627505 | h | 1.000 | 0 |

(*E*)-1-Methyl-4-(2-nitrovinyl)benzene (MAA* = 224.1 kJ/mol, E = -14.23):

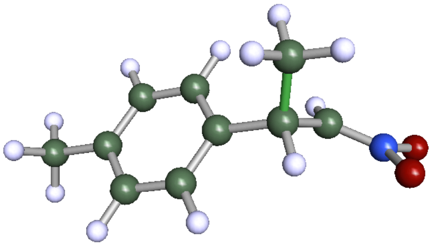


Total Energy = -553.08293076276 hartree
Enthalpy Correction = 0.177077 hartree
Entropy = 0.000163 hartree/K
LUMO Energy = -0.1027 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -6.97275718 | 0.74467398 | -0.12006953 | c | 6.000 | 0 |
| -4.17754490 | 0.39779543 | 0.08958361 | c | 6.000 | 0 |
| -2.56785012 | 1.06827821 | -1.89207326 | c | 6.000 | 0 |
| 0.01432795 | 0.74844238 | -1.70558320 | c | 6.000 | 0 |
| 1.08372512 | -0.26185912 | 0.49275906 | c | 6.000 | 0 |
| 3.76494202 | -0.65189346 | 0.80958743 | c | 6.000 | 0 |
| 5.55913222 | -0.15929127 | -0.90105594 | c | 6.000 | 0 |
| 8.14979028 | -0.64318077 | -0.33686402 | n | 7.000 | 0 |
| 9.67458343 | -0.16249399 | -2.00824884 | o | 8.000 | 0 |
| 8.75873180 | -1.49246685 | 1.71855736 | o | 8.000 | 0 |
| -0.52724721 | -0.93089615 | 2.48222603 | c | 6.000 | 0 |
| -3.10909390 | -0.60726978 | 2.28020434 | c | 6.000 | 0 |
| -7.49808625 | 1.53695071 | -1.94776890 | h | 1.000 | 0 |
| -7.66657862 | 2.00720241 | 1.36115991 | h | 1.000 | 0 |
| -7.95420648 | -1.05818220 | 0.11506888 | h | 1.000 | 0 |
| -3.36491689 | 1.85489774 | -3.60864290 | h | 1.000 | 0 |
| 1.20482082 | 1.29072225 | -3.28093510 | h | 1.000 | 0 |
| 4.37502914 | -1.42415672 | 2.60987788 | h | 1.000 | 0 |
| 5.30007930 | 0.59904892 | -2.77536832 | h | 1.000 | 0 |
| 0.27537249 | -1.71504843 | 4.19771376 | h | 1.000 | 0 |
| -4.32225303 | -1.14127327 | 3.84388380 | h | 1.000 | 0 |

(*E*)-1-Methyl-4-(2-nitrovinyl)benzene Product:

The $CH_3$-C-C-N Torsion Angle was constrained to 90°.

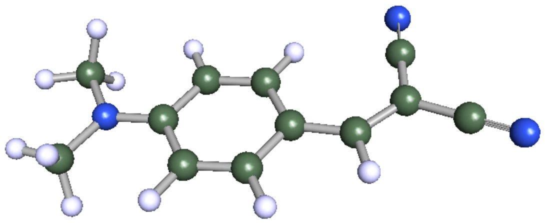


Total Energy = -593.10151614634 hartree
Enthalpy Correction = 0.216595 hartree
Entropy = 0.000177 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -7.11065293 | -1.87559048 | -0.30329800 | c | 6.000 | 0 |
| -4.41398659 | -1.05076443 | -0.03961936 | c | 6.000 | 0 |
| -3.12679394 | -1.33442965 | 2.23936559 | c | 6.000 | 0 |
| -0.63611701 | -0.55782508 | 2.49298314 | c | 6.000 | 0 |
| 0.66481357 | 0.53350621 | 0.48327127 | c | 6.000 | 0 |
| 3.38201782 | 1.35578506 | 0.77611693 | c | 6.000 | 0 |
| 3.68263628 | 4.20377564 | 0.33000851 | c | 6.000 | 0 |
| 5.05488732 | -0.16148756 | -0.91555621 | c | 6.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 7.35523881 | -0.79932162 | -0.25194932 | n | 7.000 | 0 |
| 8.29925049 | -0.10711854 | 1.86700666 | o | 8.000 | 0 |
| 8.74836332 | -2.15012194 | -1.72386281 | o | 8.000 | 0 |
| -0.62207364 | 0.82092950 | -1.79375687 | c | 6.000 | 0 |
| -3.11220006 | 0.03890013 | -2.05000032 | c | 6.000 | 0 |
| -8.36366561 | -0.69640941 | 0.84271070 | h | 1.000 | 0 |
| -7.74071768 | -1.75065242 | -2.26237086 | h | 1.000 | 0 |
| -7.36228701 | -3.82431896 | 0.33327054 | h | 1.000 | 0 |
| -4.08772321 | -2.18058265 | 3.84320541 | h | 1.000 | 0 |
| 0.32263162 | -0.80674186 | 4.28987851 | h | 1.000 | 0 |
| 3.96307439 | 0.95951855 | 2.71830647 | h | 1.000 | 0 |
| 5.65066704 | 4.75224894 | 0.62526081 | h | 1.000 | 0 |
| 3.15403456 | 4.70804695 | -1.60118975 | h | 1.000 | 0 |
| 2.49561847 | 5.28772702 | 1.62926264 | h | 1.000 | 0 |
| 4.44552063 | -0.82860861 | -2.74611505 | h | 1.000 | 0 |
| 0.32830201 | 1.66198129 | -3.40553732 | h | 1.000 | 0 |
| -4.06448428 | 0.27846038 | -3.85147649 | h | 1.000 | 0 |

2-(4-(Dimethylamino)benzylidene)malononitrile (MAA* = 223.7 kJ/mol, E = -13.3):



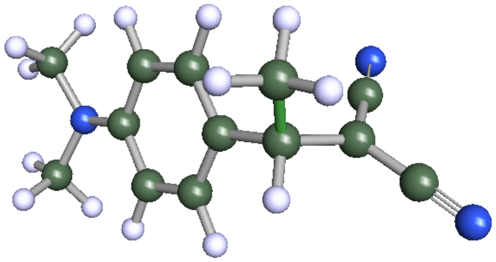
Total Energy = -627.62938029164 hartree
Enthalpy Correction = 0.221332 hartree
Entropy = 0.000189 hartree/K
LUMO Energy = -0.0888 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -6.80149358 | 0.14673451 | 1.22567550 | c | 6.000 | 0 |
| -4.92867023 | -0.43461082 | -0.68282493 | n | 7.000 | 0 |
| -5.76119578 | -1.33281472 | -3.13042882 | c | 6.000 | 0 |
| -2.45969062 | -0.13629935 | -0.18906013 | c | 6.000 | 0 |
| -1.61102813 | 0.74968166 | 2.19301576 | c | 6.000 | 0 |
| 0.91316402 | 1.03833375 | 2.66060995 | c | 6.000 | 0 |
| 2.77631064 | 0.47914275 | 0.83211576 | c | 6.000 | 0 |
| 5.32666957 | 0.84412508 | 1.53139745 | c | 6.000 | 0 |
| 7.54414014 | 0.47047631 | 0.22352991 | c | 6.000 | 0 |
| 9.87506153 | 1.00614963 | 1.42939713 | c | 6.000 | 0 |
| 11.77636180 | 1.44076955 | 2.40828023 | n | 7.000 | 0 |
| 7.74208874 | -0.42978815 | -2.28678949 | c | 6.000 | 0 |
| 7.95818330 | -1.16230149 | -4.33072446 | n | 7.000 | 0 |
| 1.91880580 | -0.39925066 | -1.53876412 | c | 6.000 | 0 |
| -0.59634037 | -0.69711690 | -2.03948680 | c | 6.000 | 0 |
| -8.66890254 | -0.23826656 | 0.46429033 | h | 1.000 | 0 |
| -6.53593918 | -1.01354651 | 2.91515817 | h | 1.000 | 0 |
| -6.72001976 | 2.13741660 | 1.77656566 | h | 1.000 | 0 |
| -5.01346284 | -3.21689232 | -3.53422061 | h | 1.000 | 0 |
| -7.81145923 | -1.43720824 | -3.13665163 | h | 1.000 | 0 |
| -5.17038052 | -0.05300448 | -4.64196683 | h | 1.000 | 0 |
| -2.95503138 | 1.20555602 | 3.66128114 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 1.51351962 | 1.71941907 | 4.49889038 | h | 1.000 | 0 |
| 5.59695902 | 1.54259689 | 3.44293719 | h | 1.000 | 0 |
| 3.25261575 | -0.85559663 | -3.01855605 | h | 1.000 | 0 |
| -1.16026576 | -1.37370496 | -3.88223486 | h | 1.000 | 0 |

2-(4-(Dimethylamino)benzylidene)malononitrile Product:

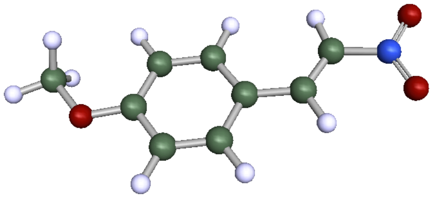
The $CH_3$-CH-C-CN Torsion Angle was constrained to 90°.



Total Energy = -667.64752317796 hartree
Enthalpy Correction = 0.260856 hartree
Entropy = 0.000204 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.43563711 | -3.20846938 | -2.04673476 | c | 6.000 | 0 |
| 4.89864212 | -0.76162458 | -0.61572734 | c | 6.000 | 0 |
| 6.33852808 | -0.63968639 | 1.88320216 | c | 6.000 | 0 |
| 8.79279879 | 0.25572817 | 1.92845421 | c | 6.000 | 0 |
| 10.85826934 | 1.04347992 | 1.89670603 | n | 7.000 | 0 |
| 5.30808215 | -1.56290101 | 4.10182558 | c | 6.000 | 0 |
| 4.40886514 | -2.33866857 | 5.96378561 | n | 7.000 | 0 |
| 2.11741891 | -0.25223163 | -0.23476952 | c | 6.000 | 0 |
| 0.35696190 | -2.15532700 | 0.18562675 | c | 6.000 | 0 |
| -2.17954064 | -1.63681955 | 0.58765312 | c | 6.000 | 0 |
| -3.08379130 | 0.85745770 | 0.61389778 | c | 6.000 | 0 |
| -5.58846150 | 1.39822886 | 1.08693277 | n | 7.000 | 0 |
| -7.40680454 | -0.63163635 | 0.97733831 | c | 6.000 | 0 |
| -6.51350886 | 3.90413695 | 0.53549367 | c | 6.000 | 0 |
| -1.31036309 | 2.78218119 | 0.15042461 | c | 6.000 | 0 |
| 1.21179318 | 2.21711338 | -0.24463701 | c | 6.000 | 0 |
| 4.86332439 | -4.86184115 | -0.95018144 | h | 1.000 | 0 |
| 4.44022402 | -3.25414365 | -3.85783891 | h | 1.000 | 0 |
| 7.46038031 | -3.37697661 | -2.41131082 | h | 1.000 | 0 |
| 5.62627332 | 0.79797784 | -1.76684882 | h | 1.000 | 0 |
| 0.95100684 | -4.11613521 | 0.19162035 | h | 1.000 | 0 |
| -3.46101750 | -3.20170778 | 0.88253062 | h | 1.000 | 0 |
| -9.26604327 | 0.11503702 | 1.44426999 | h | 1.000 | 0 |
| -7.50883858 | -1.51786842 | -0.89954356 | h | 1.000 | 0 |
| -6.96180085 | -2.10270857 | 2.35486208 | h | 1.000 | 0 |
| -5.49496036 | 5.32866231 | 1.62744415 | h | 1.000 | 0 |
| -8.49739569 | 4.01314800 | 1.06990570 | h | 1.000 | 0 |
| -6.34957347 | 4.39708848 | -1.47640743 | h | 1.000 | 0 |
| -1.89951007 | 4.73823355 | 0.08681948 | h | 1.000 | 0 |
| 2.52262965 | 3.75960597 | -0.58756512 | h | 1.000 | 0 |

(*E*)-1-Methoxy-4-(2-nitrovinyl)benzene (MAA* = 218.5 kJ/mol, E = -14.7):

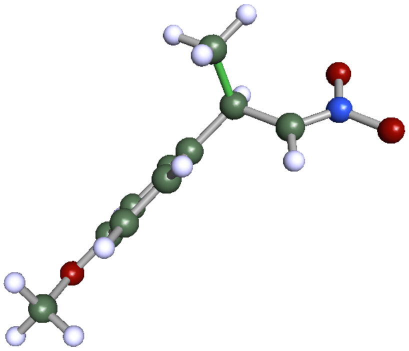


Total Energy = -628.25058434022 hartree
Enthalpy Correction = 0.183296 hartree
Entropy = 0.000168 hartree/K
LUMO Energy = -0.0999 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -7.69337062 | 0.90800411 | -0.69485253 | c | 6.000 | 0 |
| -6.16686134 | -1.24667183 | -0.21289780 | o | 8.000 | 0 |
| -3.65331092 | -0.95947958 | -0.18375864 | c | 6.000 | 0 |
| -2.42518164 | 1.34614340 | -0.59249289 | c | 6.000 | 0 |
| 0.17746405 | 1.45027275 | -0.52566672 | c | 6.000 | 0 |
| 1.62949116 | -0.71132915 | -0.05636117 | c | 6.000 | 0 |
| 4.34506557 | -0.69721308 | 0.02575300 | c | 6.000 | 0 |
| 5.85195338 | 1.31497942 | -0.28985650 | c | 6.000 | 0 |
| 8.52117363 | 1.04846876 | -0.16453668 | n | 7.000 | 0 |
| 9.76947955 | 2.97898851 | -0.44838224 | o | 8.000 | 0 |
| 9.47771749 | -1.02024290 | 0.20809348 | o | 8.000 | 0 |
| 0.35941506 | -3.00478713 | 0.34822283 | c | 6.000 | 0 |
| -2.23488928 | -3.13751445 | 0.28910751 | c | 6.000 | 0 |
| -9.63741616 | 0.24545550 | -0.63536173 | h | 1.000 | 0 |
| -7.28781495 | 1.69780594 | -2.55946318 | h | 1.000 | 0 |
| -7.40857426 | 2.35302333 | 0.75218645 | h | 1.000 | 0 |
| -3.48927503 | 3.05055552 | -0.96261795 | h | 1.000 | 0 |
| 1.08983728 | 3.25455473 | -0.84999302 | h | 1.000 | 0 |
| 5.26121281 | -2.49866716 | 0.37924165 | h | 1.000 | 0 |
| 5.27552102 | 3.23733216 | -0.64620227 | h | 1.000 | 0 |
| 1.45048869 | -4.70060526 | 0.71478212 | h | 1.000 | 0 |
| -3.21212550 | -4.90907361 | 0.60205609 | h | 1.000 | 0 |

(*E*)-1-Methoxy-4-(2-nitrovinyl)benzene Product:

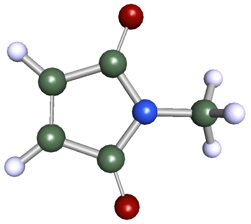
The $CH_3$-C-C-N Torsion Angle was constrained to 270°.



Total Energy = -668.26688620613 hartree
Enthalpy Correction = 0.222667 hartree
Entropy = 0.000182 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 8.20457486 | 0.91599333 | 1.42664795 | c | 6.000 | 0 |
| 6.42467774 | 2.49290385 | 0.20488301 | o | 8.000 | 0 |
| 4.02982617 | 1.61768994 | -0.03745794 | c | 6.000 | 0 |
| 3.21806796 | -0.73252172 | 0.82068424 | c | 6.000 | 0 |
| 0.71350233 | -1.44441110 | 0.47697477 | c | 6.000 | 0 |
| -1.02977815 | 0.13015781 | -0.69950102 | c | 6.000 | 0 |
| -3.75318164 | -0.64995060 | -1.05192139 | c | 6.000 | 0 |
| -3.97125071 | -2.99109924 | -2.74714041 | c | 6.000 | 0 |
| -5.00390668 | -1.03608135 | 1.44757075 | c | 6.000 | 0 |
| -7.38807280 | -0.47667562 | 1.82014389 | n | 7.000 | 0 |
| -8.41299141 | -0.77774919 | 4.00933231 | o | 8.000 | 0 |
| -8.78124428 | 0.38159424 | 0.03523345 | o | 8.000 | 0 |
| -0.17322763 | 2.47277000 | -1.54654366 | c | 6.000 | 0 |
| 2.31376000 | 3.21800664 | -1.23128567 | c | 6.000 | 0 |
| 9.97848437 | 1.95596054 | 1.43945011 | h | 1.000 | 0 |
| 7.63406323 | 0.50857912 | 3.37167389 | h | 1.000 | 0 |
| 8.45894262 | -0.86207275 | 0.40286122 | h | 1.000 | 0 |
| 4.50713982 | -2.01747537 | 1.75197593 | h | 1.000 | 0 |
| 0.12551559 | -3.28665784 | 1.16026313 | h | 1.000 | 0 |
| -4.74424131 | 0.89967391 | -1.99224885 | h | 1.000 | 0 |
| -5.95917649 | -3.47196677 | -3.02754863 | h | 1.000 | 0 |
| -3.10947042 | -2.65053168 | -4.59489976 | h | 1.000 | 0 |
| -3.02943850 | -4.61413517 | -1.88514118 | h | 1.000 | 0 |
| -4.00224636 | -1.75953905 | 3.07289886 | h | 1.000 | 0 |
| -1.48556109 | 3.74683400 | -2.47517382 | h | 1.000 | 0 |
| 2.95781066 | 5.04459621 | -1.90012955 | h | 1.000 | 0 |

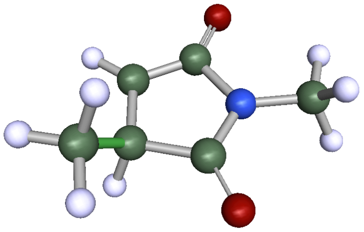
1-Methyl-1*H*-pyrrole-2,5-dione (MAA* = 210.0 kJ/mol, E = -14.07):



Total Energy = -398.47961401177 hartree
Enthalpy Correction = 0.105223 hartree
Entropy = 0.000131 hartree/K
LUMO Energy = -0.0965 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.14757381 | -0.00406514 | -4.28812818 | o | 8.000 | 0 |
| 0.62362594 | -0.01667760 | -2.13851257 | c | 6.000 | 0 |
| -0.87037191 | 0.02758531 | 0.00000000 | n | 7.000 | 0 |
| -3.59313962 | 0.07138142 | 0.00000000 | c | 6.000 | 0 |
| 3.30177563 | -0.07209436 | -1.25418787 | c | 6.000 | 0 |
| 3.30177563 | -0.07209436 | 1.25418787 | c | 6.000 | 0 |
| 0.62362594 | -0.01667760 | 2.13851257 | c | 6.000 | 0 |
| -0.14757381 | -0.00406514 | 4.28812818 | o | 8.000 | 0 |
| -4.24088035 | 1.06526011 | 1.68081182 | h | 1.000 | 0 |
| -4.36704120 | -1.84063998 | 0.00000000 | h | 1.000 | 0 |
| -4.24088035 | 1.06526011 | -1.68081182 | h | 1.000 | 0 |
| 4.87874664 | -0.10421408 | -2.54962786 | h | 1.000 | 0 |
| 4.87874664 | -0.10421408 | 2.54962786 | h | 1.000 | 0 |

1-Methyl-1*H*-pyrrole-2,5-dione Product:

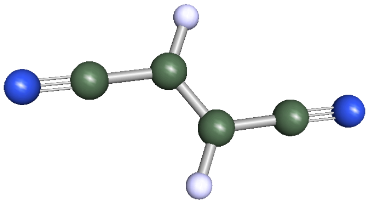


Total Energy = -438.49313383794 hartree
Enthalpy Correction = 0.144441 hartree
Entropy = 0.000143 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.11759397 | -4.47038683 | 0.00923668 | o | 8.000 | 0 |
| 0.07986558 | -2.29151558 | -0.81376132 | c | 6.000 | 0 |
| 2.05727977 | -1.07154968 | -1.82002600 | n | 7.000 | 0 |
| 4.53314707 | -2.13834852 | -2.08451423 | c | 6.000 | 0 |
| -2.17249997 | -0.51666508 | -0.85412018 | c | 6.000 | 0 |
| -3.27784393 | -0.21283372 | 1.79342472 | c | 6.000 | 0 |
| -1.10801419 | 1.82239946 | -2.03426786 | c | 6.000 | 0 |
| 1.39484982 | 1.49359932 | -2.60033954 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 3.08545409 | 2.84902170 | -3.57754151 | o | 8.000 | 0 |
| 5.33328536 | -2.63812237 | -0.24626211 | h | 1.000 | 0 |
| 4.49145411 | -3.83803217 | -3.25751038 | h | 1.000 | 0 |
| 5.72107512 | -0.71661378 | -2.98168403 | h | 1.000 | 0 |
| -3.61358799 | -1.43993418 | -2.03774877 | h | 1.000 | 0 |
| -1.87953170 | 0.62180615 | 3.06550947 | h | 1.000 | 0 |
| -3.87051242 | -2.03491903 | 2.56640307 | h | 1.000 | 0 |
| -4.92084334 | 1.03567355 | 1.74396943 | h | 1.000 | 0 |
| -2.16079641 | 3.53707835 | -2.38829923 | h | 1.000 | 0 |

Fumaronitrile (MAA* = 204.4 kJ/mol, E = -15.71):

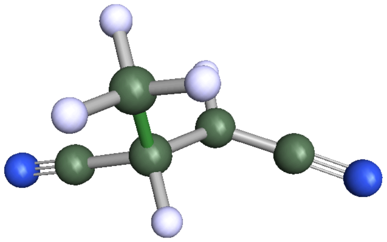


Total Energy = -262.87201845455 hartree
Enthalpy Correction = 0.056981 hartree
Entropy = 0.000117 hartree/K
LUMO Energy = -0.1016 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.59628751 | 0.62514342 | 0.00000000 | n | 7.000 | 0 |
| 3.51102919 | 0.00296501 | 0.00000000 | c | 6.000 | 0 |
| 0.95914372 | -0.82328892 | 0.00000000 | c | 6.000 | 0 |
| -0.95914372 | 0.82328892 | 0.00000000 | c | 6.000 | 0 |
| -3.51102919 | -0.00296501 | 0.00000000 | c | 6.000 | 0 |
| -5.59628751 | -0.62514342 | 0.00000000 | n | 7.000 | 0 |
| 0.65892705 | -2.85012234 | 0.00000000 | h | 1.000 | 0 |
| -0.65892705 | 2.85012234 | 0.00000000 | h | 1.000 | 0 |

Fumaronitrile Product:

The $CH_3$-CH-CH-CN Torsion Angle was constrained to 270°.

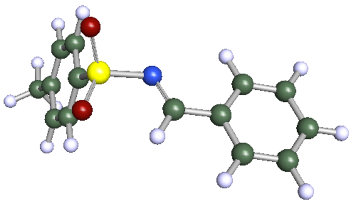


Total Energy = -302.88239217391 hartree
Enthalpy Correction = 0.09637 hartree
Entropy = 0.000133 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.71645865 | -0.72370239 | -0.23087426 | c | 6.000 | 0 |
| -0.18183007 | 0.68895138 | -0.25409437 | c | 6.000 | 0 |
| -0.37594923 | 2.97980801 | 1.28222085 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -0.52703728 | 4.75628506 | 2.53415943 | n | 7.000 | 0 |
| 2.08644794 | -0.81963488 | 0.58387525 | c | 6.000 | 0 |
| 3.43929532 | -2.14710242 | -1.17279928 | c | 6.000 | 0 |
| 4.65312257 | -3.23501765 | -2.69352215 | n | 7.000 | 0 |
| -2.57471221 | -2.33354851 | -1.51093089 | h | 1.000 | 0 |
| -4.28092049 | 0.48046261 | -0.84273881 | h | 1.000 | 0 |
| -3.12601061 | -1.43133775 | 1.66369200 | h | 1.000 | 0 |
| 0.15383718 | 1.36649026 | -2.18325468 | h | 1.000 | 0 |
| 2.08314337 | -1.52628953 | 2.50934825 | h | 1.000 | 0 |

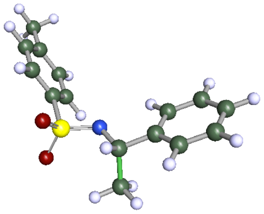
(E)-N-Benzylidene-4-methylbenzenesulfonamide (MAA* = 203.5 kJ/mol, E = -11.5):



Total Energy = -1144.03374841468 hartree
Enthalpy Correction = 0.259938 hartree
Entropy = 0.000204 hartree/K
LUMO Energy = -0.0862 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -9.63146628 | -2.29390878 | -1.22038664 | c | 6.000 | 0 |
| -7.41205381 | -0.95712201 | -0.09263360 | c | 6.000 | 0 |
| -6.76891556 | 1.48294435 | -0.84400987 | c | 6.000 | 0 |
| -4.71851549 | 2.72625320 | 0.20676274 | c | 6.000 | 0 |
| -3.29562295 | 1.50878473 | 2.04183983 | c | 6.000 | 0 |
| -0.69742283 | 3.05259369 | 3.38271572 | s | 16.000 | 0 |
| 1.58417681 | 2.32695540 | 1.37497000 | n | 7.000 | 0 |
| 3.39739530 | 0.94775876 | 2.19374601 | c | 6.000 | 0 |
| 5.52092012 | 0.22311199 | 0.62453620 | c | 6.000 | 0 |
| 5.72395974 | 0.99393340 | -1.89500082 | c | 6.000 | 0 |
| 7.78613601 | 0.25737802 | -3.31419804 | c | 6.000 | 0 |
| 9.65848897 | -1.24771628 | -2.23701039 | c | 6.000 | 0 |
| 9.46860679 | -2.01988257 | 0.26286004 | c | 6.000 | 0 |
| 7.40291558 | -1.28600017 | 1.69296704 | c | 6.000 | 0 |
| -0.24239327 | 2.01500085 | 5.86344068 | o | 8.000 | 0 |
| -1.04708052 | 5.74139158 | 3.16682717 | o | 8.000 | 0 |
| -3.89149809 | -0.92792751 | 2.82464941 | c | 6.000 | 0 |
| -5.94236449 | -2.13885045 | 1.75398298 | c | 6.000 | 0 |
| -10.57156428 | -1.12846716 | -2.63480355 | h | 1.000 | 0 |
| -11.00740538 | -2.78372250 | 0.24042993 | h | 1.000 | 0 |
| -9.04271981 | -4.06011257 | -2.11546246 | h | 1.000 | 0 |
| -7.89468529 | 2.43092880 | -2.26953920 | h | 1.000 | 0 |
| -4.23940336 | 4.62791307 | -0.37689751 | h | 1.000 | 0 |
| 3.41117720 | 0.26178027 | 4.14303849 | h | 1.000 | 0 |
| 4.25653474 | 2.16705156 | -2.70852476 | h | 1.000 | 0 |
| 7.95036579 | 0.85161826 | -5.26676607 | h | 1.000 | 0 |
| 11.27415153 | -1.81822980 | -3.35977907 | h | 1.000 | 0 |
| 10.92802506 | -3.19076393 | 1.09361189 | h | 1.000 | 0 |
| 7.23325528 | -1.87657158 | 3.64861841 | h | 1.000 | 0 |
| -2.77149338 | -1.85133644 | 4.26714122 | h | 1.000 | 0 |
| -6.42150412 | -4.03478617 | 2.36711914 | h | 1.000 | 0 |

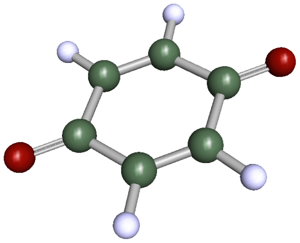
(E)-N-Benzylidene-4-methylbenzenesulfonamide Product:



Total Energy = -1184.04520516903 hartree
Enthalpy Correction = 0.299578 hartree
Entropy = 0.000216 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.58950444 | 4.43173101 | 1.12073111 | c | 6.000 | 0 |
| 3.47478137 | 2.52315246 | -0.75346941 | c | 6.000 | 0 |
| 0.97515563 | 1.67759163 | -0.03184410 | n | 7.000 | 0 |
| -1.27342822 | 3.40913507 | -0.61790631 | s | 16.000 | 0 |
| -3.85539729 | 1.35878838 | -0.04846547 | c | 6.000 | 0 |
| -5.63686577 | 0.93262343 | -1.91600462 | c | 6.000 | 0 |
| -7.69392283 | -0.62752520 | -1.42819640 | c | 6.000 | 0 |
| -8.00495028 | -1.77470091 | 0.91431217 | c | 6.000 | 0 |
| -10.22598558 | -3.44470770 | 1.45025619 | c | 6.000 | 0 |
| -6.18664398 | -1.31867315 | 2.77526898 | c | 6.000 | 0 |
| -4.13633042 | 0.23304443 | 2.31138361 | c | 6.000 | 0 |
| -1.66178303 | 5.55891540 | 1.10464875 | o | 8.000 | 0 |
| -1.46680573 | 4.24530262 | -3.26297471 | o | 8.000 | 0 |
| 5.23392584 | 0.27964212 | -0.98143723 | c | 6.000 | 0 |
| 4.65162676 | -2.04106203 | 0.10239642 | c | 6.000 | 0 |
| 6.32658030 | -4.05801041 | -0.05750577 | c | 6.000 | 0 |
| 8.60908634 | -3.78515228 | -1.32022222 | c | 6.000 | 0 |
| 9.20208276 | -1.47680340 | -2.42531203 | c | 6.000 | 0 |
| 7.52802090 | 0.53273585 | -2.25109359 | c | 6.000 | 0 |
| 3.39699983 | 6.11162343 | 1.21294802 | h | 1.000 | 0 |
| 6.49881284 | 4.99765397 | 0.57169722 | h | 1.000 | 0 |
| 4.66763120 | 3.58727255 | 3.00452522 | h | 1.000 | 0 |
| 3.43853662 | 3.43825748 | -2.62306905 | h | 1.000 | 0 |
| -5.40697788 | 1.81507230 | -3.74872008 | h | 1.000 | 0 |
| -9.07931524 | -0.95729809 | -2.90392584 | h | 1.000 | 0 |
| -9.61550860 | -5.30099839 | 2.11933211 | h | 1.000 | 0 |
| -11.38429555 | -3.71202952 | -0.23371030 | h | 1.000 | 0 |
| -11.42138869 | -2.63142609 | 2.92737263 | h | 1.000 | 0 |
| -6.38877074 | -2.19705704 | 4.61801031 | h | 1.000 | 0 |
| -2.73429443 | 0.56726466 | 3.76497330 | h | 1.000 | 0 |
| 2.84969378 | -2.24028634 | 1.05399692 | h | 1.000 | 0 |
| 5.84074564 | -5.85470776 | 0.80228400 | h | 1.000 | 0 |
| 9.91323540 | -5.35994403 | -1.45508238 | h | 1.000 | 0 |
| 10.97175865 | -1.24580049 | -3.43370668 | h | 1.000 | 0 |
| 8.00448595 | 2.32637604 | -3.12778620 | h | 1.000 | 0 |

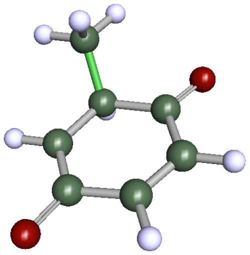
Benzoquinone (MAA* = 203.2 kJ/mol, E = -16.19):



Total Energy = -381.18839311061 hartree
Enthalpy Correction = 0.085033 hartree
Entropy = 0.000120 hartree/K
LUMO Energy = -0.1306 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.90992333 | -4.06462808 | 0.01143718 | o | 8.000 | 0 |
| -1.56918173 | -2.19166115 | 0.00626558 | c | 6.000 | 0 |
| 1.20731926 | -2.41409878 | -0.04210492 | c | 6.000 | 0 |
| 2.67431077 | -0.36524063 | -0.04812043 | c | 6.000 | 0 |
| -2.67432263 | 0.36524854 | 0.04807995 | c | 6.000 | 0 |
| -1.20731314 | 2.41410055 | 0.04228403 | c | 6.000 | 0 |
| 1.56918093 | 2.19166218 | -0.00625558 | c | 6.000 | 0 |
| 2.90993483 | 4.06462064 | -0.01160548 | o | 8.000 | 0 |
| 1.97429890 | -4.31373899 | -0.07219723 | h | 1.000 | 0 |
| 4.71961740 | -0.47978871 | -0.08352314 | h | 1.000 | 0 |
| -4.71963498 | 0.47978620 | 0.08316909 | h | 1.000 | 0 |
| -1.97428629 | 4.31373823 | 0.07257097 | h | 1.000 | 0 |

Benzoquinone Product:

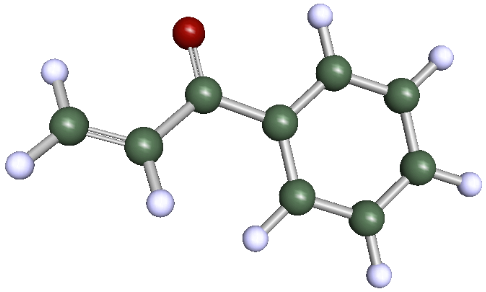


Total Energy = -421.20525519937 hartree
Enthalpy Correction = 0.132267 hartree
Entropy = 0.000139 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.26326939 | -3.97645116 | -1.20278116 | o | 8.000 | 0 |
| -2.74792044 | -2.19503867 | -0.52373334 | c | 6.000 | 0 |
| -3.74579630 | 0.40806546 | -0.52965913 | c | 6.000 | 0 |
| -2.44117598 | 2.49194880 | 0.13383032 | c | 6.000 | 0 |
| -0.27601204 | -2.43084254 | 0.20695341 | c | 6.000 | 0 |
| 1.37528373 | -0.27082104 | 0.95607542 | c | 6.000 | 0 |
| 3.80334796 | -0.17715560 | -0.63237321 | c | 6.000 | 0 |
| 0.16225688 | 2.31490409 | 0.94711530 | c | 6.000 | 0 |
| 1.36498677 | 4.19333576 | 1.61262400 | o | 8.000 | 0 |

```
 -5.70434418    0.59341589   -1.12911105     h      1.000      0
 -3.29180975    4.35854018    0.08601798     h      1.000      0
  0.58586134   -4.29709498    0.23061324     h      1.000      0
  1.98200225   -0.52322813    2.93295018     h      1.000      0
  4.82508210   -1.96114615   -0.46552414     h      1.000      0
  3.34242058    0.11517549   -2.62451999     h      1.000      0
  5.02908647    1.35639261    0.00152218     h      1.000      0
```

1-Phenylprop-2-en-1-one (MAA* = 198.4 kJ/mol, E = -15.25):

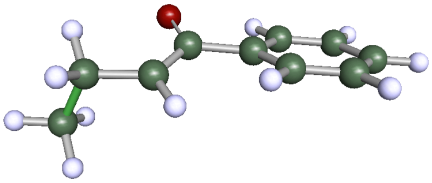


Total Energy = -422.65372676021 hartree
Enthalpy Correction = 0.153814 hartree
Entropy = 0.000145 hartree/K
LUMO Energy = -0.0828 hartree

```
                  atomic coordinates              atom    charge  isotop
  6.79566055    0.04620597   -0.51731477     c      6.000      0
  4.36572494   -0.59316259   -0.51751608     c      6.000      0
  2.35854342    1.36003263   -0.47487495     c      6.000      0
 -0.31070311    0.54300359   -0.16825157     c      6.000      0
 -0.96856637   -1.86484371    0.68116816     c      6.000      0
 -3.48854115   -2.51366180    0.99136504     c      6.000      0
 -5.37150489   -0.77746524    0.42852442     c      6.000      0
 -4.73323129    1.62433689   -0.42809224     c      6.000      0
 -2.22029696    2.28214522   -0.70993244     c      6.000      0
  2.87259602    3.59822747   -0.70637961     o      8.000      0
  7.35833579    2.01673356   -0.46233344     h      1.000      0
  8.27126531   -1.37245023   -0.56759055     h      1.000      0
  3.81991109   -2.56391765   -0.57307689     h      1.000      0
  0.47260218   -3.23997193    1.14604008     h      1.000      0
 -3.98169547   -4.38092001    1.67221751     h      1.000      0
 -7.34095242   -1.29310606    0.65700067     h      1.000      0
 -6.20312705    2.97952673   -0.87284698     h      1.000      0
 -1.69602058    4.14928717   -1.36518521     h      1.000      0
```

1-Phenylprop-2-en-1-one Product:

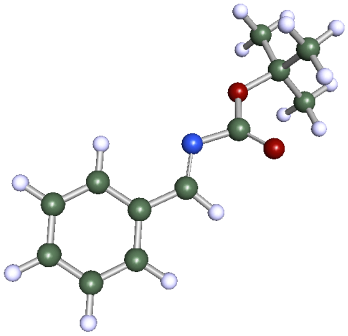
The $CH_3$-$CH_2$-CH-C Torsion Angle was constrained to 90°



Total Energy = -462.66292995584 hartree
Enthalpy Correction = 0.193434 hartree
Entropy = 0.000158 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.26069733 | -5.28930866 | -1.85442930 | o | 8.000 | 0 |
| 0.77990086 | -3.11473218 | -0.89934918 | c | 6.000 | 0 |
| -1.44344762 | -1.54962694 | -0.05720468 | c | 6.000 | 0 |
| -3.83170316 | -2.16255664 | -0.99422653 | c | 6.000 | 0 |
| -5.96307256 | -0.79090648 | -0.31548116 | c | 6.000 | 0 |
| -5.75951245 | 1.22341686 | 1.35271785 | c | 6.000 | 0 |
| -3.39876699 | 1.84039196 | 2.33113778 | c | 6.000 | 0 |
| -1.27482546 | 0.47270161 | 1.63464843 | c | 6.000 | 0 |
| 3.16116778 | -2.12866725 | -0.64750701 | c | 6.000 | 0 |
| 5.45407730 | -3.51408448 | -1.54266518 | c | 6.000 | 0 |
| 6.17015074 | -2.92951824 | -4.28091760 | c | 6.000 | 0 |
| -3.96928585 | -3.75416667 | -2.27571103 | h | 1.000 | 0 |
| -7.79303808 | -1.29976851 | -1.08883640 | h | 1.000 | 0 |
| -7.41978578 | 2.29249387 | 1.90051973 | h | 1.000 | 0 |
| -3.21582142 | 3.39012635 | 3.66127243 | h | 1.000 | 0 |
| 0.53840684 | 0.96299693 | 2.45135238 | h | 1.000 | 0 |
| 3.40343279 | -0.23015340 | 0.08627844 | h | 1.000 | 0 |
| 7.07966654 | -3.09007395 | -0.32716966 | h | 1.000 | 0 |
| 5.10207999 | -5.54869307 | -1.38449675 | h | 1.000 | 0 |
| 6.56843842 | -0.91530721 | -4.52477925 | h | 1.000 | 0 |
| 7.84466038 | -3.98605619 | -4.88620219 | h | 1.000 | 0 |
| 4.60866696 | -3.41855788 | -5.54217698 | h | 1.000 | 0 |

*tert*-Butyl (*E*)-benzylidenecarbamate (MAA* = 195.9 kJ/mol, E = -14.22):

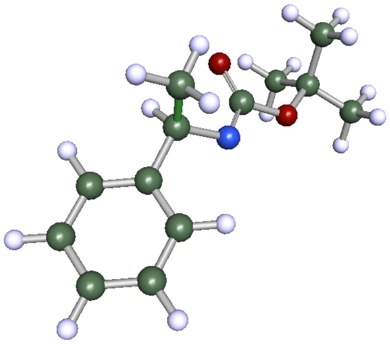


Total Energy = -671.03149647377 hartree

Enthalpy Correction = 0.265822 hartree
Entropy = 0.000191 hartree/K
LUMO Energy = -0.0804 hartree

```
                   atomic coordinates              atom    charge  isotop
  -1.62997017    2.35431084   -2.09430934     o      8.000     0
  -1.44670038    0.94115790   -0.30402674     c      6.000     0
  -3.32878852   -0.26046045    0.82052307     o      8.000     0
  -5.94266948   -0.04769968   -0.07861646     c      6.000     0
  -7.37498460   -1.72651546    1.75025437     c      6.000     0
  -6.14705579   -1.06474806   -2.75177570     c      6.000     0
  -6.83723927    2.66842637    0.13718368     c      6.000     0
   0.80064500    0.37529491    0.98232946     n      7.000     0
   2.81923709    0.48819212   -0.33635473     c      6.000     0
   5.31749342    0.05810744    0.71271038     c      6.000     0
   7.40439417    0.26449738   -0.88687815     c      6.000     0
   9.82320432   -0.10995440    0.04386702     c      6.000     0
  10.16497427   -0.69936461    2.57694072     c      6.000     0
   8.09032883   -0.91499301    4.18312212     c      6.000     0
   5.67706573   -0.53977159    3.26101513     c      6.000     0
  -9.37884468   -1.72564792    1.26533856     h      1.000     0
  -7.16735478   -1.03727900    3.68370980     h      1.000     0
  -6.67683343   -3.66541721    1.65566441     h      1.000     0
  -5.14345177    0.12791329   -4.09442338     h      1.000     0
  -8.13750200   -1.13037495   -3.29033879     h      1.000     0
  -5.39057528   -2.98257886   -2.84984252     h      1.000     0
  -5.85884011    3.89683574   -1.19095056     h      1.000     0
  -6.54281464    3.37119389    2.05565824     h      1.000     0
  -8.85922598    2.73722595   -0.26870897     h      1.000     0
   2.73743282    0.92308947   -2.35746427     h      1.000     0
   7.11621047    0.72620899   -2.86351657     h      1.000     0
  11.43926560    0.05654507   -1.20220948     h      1.000     0
  12.05475284   -0.99631372    3.30987874     h      1.000     0
   8.37110098   -1.38055325    6.15763594     h      1.000     0
   4.04674535   -0.70732719    4.48788937     h      1.000     0
```

*tert*-Butyl (*E*)-benzylidenecarbamate Product:

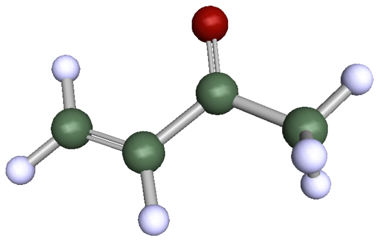


Total Energy = -711.03942511727 hartree
Enthalpy Correction = 0.30513 hartree
Entropy = 0.000204 hartree/K

```
                   atomic coordinates              atom    charge  isotop
  -2.97728828    0.44466442    0.78311373     o      8.000     0
```

```
   -1.32826079   -0.07994178    2.38406814    c       6.000      0
   -2.00142202   -0.32310088    4.91443980    o       8.000      0
   -4.58399505   -0.15884742    5.73328385    c       6.000      0
   -6.18035640   -2.23680842    4.54614677    c       6.000      0
   -5.68696058    2.45006986    5.22627380    c       6.000      0
   -4.41168275   -0.58155790    8.57207222    c       6.000      0
    1.10057332   -0.44288847    2.10457386    n       7.000      0
    1.96800382   -0.22443568   -0.46902098    c       6.000      0
    1.55851771   -2.69026507   -1.93310200    c       6.000      0
    4.73149495    0.48669244   -0.57125188    c       6.000      0
    6.42847936   -0.35767753    1.25356029    c       6.000      0
    8.98049920    0.23104053    1.09671863    c       6.000      0
    9.88316886    1.69009561   -0.89070029    c       6.000      0
    8.20870297    2.54837628   -2.71992558    c       6.000      0
    5.65989236    1.94427562   -2.55677052    c       6.000      0
   -6.30284753   -1.98210404    2.50912524    h       1.000      0
   -8.08150936   -2.20684793    5.35191500    h       1.000      0
   -5.34365880   -4.08391998    4.94075087    h       1.000      0
   -4.46464715    3.90078473    6.04405393    h       1.000      0
   -7.54789738    2.60678166    6.10885776    h       1.000      0
   -5.86192894    2.78751186    3.20577835    h       1.000      0
   -6.29335456   -0.52031936    9.41735215    h       1.000      0
   -3.56850834   -2.42110781    8.98091395    h       1.000      0
   -3.25175648    0.88299023    9.45108860    h       1.000      0
    0.91045249    1.25343725   -1.48072110    h       1.000      0
    2.59529056   -4.22813873   -1.01967830    h       1.000      0
    2.20630103   -2.53922052   -3.89045028    h       1.000      0
   -0.45288586   -3.15361057   -1.93217445    h       1.000      0
    5.70767218   -1.46563076    2.81702723    h       1.000      0
   10.27288373   -0.44362776    2.53822843    h       1.000      0
   11.87296897    2.16513930   -1.00614517    h       1.000      0
    8.88628578    3.70471867   -4.27124910    h       1.000      0
    4.36101991    2.62972482   -3.99072250    h       1.000      0
```

But-3-en-2-one (MAA* = 186.0 kJ/mol, E = -16.76):



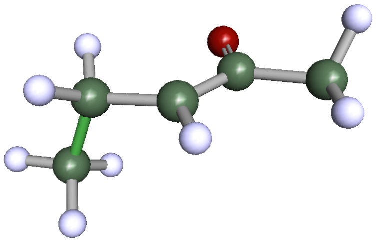
Total Energy = -231.06503253699 hartree
Enthalpy Correction = 0.096493 hartree
Entropy = 0.000118 hartree/K
LUMO Energy = -0.0623 hartree

```
                   atomic coordinates             atom    charge  isotop
   -3.57283416    2.92361005    0.05017362    c       6.000      0
   -1.82979296    1.11660441   -0.00042512    c       6.000      0
    0.90935638    1.69778598    0.17033982    c       6.000      0
    2.65330057   -0.52411647    0.08501596    c       6.000      0
    1.68571728    3.85485502    0.36749703    o       8.000      0
```

```
 -5.57051448    2.49156314   -0.07531604    h      1.000     0
 -3.02561066    4.89285863    0.21985044    h      1.000     0
 -2.35732972   -0.85806276   -0.17017193    h      1.000     0
  2.35299855   -1.57080128   -1.67284419    h      1.000     0
  4.61553831    0.07605294    0.22448513    h      1.000     0
  2.19441170   -1.82226726    1.62739109    h      1.000     0
```

But-3-en-2-one product:

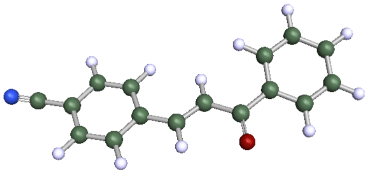
The $CH_3$-$CH_2$-CH-C Torsion Angle was constrained to 90°.



Total Energy = -271.06953423463 hartree
Enthalpy Correction = 0.136439 hartree
Entropy = 0.000132 hartree/K

```
                  atomic coordinates               atom    charge  isotop
  4.15666455   -0.20465259   -0.02554535    o      8.000     0
  2.62489817    1.52104382    0.75003786    c      6.000     0
  3.85239744    3.87849844    1.82477669    c      6.000     0
  0.04217583    1.39681516    0.66471747    c      6.000     0
 -1.34227404   -0.88519614   -0.27021074    c      6.000     0
 -1.95351270   -2.81830695    1.78888522    c      6.000     0
  5.03852542    3.37339909    3.44530968    h      1.000     0
  5.10799199    4.72456241    0.41237902    h      1.000     0
  2.48154046    5.29956981    2.42846153    h      1.000     0
 -1.04679217    2.96320405    1.42718487    h      1.000     0
 -0.17649670   -1.81872708   -1.70699520    h      1.000     0
 -3.10899602   -0.33644866   -1.20877057    h      1.000     0
 -2.95262914   -4.46949096    1.03742352    h      1.000     0
 -0.21163661   -3.47315369    2.68678951    h      1.000     0
 -3.13801902   -1.97669247    3.26077686    h      1.000     0
```

(*E*)-4-(3-Oxo-3-phenylprop-1-en-1-yl)benzonitrile (MAA* = 185.9 kJ/mol, E = -17.64):

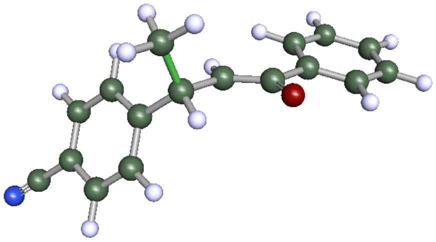


Total Energy = -745.71603243125 hartree
Enthalpy Correction = 0.241057 hartree
Entropy = 0.000197 hartree/K
LUMO Energy = -0.0971 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.28117506 | -2.13798769 | 0.79233434 | o | 8.000 | 0 |
| -2.96600992 | -3.49004691 | -0.54482185 | c | 6.000 | 0 |
| -4.10724411 | -5.66248472 | -1.91219529 | c | 6.000 | 0 |
| -2.66307635 | -7.58407689 | -2.99584484 | c | 6.000 | 0 |
| -3.83089973 | -9.59210037 | -4.20847007 | c | 6.000 | 0 |
| -6.44642110 | -9.68697495 | -4.37369261 | c | 6.000 | 0 |
| -7.90131211 | -7.77660569 | -3.30453614 | c | 6.000 | 0 |
| -6.73861499 | -5.78736170 | -2.07252929 | c | 6.000 | 0 |
| -0.24372564 | -2.99396768 | -0.86740076 | c | 6.000 | 0 |
| 0.87497663 | -1.12651662 | 0.42255604 | c | 6.000 | 0 |
| 3.51608026 | -0.38334219 | 0.28386399 | c | 6.000 | 0 |
| 5.26885600 | -1.59159963 | -1.28752347 | c | 6.000 | 0 |
| 7.75263772 | -0.81522042 | -1.35425172 | c | 6.000 | 0 |
| 8.53202260 | 1.20256123 | 0.16364068 | c | 6.000 | 0 |
| 11.09926640 | 2.00739982 | 0.09663184 | c | 6.000 | 0 |
| 13.17744617 | 2.65717933 | 0.04151064 | n | 7.000 | 0 |
| 6.81458702 | 2.42997851 | 1.74053354 | c | 6.000 | 0 |
| 4.33101715 | 1.63012211 | 1.78845318 | c | 6.000 | 0 |
| -0.62191993 | -7.55817827 | -2.87214206 | h | 1.000 | 0 |
| -2.69379166 | -11.08540426 | -5.02725054 | h | 1.000 | 0 |
| -7.35566175 | -11.25062421 | -5.33545956 | h | 1.000 | 0 |
| -9.94398288 | -7.84643189 | -3.43589317 | h | 1.000 | 0 |
| -7.84889161 | -4.29175743 | -1.22385527 | h | 1.000 | 0 |
| 0.81032203 | -4.14212464 | -2.18879412 | h | 1.000 | 0 |
| -0.29391145 | -0.03670389 | 1.71303629 | h | 1.000 | 0 |
| 4.69031962 | -3.15510899 | -2.47361575 | h | 1.000 | 0 |
| 9.10007273 | -1.75603253 | -2.57290760 | h | 1.000 | 0 |
| 7.42810819 | 3.99160954 | 2.91123732 | h | 1.000 | 0 |
| 2.98761355 | 2.57695015 | 3.01107146 | h | 1.000 | 0 |

(*E*)-4-(3-Oxo-3-phenylprop-1-en-1-yl)benzonitrile Product:

The $CH_3$-CH-CH-C Torsion Angle was constrained to 90°.

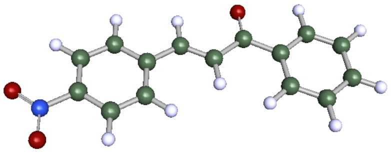


Total Energy = -785.71947767600 hartree
Enthalpy Correction = 0.279999 hartree
Entropy = 0.000211 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.81306595 | 0.88296708 | -5.07589284 | o | 8.000 | 0 |
| 3.36727993 | -0.33968100 | -3.03061775 | c | 6.000 | 0 |
| 5.63605987 | -1.06401567 | -1.46828152 | c | 6.000 | 0 |
| 5.59575386 | -2.87894472 | 0.45084729 | c | 6.000 | 0 |
| 7.75688549 | -3.45735955 | 1.81481880 | c | 6.000 | 0 |
| 10.02553030 | -2.23489865 | 1.29644734 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 10.10148906 | -0.44040113 | -0.61508865 | c | 6.000 | 0 |
| 7.93431917 | 0.12171471 | -1.98319729 | c | 6.000 | 0 |
| 1.00891901 | -0.97028115 | -2.16179402 | c | 6.000 | 0 |
| -1.32506685 | -0.30335294 | -3.63100261 | c | 6.000 | 0 |
| -2.09916669 | -2.37316921 | -5.50435126 | c | 6.000 | 0 |
| -3.44374509 | 0.37831451 | -1.86027731 | c | 6.000 | 0 |
| -4.21880345 | 2.88349736 | -1.59258356 | c | 6.000 | 0 |
| -6.12644565 | 3.55097624 | 0.06269963 | c | 6.000 | 0 |
| -7.30542846 | 1.68267215 | 1.50424439 | c | 6.000 | 0 |
| -9.27436368 | 2.34274693 | 3.21106549 | c | 6.000 | 0 |
| -10.87133514 | 2.87751065 | 4.59537974 | n | 7.000 | 0 |
| -6.55589012 | -0.83801562 | 1.26644925 | c | 6.000 | 0 |
| -4.65081888 | -1.46361442 | -0.40352163 | c | 6.000 | 0 |
| 3.86086071 | -3.88367416 | 0.86861511 | h | 1.000 | 0 |
| 7.67565019 | -4.88329438 | 3.28580678 | h | 1.000 | 0 |
| 11.71500403 | -2.69096660 | 2.36268524 | h | 1.000 | 0 |
| 11.85936780 | 0.52302645 | -1.04745782 | h | 1.000 | 0 |
| 7.97245084 | 1.50269498 | -3.49480125 | h | 1.000 | 0 |
| 0.77521213 | -1.99010096 | -0.40216855 | h | 1.000 | 0 |
| -0.87030368 | 1.38299811 | -4.74149100 | h | 1.000 | 0 |
| -2.49649962 | -4.15361276 | -4.53518948 | h | 1.000 | 0 |
| -3.77831005 | -1.83769595 | -6.58909755 | h | 1.000 | 0 |
| -0.54457218 | -2.70295786 | -6.82016653 | h | 1.000 | 0 |
| -3.30550191 | 4.33909160 | -2.70992268 | h | 1.000 | 0 |
| -6.71241415 | 5.50396157 | 0.24357235 | h | 1.000 | 0 |
| -7.47285174 | -2.28472547 | 2.38760684 | h | 1.000 | 0 |
| -4.08593935 | -3.42523898 | -0.57142970 | h | 1.000 | 0 |

(*E*)-3-(4-Nitrophenyl)-1-phenylprop-2-en-1-one (MAA* = 182.2 kJ/mol, E = -17.33):



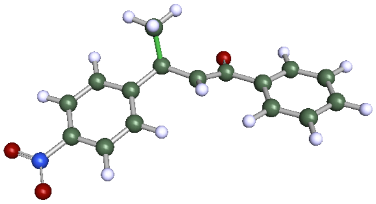
Total Energy = -857.93043013105 hartree
Enthalpy Correction = 0.245884 hartree
Entropy = 0.000204 hartree/K
LUMO Energy = -0.1116 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.71238007 | -1.13944381 | -1.39828019 | o | 8.000 | 0 |
| 3.52893907 | -0.47674299 | -3.27015673 | c | 6.000 | 0 |
| 4.86086790 | -0.08323302 | -5.71313846 | c | 6.000 | 0 |
| 7.45702417 | -0.55878649 | -5.78668052 | c | 6.000 | 0 |
| 8.81049820 | -0.22610881 | -7.99532222 | c | 6.000 | 0 |
| 7.58583323 | 0.59262598 | -10.17261273 | c | 6.000 | 0 |
| 5.00857118 | 1.07283520 | -10.12348889 | c | 6.000 | 0 |
| 3.64915841 | 0.73664935 | -7.90794394 | c | 6.000 | 0 |
| 0.77477055 | -0.06000976 | -3.14432329 | c | 6.000 | 0 |
| -0.45108016 | -0.38928132 | -0.95601167 | c | 6.000 | 0 |
| -3.14183306 | -0.06428634 | -0.50902466 | c | 6.000 | 0 |
| -4.06243340 | -0.48932682 | 1.93255721 | c | 6.000 | 0 |
| -6.59872136 | -0.21393853 | 2.48438901 | c | 6.000 | 0 |
| -8.22046274 | 0.49530251 | 0.55785588 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -10.89779450 | 0.79098883 | 1.11408002 | n | 7.000 | 0 |
| -12.29622961 | 1.41256082 | -0.59877937 | o | 8.000 | 0 |
| -11.60706263 | 0.40252243 | 3.26343921 | o | 8.000 | 0 |
| -7.37675365 | 0.93340621 | -1.88744298 | c | 6.000 | 0 |
| -4.84079213 | 0.65133938 | -2.40814070 | c | 6.000 | 0 |
| 8.38500730 | -1.19365888 | -4.07685390 | h | 1.000 | 0 |
| 10.82328055 | -0.60268369 | -8.02831447 | h | 1.000 | 0 |
| 8.64494652 | 0.85559994 | -11.90660778 | h | 1.000 | 0 |
| 4.05008984 | 1.71210091 | -11.81633478 | h | 1.000 | 0 |
| 1.64337228 | 1.12858231 | -7.92364955 | h | 1.000 | 0 |
| -0.22079169 | 0.50590150 | -4.83574007 | h | 1.000 | 0 |
| 0.66354693 | -0.95979061 | 0.67219491 | h | 1.000 | 0 |
| -2.76225780 | -1.04402259 | 3.41392322 | h | 1.000 | 0 |
| -7.31357377 | -0.54149823 | 4.36932961 | h | 1.000 | 0 |
| -8.69686949 | 1.48500263 | -3.34514349 | h | 1.000 | 0 |
| -4.18166143 | 0.99259296 | -4.31388849 | h | 1.000 | 0 |

(*E*)-3-(4-Nitrophenyl)-1-phenylprop-2-en-1-one Product:

The $CH_3$-CH-CH-C Torsion Angle was constrained to 270°.

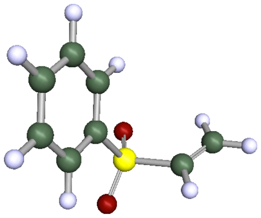


Total Energy = -897.93319285807 hartree
Enthalpy Correction = 0.284951 hartree
Entropy = 0.000216 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.76547486 | -2.81764174 | -3.91787438 | o | 8.000 | 0 |
| -3.46329605 | -2.40828173 | -1.54535027 | c | 6.000 | 0 |
| -5.83655250 | -2.24716553 | 0.01995130 | c | 6.000 | 0 |
| -5.93317345 | -1.24275237 | 2.46142196 | c | 6.000 | 0 |
| -8.18267262 | -1.15081843 | 3.80163468 | c | 6.000 | 0 |
| -10.40577648 | -2.06095872 | 2.73344068 | c | 6.000 | 0 |
| -10.34519818 | -3.04960624 | 0.30477100 | c | 6.000 | 0 |
| -8.08797195 | -3.12842279 | -1.03168425 | c | 6.000 | 0 |
| -1.17355691 | -2.13767162 | -0.36386615 | c | 6.000 | 0 |
| 1.23697610 | -2.50863679 | -1.78371222 | c | 6.000 | 0 |
| 2.11179926 | -5.27874613 | -1.66471086 | c | 6.000 | 0 |
| 3.36117555 | -0.74124269 | -1.07069769 | c | 6.000 | 0 |
| 5.64557791 | -0.83274393 | -2.40304291 | c | 6.000 | 0 |
| 7.62209344 | 0.77075380 | -1.84063552 | c | 6.000 | 0 |
| 7.31942497 | 2.50538886 | 0.10528610 | c | 6.000 | 0 |
| 9.37905468 | 4.20347131 | 0.71395103 | n | 7.000 | 0 |
| 11.32404456 | 4.04208022 | -0.50490667 | o | 8.000 | 0 |
| 9.07953225 | 5.72169864 | 2.41682933 | o | 8.000 | 0 |
| 5.08882638 | 2.65996731 | 1.46531011 | c | 6.000 | 0 |
| 3.12925736 | 1.03672299 | 0.86171802 | c | 6.000 | 0 |
| -4.23377713 | -0.48830360 | 3.32032008 | h | 1.000 | 0 |
| -8.20692693 | -0.34905260 | 5.68840347 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -12.16510494 | -1.98444833 | 3.78132734 | h | 1.000 | 0 |
| -12.06591461 | -3.75923800 | -0.55602549 | h | 1.000 | 0 |
| -8.01818291 | -3.87793245 | -2.93602795 | h | 1.000 | 0 |
| -1.09178098 | -1.98777082 | 1.67624893 | h | 1.000 | 0 |
| 0.80544839 | -2.12804538 | -3.77803944 | h | 1.000 | 0 |
| 3.80291815 | -5.63375584 | -2.79774503 | h | 1.000 | 0 |
| 0.59554449 | -6.48646737 | -2.36906709 | h | 1.000 | 0 |
| 2.51905168 | -5.82050955 | 0.28807041 | h | 1.000 | 0 |
| 5.87251707 | -2.17467669 | -3.93320618 | h | 1.000 | 0 |
| 9.37380270 | 0.69944020 | -2.89000807 | h | 1.000 | 0 |
| 4.89376634 | 4.03466081 | 2.96494144 | h | 1.000 | 0 |
| 1.37002999 | 1.17055456 | 1.89458706 | h | 1.000 | 0 |

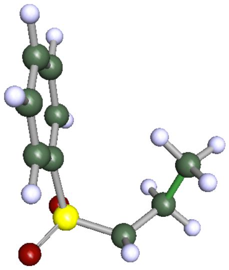
(Vinylsulfonyl)benzene (MAA* = 180.8 kJ/mol, E = -18.36):



Total Energy = -857.81927743568 hartree
Enthalpy Correction = 0.155815 hartree
Entropy = 0.000155 hartree/K
LUMO Energy = -0.0593 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.81475772 | -2.17795334 | -0.90625046 | c | 6.000 | 0 |
| 4.33061183 | -0.17781770 | -1.10993898 | c | 6.000 | 0 |
| 2.68207379 | 0.98796762 | 1.51196715 | s | 16.000 | 0 |
| 3.32273905 | -0.51206015 | 3.69838200 | o | 8.000 | 0 |
| -0.51017459 | 0.44567759 | 0.75478300 | c | 6.000 | 0 |
| -1.54517493 | -1.92356968 | 1.21866562 | c | 6.000 | 0 |
| -4.04992894 | -2.35261640 | 0.59505137 | c | 6.000 | 0 |
| -5.48544146 | -0.43255863 | -0.47963202 | c | 6.000 | 0 |
| -4.42791371 | 1.92491118 | -0.93393689 | c | 6.000 | 0 |
| -1.92057839 | 2.37822847 | -0.32119916 | c | 6.000 | 0 |
| 3.08968836 | 3.68645540 | 1.60870318 | o | 8.000 | 0 |
| 6.87256777 | -2.85925366 | -2.52242804 | h | 1.000 | 0 |
| 6.01533795 | -3.17307515 | 0.87305721 | h | 1.000 | 0 |
| 4.04248700 | 0.89746829 | -2.83047269 | h | 1.000 | 0 |
| -0.40925395 | -3.39947522 | 2.06771539 | h | 1.000 | 0 |
| -4.88636828 | -4.18678986 | 0.95205174 | h | 1.000 | 0 |
| -7.44551722 | -0.77845849 | -0.96250807 | h | 1.000 | 0 |
| -5.55594329 | 3.41807503 | -1.76385406 | h | 1.000 | 0 |
| -1.06993321 | 4.20930427 | -0.65213519 | h | 1.000 | 0 |

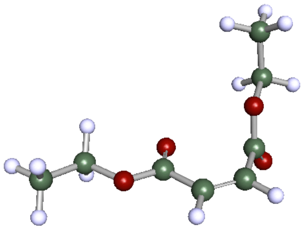
(Vinylsulfonyl)benzene Product:



Total Energy = -897.82170964519 hartree
Enthalpy Correction = 0.195353 hartree
Entropy = 0.000168 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.15085710 | 1.65238850 | -1.39875521 | c | 6.000 | 0 |
| -4.73985294 | -1.00146185 | -0.42513818 | c | 6.000 | 0 |
| -2.94770208 | -3.02744142 | -1.31802032 | c | 6.000 | 0 |
| -0.47392921 | -3.74103517 | 0.42553669 | s | 16.000 | 0 |
| -1.19212976 | -4.20183413 | 3.05819735 | o | 8.000 | 0 |
| 1.70836224 | -1.15985748 | 0.67482428 | c | 6.000 | 0 |
| 3.37077282 | -0.67412212 | -1.30629817 | c | 6.000 | 0 |
| 4.89271067 | 1.45570844 | -1.25083651 | c | 6.000 | 0 |
| 4.75970366 | 3.12549609 | 0.77565340 | c | 6.000 | 0 |
| 3.10845214 | 2.63644268 | 2.75442836 | c | 6.000 | 0 |
| 1.58845442 | 0.49716859 | 2.71056621 | c | 6.000 | 0 |
| 1.00780558 | -5.73291849 | -0.79923072 | o | 8.000 | 0 |
| -5.53231803 | 3.04011350 | -0.72907165 | h | 1.000 | 0 |
| -2.27431974 | 2.26077860 | -0.78890511 | h | 1.000 | 0 |
| -4.17540824 | 1.68477060 | -3.46602141 | h | 1.000 | 0 |
| -4.76254529 | -0.99153739 | 1.64511085 | h | 1.000 | 0 |
| -6.67822659 | -1.48266328 | -0.98745688 | h | 1.000 | 0 |
| -2.42965060 | -2.99797620 | -3.31062502 | h | 1.000 | 0 |
| 3.46696852 | -1.97396646 | -2.88662106 | h | 1.000 | 0 |
| 6.19267084 | 1.81753368 | -2.79349295 | h | 1.000 | 0 |
| 5.94825439 | 4.79372974 | 0.81359526 | h | 1.000 | 0 |
| 3.00683429 | 3.92180474 | 4.34759667 | h | 1.000 | 0 |
| 0.30595001 | 0.09887883 | 4.25496411 | h | 1.000 | 0 |

Diethyl maleate (MAA* = 176.6 kJ/mol, E = -19.49):



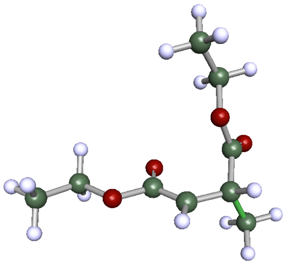
Total Energy = -612.55584166244 hartree
Enthalpy Correction = 0.210428 hartree

Entropy = 0.000183 hartree/K
LUMO Energy = -0.0597 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.21654594 | 0.33091200 | -2.63879082 | o | 8.000 | 0 |
| -4.09069350 | 1.91357409 | -1.43958089 | c | 6.000 | 0 |
| -2.60717342 | 3.97204271 | -2.66037012 | c | 6.000 | 0 |
| -0.11038080 | 3.99199581 | -2.90551645 | c | 6.000 | 0 |
| 1.48419599 | 1.93257592 | -1.90877588 | c | 6.000 | 0 |
| 3.92135172 | 2.50025809 | -2.08933045 | o | 8.000 | 0 |
| 5.67211549 | 0.63080537 | -1.16733270 | c | 6.000 | 0 |
| 8.29830527 | 1.65009077 | -1.52746312 | c | 6.000 | 0 |
| 0.68582679 | -0.02898676 | -1.04410645 | o | 8.000 | 0 |
| -4.15296886 | 2.13940687 | 1.04302381 | o | 8.000 | 0 |
| -5.54860121 | 0.23416709 | 2.40514761 | c | 6.000 | 0 |
| -5.34870245 | 0.83730265 | 5.17287004 | c | 6.000 | 0 |
| -3.73481130 | 5.49429895 | -3.44829142 | h | 1.000 | 0 |
| 0.83295683 | 5.53630520 | -3.86136245 | h | 1.000 | 0 |
| 5.37096838 | -1.11776176 | -2.22101553 | h | 1.000 | 0 |
| 5.25025899 | 0.26835958 | 0.81971901 | h | 1.000 | 0 |
| 8.68633918 | 2.01077794 | -3.52135643 | h | 1.000 | 0 |
| 8.56436487 | 3.40082066 | -0.46914580 | h | 1.000 | 0 |
| 9.66419482 | 0.26424876 | -0.84194366 | h | 1.000 | 0 |
| -7.50302647 | 0.25830547 | 1.74603371 | h | 1.000 | 0 |
| -4.73103538 | -1.60527468 | 1.95226107 | h | 1.000 | 0 |
| -3.38145273 | 0.81857504 | 5.79328087 | h | 1.000 | 0 |
| -6.38451487 | -0.58141966 | 6.25460754 | h | 1.000 | 0 |
| -6.16023466 | 2.68818053 | 5.58739591 | h | 1.000 | 0 |

Diethyl maleate Product:

The $CH_3$-CH-CH-C Torsion Angle was constrained to 270°.

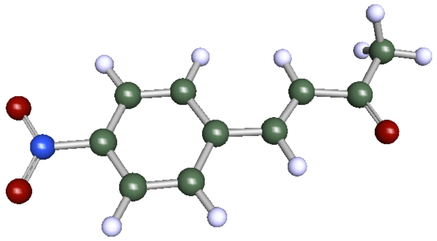


Total Energy = -652.55591872807 hartree
Enthalpy Correction = 0.249229 hartree
Entropy = 0.000196 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.14757077 | 2.66970492 | -3.81812640 | c | 6.000 | 0 |
| 1.54720202 | -0.15157440 | -3.37045622 | c | 6.000 | 0 |
| 3.58401334 | -0.55535464 | -1.40466325 | c | 6.000 | 0 |
| 4.10614204 | -2.99556420 | -1.05784900 | o | 8.000 | 0 |
| 5.91804711 | -3.57847807 | 0.85857140 | c | 6.000 | 0 |
| 6.06095838 | -6.40985042 | 1.08446522 | c | 6.000 | 0 |
| 4.74868318 | 1.10432526 | -0.33833022 | o | 8.000 | 0 |
| -0.81892876 | -1.59500017 | -2.77379069 | c | 6.000 | 0 |
| -1.60023056 | -1.87172005 | -0.31796259 | c | 6.000 | 0 |

```
 -3.79569637   -3.33034618   -0.04348081     o      8.000     0
 -4.63111454   -3.72787975    2.46291573     c      6.000     0
 -6.98844858   -5.32888620    2.35993592     c      6.000     0
 -0.58940824   -0.99622318    1.63671782     o      8.000     0
  2.90307100    3.64527485   -4.31060445     h      1.000     0
 -0.20257962    2.93036709   -5.35635849     h      1.000     0
  0.37020655    3.55006766   -2.12090812     h      1.000     0
  2.36247284   -0.95915237   -5.10263390     h      1.000     0
  5.30774045   -2.70474127    2.62663505     h      1.000     0
  7.74512136   -2.76351386    0.34171695     h      1.000     0
  4.22652855   -7.19641636    1.60851469     h      1.000     0
  6.66170973   -7.26587135   -0.69503066     h      1.000     0
  7.42894599   -6.92216267    2.54210280     h      1.000     0
 -1.84116343   -2.51429618   -4.29010211     h      1.000     0
 -3.15319346   -4.66717351    3.56693637     h      1.000     0
 -5.01650313   -1.91657306    3.38852601     h      1.000     0
 -7.69030350   -5.68104656    4.26953883     h      1.000     0
 -6.60542667   -7.15124425    1.46656083     h      1.000     0
 -8.47844196   -4.38140175    1.28882751     h      1.000     0
```

(*E*)-4-(4-Nitrophenyl)but-3-en-2-one (MAA* = 174.7 kJ/mol, E = -19.36):



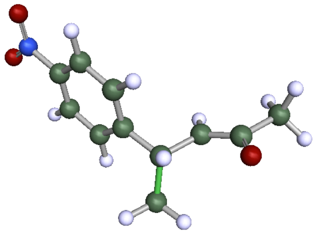
Total Energy = -666.34177297676 hartree
Enthalpy Correction = 0.188541 hartree
Entropy = 0.000178 hartree/K
LUMO Energy = -0.1109 hartree

```
                 atomic coordinates             atom    charge  isotop
  8.44216407    1.36075867   -1.25884079     c      6.000     0
  6.56235852   -0.36245797   -0.04086198     c      6.000     0
  3.87597783    0.30161196   -0.42243645     c      6.000     0
  2.02848818   -1.12697337    0.54389457     c      6.000     0
 -0.67612024   -0.69682915    0.30731127     c      6.000     0
 -2.32693604   -2.46927592    1.36477133     c      6.000     0
 -4.91477751   -2.17107473    1.19263815     c      6.000     0
 -5.84420527   -0.06286913   -0.04699910     c      6.000     0
 -8.56661759    0.27733155   -0.23784284     n      7.000     0
 -9.92644472   -1.34891736    0.64551988     o      8.000     0
 -9.35053571    2.17242941   -1.27225927     o      8.000     0
 -4.26414754    1.74023264   -1.11237682     c      6.000     0
 -1.68735600    1.41197304   -0.93163670     c      6.000     0
  7.20421306   -2.20095432    1.19001884     o      8.000     0
 10.36343533    0.73006100   -0.88569375     h      1.000     0
  8.17673022    3.28543003   -0.55105400     h      1.000     0
  8.09991918    1.42954233   -3.29683363     h      1.000     0
  3.48452596    1.98479741   -1.52352508     h      1.000     0
  2.58273849   -2.79235205    1.61233319     h      1.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -1.56121553 | -4.10349984 | 2.33242130 | h | 1.000 | 0 |
| -6.19482742 | -3.53996836 | 2.00500542 | h | 1.000 | 0 |
| -5.05526138 | 3.36514647 | -2.06431808 | h | 1.000 | 0 |
| -0.45210588 | 2.81585770 | -1.76058180 | h | 1.000 | 0 |

(*E*)-4-(4-Nitrophenyl)but-3-en-2-one Product:

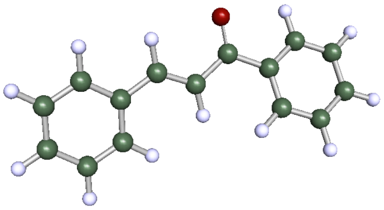
The $CH_3$-CH-CH-C Torsion Angle was constrained to 270°.



Total Energy = -706.34195236151 hartree
Enthalpy Correction = 0.22785 hartree
Entropy = 0.00019 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.66753492 | 2.42486592 | 3.61550773 | c | 6.000 | 0 |
| -3.69928070 | 1.65715711 | 1.67519111 | c | 6.000 | 0 |
| -1.94576014 | 3.26565905 | 1.23689581 | o | 8.000 | 0 |
| -3.93240009 | -0.66195263 | 0.54833229 | c | 6.000 | 0 |
| -2.09507085 | -1.64157285 | -1.39111591 | c | 6.000 | 0 |
| -2.83773562 | -0.93798368 | -4.08978638 | c | 6.000 | 0 |
| 0.60869013 | -1.02500484 | -0.73493392 | c | 6.000 | 0 |
| 2.28956891 | 0.09657800 | -2.42999621 | c | 6.000 | 0 |
| 4.78013387 | 0.53995744 | -1.78331452 | c | 6.000 | 0 |
| 5.61865164 | -0.16260030 | 0.59927587 | c | 6.000 | 0 |
| 8.21229309 | 0.28603984 | 1.28810779 | n | 7.000 | 0 |
| 9.62164043 | 1.24132519 | -0.26891067 | o | 8.000 | 0 |
| 8.90897676 | -0.30762252 | 3.40618860 | o | 8.000 | 0 |
| 4.00073601 | -1.30559010 | 2.33148697 | c | 6.000 | 0 |
| 1.52800730 | -1.72224412 | 1.64638902 | c | 6.000 | 0 |
| -6.56902798 | 4.19527371 | 3.03465546 | h | 1.000 | 0 |
| -4.74424370 | 2.79221266 | 5.43193927 | h | 1.000 | 0 |
| -7.13070961 | 0.99619670 | 3.89673012 | h | 1.000 | 0 |
| -5.50748498 | -1.87410776 | 1.05388833 | h | 1.000 | 0 |
| -2.17840914 | -3.71746749 | -1.28337357 | h | 1.000 | 0 |
| -1.60526861 | -1.80440729 | -5.50905610 | h | 1.000 | 0 |
| -4.76623738 | -1.57567658 | -4.44869773 | h | 1.000 | 0 |
| -2.79258184 | 1.11174831 | -4.34562787 | h | 1.000 | 0 |
| 1.64641773 | 0.65881063 | -4.28754873 | h | 1.000 | 0 |
| 6.07007152 | 1.41990041 | -3.10190464 | h | 1.000 | 0 |
| 4.69754946 | -1.85227698 | 4.17329516 | h | 1.000 | 0 |
| 0.23146872 | -2.57940720 | 2.98035311 | h | 1.000 | 0 |

(*E*)-Chalcone (MAA* = 174.3 kJ/mol, E = -19.39):

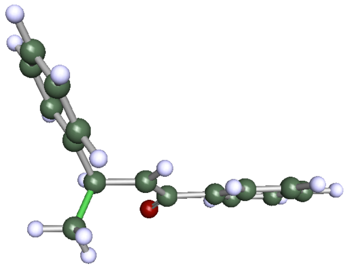


Total Energy = -653.53731237207 hartree
Enthalpy Correction = 0.240538 hartree
Entropy = 0.000182 hartree/K
LUMO Energy = -0.0906 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.20129883 | -3.34845354 | 3.13705426 | o | 8.000 | 0 |
| 2.28583357 | -1.66541869 | 1.54897401 | c | 6.000 | 0 |
| 4.77298297 | -0.76957961 | 0.58734688 | c | 6.000 | 0 |
| 6.94130756 | -1.41281789 | 1.94574622 | c | 6.000 | 0 |
| 9.30128864 | -0.65013177 | 1.12061837 | c | 6.000 | 0 |
| 9.52872604 | 0.74421728 | -1.09553078 | c | 6.000 | 0 |
| 7.38766735 | 1.37593318 | -2.47191665 | c | 6.000 | 0 |
| 5.01881924 | 0.63708465 | -1.62888394 | c | 6.000 | 0 |
| -0.01800812 | -0.46559096 | 0.57057064 | c | 6.000 | 0 |
| -2.30360212 | -1.32210099 | 1.25361413 | c | 6.000 | 0 |
| -4.74498064 | -0.33663787 | 0.48123163 | c | 6.000 | 0 |
| -6.92404093 | -1.55224182 | 1.35177004 | c | 6.000 | 0 |
| -9.30382605 | -0.70002874 | 0.66755637 | c | 6.000 | 0 |
| -9.54215410 | 1.38934154 | -0.89927763 | c | 6.000 | 0 |
| -7.38984606 | 2.62167925 | -1.77643643 | c | 6.000 | 0 |
| -5.01578684 | 1.77099645 | -1.09628297 | c | 6.000 | 0 |
| 6.73878514 | -2.50968827 | 3.66220447 | h | 1.000 | 0 |
| 10.97144085 | -1.14111572 | 2.19989924 | h | 1.000 | 0 |
| 11.37794782 | 1.33644532 | -1.74851145 | h | 1.000 | 0 |
| 7.55998630 | 2.44870921 | -4.20781151 | h | 1.000 | 0 |
| 3.37422432 | 1.13232086 | -2.73994208 | h | 1.000 | 0 |
| 0.17457290 | 1.13546115 | -0.68557346 | h | 1.000 | 0 |
| -2.35545074 | -2.93969579 | 2.52074500 | h | 1.000 | 0 |
| -6.73190760 | -3.18480316 | 2.57695670 | h | 1.000 | 0 |
| -10.97287827 | -1.66615698 | 1.35724233 | h | 1.000 | 0 |
| -11.39961091 | 2.06320078 | -1.43927044 | h | 1.000 | 0 |
| -7.57322955 | 4.25585463 | -2.99757577 | h | 1.000 | 0 |
| -3.35955960 | 2.75321749 | -1.79295791 | h | 1.000 | 0 |

(*E*)-Chalcone Product:

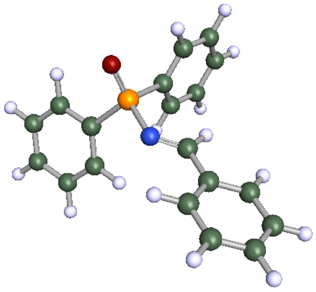
The $CH_3$-CH-CH-C Torsion Angle was constrained to 90°.



Total Energy = -693.53665373992 hartree
Enthalpy Correction = 0.279475 hartree
Entropy = 0.000195 hartree/K

```
                  atomic coordinates               atom    charge  isotop
   2.28341190   -4.21098757   -3.64706499    o      8.000     0
   2.41931751   -2.90632036   -1.60273174    c      6.000     0
   5.03424765   -2.17039661   -0.74753801    c      6.000     0
   7.02163308   -2.40884547   -2.46463104    c      6.000     0
   9.47952055   -1.75941298   -1.81488389    c      6.000     0
  10.01647949   -0.87458665    0.59506229    c      6.000     0
   8.06342496   -0.65387828    2.34090820    c      6.000     0
   5.61085291   -1.29316980    1.67710367    c      6.000     0
   0.38666363   -2.10819351   -0.21268080    c      6.000     0
  -2.27121442   -2.75698534   -0.96106549    c      6.000     0
  -3.17133914   -5.24484790    0.22365567    c      6.000     0
  -4.06575325   -0.61884024   -0.38255545    c      6.000     0
  -5.23998574    0.72146635   -2.31960845    c      6.000     0
  -6.86929395    2.71578760   -1.80503612    c      6.000     0
  -7.35791727    3.40968212    0.67664666    c      6.000     0
  -6.20294526    2.08868605    2.63145593    c      6.000     0
  -4.58084443    0.09786784    2.10307986    c      6.000     0
   6.58027363   -3.12373288   -4.33231580    h      1.000     0
  10.98410961   -1.95101724   -3.19524151    h      1.000     0
  11.93430978   -0.37633932    1.11743871    h      1.000     0
   8.45903330    0.00954587    4.24027238    h      1.000     0
   4.13019420   -1.13640472    3.08338945    h      1.000     0
   0.65514442   -0.98729086    1.47935589    h      1.000     0
  -2.26833195   -3.03488317   -3.01289651    h      1.000     0
  -1.89395874   -6.76841746   -0.33112097    h      1.000     0
  -3.16597134   -5.12852586    2.28639997    h      1.000     0
  -5.08661323   -5.73382838   -0.38933275    h      1.000     0
  -4.86744511    0.19153504   -4.26663447    h      1.000     0
  -7.76015478    3.72795214   -3.34915796    h      1.000     0
  -8.62784281    4.96436520    1.08717147    h      1.000     0
  -6.56971721    2.61347531    4.57900320    h      1.000     0
  -3.69338551   -0.91139506    3.65206700    h      1.000     0
```

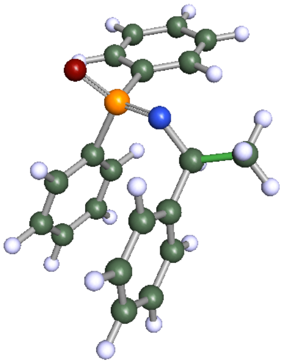
(E)-N-Benzylidene-P,P-diphenylphosphinic amide (MAA* = 174.0 kJ/mol, E = -15.89):



Total Energy = -1204.27778414334 hartree
Enthalpy Correction = 0.322241 hartree
Entropy = 0.000228 hartree/K
LUMO Energy = -0.0764 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.68990603 | -1.13922337 | -5.07409234 | o | 8.000 | 0 |
| -1.98425007 | -0.32402659 | -2.47889554 | p | 15.000 | 0 |
| 1.13220156 | 0.16416072 | -2.22521335 | n | 7.000 | 0 |
| 2.54694817 | -0.95097255 | -0.62785674 | c | 6.000 | 0 |
| 5.26687963 | -0.55876477 | -0.48984947 | c | 6.000 | 0 |
| 6.51953956 | 1.06905961 | -2.14916672 | c | 6.000 | 0 |
| 9.10398093 | 1.38644592 | -1.95718326 | c | 6.000 | 0 |
| 10.45762137 | 0.08954188 | -0.10892216 | c | 6.000 | 0 |
| 9.22450438 | -1.52767180 | 1.54833373 | c | 6.000 | 0 |
| 6.63295576 | -1.85235218 | 1.35665594 | c | 6.000 | 0 |
| -3.31878693 | 2.66709977 | -1.58876728 | c | 6.000 | 0 |
| -2.07936834 | 4.33472416 | 0.02770271 | c | 6.000 | 0 |
| -3.22475344 | 6.59035634 | 0.71392252 | c | 6.000 | 0 |
| -5.60556230 | 7.18875289 | -0.21269240 | c | 6.000 | 0 |
| -6.84460359 | 5.53527831 | -1.83224438 | c | 6.000 | 0 |
| -5.70656759 | 3.27809849 | -2.51965454 | c | 6.000 | 0 |
| -2.95579512 | -2.58805156 | -0.12900305 | c | 6.000 | 0 |
| -3.29713972 | -5.09392621 | -0.86698739 | c | 6.000 | 0 |
| -3.94287407 | -6.91066512 | 0.90811697 | c | 6.000 | 0 |
| -4.24622813 | -6.23575664 | 3.42624100 | c | 6.000 | 0 |
| -3.90888387 | -3.74157634 | 4.17164674 | c | 6.000 | 0 |
| -3.26611967 | -1.92064797 | 2.40067471 | c | 6.000 | 0 |
| 1.78378986 | -2.28708152 | 0.76304551 | h | 1.000 | 0 |
| 5.43889747 | 2.06583156 | -3.57438181 | h | 1.000 | 0 |
| 10.08059469 | 2.64489648 | -3.24413643 | h | 1.000 | 0 |
| 12.48509156 | 0.34579680 | 0.03504581 | h | 1.000 | 0 |
| 10.28167920 | -2.53293487 | 2.98503785 | h | 1.000 | 0 |
| 5.64913801 | -3.11248793 | 2.64062071 | h | 1.000 | 0 |
| -0.21281035 | 3.88396362 | 0.73985204 | h | 1.000 | 0 |
| -2.25291636 | 7.88578154 | 1.96764400 | h | 1.000 | 0 |
| -6.49617015 | 8.95402729 | 0.32326893 | h | 1.000 | 0 |
| -8.69823289 | 6.00822425 | -2.56384421 | h | 1.000 | 0 |
| -6.66336984 | 1.98856424 | -3.79294470 | h | 1.000 | 0 |
| -3.06783844 | -5.60617366 | -2.83675571 | h | 1.000 | 0 |
| -4.21345393 | -8.85540571 | 0.32538113 | h | 1.000 | 0 |
| -4.75416537 | -7.65647628 | 4.81206312 | h | 1.000 | 0 |
| -4.15251002 | -3.21219715 | 6.13495316 | h | 1.000 | 0 |
| -3.02151593 | 0.02578832 | 2.99238489 | h | 1.000 | 0 |

(E)-N-Benzylidene-P,P-diphenylphosphinic amide Product:

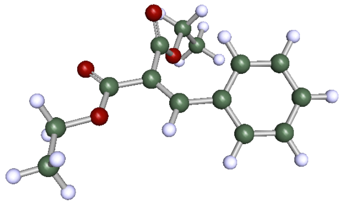


Total Energy = -1244.27825046539 hartree
Enthalpy Correction = 0.361216 hartree
Entropy = 0.000237 hartree/K

```
                   atomic coordinates                atom    charge  isotop
    3.84596182   -5.42407482    3.15270672    c       6.000     0
    2.62187594   -3.35667232    1.55268121    c       6.000     0
    1.29416927   -4.49274499   -0.54043379    n       7.000     0
   -1.02471246   -3.14305147   -1.86034140    p      15.000     0
   -3.91026178   -3.52218623    0.00885898    c       6.000     0
   -3.85649940   -4.86462397    2.26774633    c       6.000     0
   -6.04468812   -5.21321842    3.67948116    c       6.000     0
   -8.31662717   -4.21037522    2.83756454    c       6.000     0
   -8.39501827   -2.86112974    0.58241639    c       6.000     0
   -6.20584951   -2.52208799   -0.81693328    c       6.000     0
   -0.58719217    0.27879382   -1.84883459    c       6.000     0
    0.94446251    1.34533717   -3.71050171    c       6.000     0
    1.55639319    3.88996893   -3.64989741    c       6.000     0
    0.64105296    5.41640096   -1.71869099    c       6.000     0
   -0.88923080    4.38162752    0.14087279    c       6.000     0
   -1.49481447    1.82858395    0.07448644    c       6.000     0
   -1.59915351   -4.04395198   -4.49945297    o       8.000     0
    4.63298246   -1.48331591    0.71871825    c       6.000     0
    6.18577961   -2.01997151   -1.33557552    c       6.000     0
    8.02827926   -0.32712515   -2.11010491    c       6.000     0
    8.33796723    1.95674817   -0.84743739    c       6.000     0
    6.79659420    2.51415506    1.19864747    c       6.000     0
    4.96970927    0.79706059    1.97613703    c       6.000     0
    4.90826448   -4.63269656    4.73930336    h       1.000     0
    5.14047853   -6.53255949    1.98353426    h       1.000     0
    2.39694262   -6.69683515    3.89380861    h       1.000     0
    1.35495214   -2.29418665    2.82515397    h       1.000     0
   -2.07233072   -5.65455494    2.89745860    h       1.000     0
   -5.97589221   -6.26719250    5.43627068    h       1.000     0
  -10.02805991   -4.47825726    3.93259131    h       1.000     0
  -10.16949739   -2.07871278   -0.08145133    h       1.000     0
   -6.27621253   -1.46890099   -2.57560612    h       1.000     0
    1.68191885    0.15276591   -5.20593073    h       1.000     0
    2.76429349    4.68683964   -5.10118616    h       1.000     0
    1.12646256    7.40665601   -1.66281582    h       1.000     0
   -1.60896084    5.56274857    1.65400032    h       1.000     0
   -2.68454602    1.03649937    1.54350659    h       1.000     0
```

| | | | | | |
|---|---|---|---|---|---|
| 5.88003864 | -3.76947424 | -2.35703712 | h | 1.000 | 0 |
| 9.21648633 | -0.77452065 | -3.72078832 | h | 1.000 | 0 |
| 9.75668447 | 3.29869256 | -1.46989310 | h | 1.000 | 0 |
| 6.99775497 | 4.30393140 | 2.17817299 | h | 1.000 | 0 |
| 3.74367494 | 1.25896763 | 3.55513295 | h | 1.000 | 0 |

Diethyl 2-benzylidenemalonate (MAA* = 169.9 kJ/mol, E = -20.55):

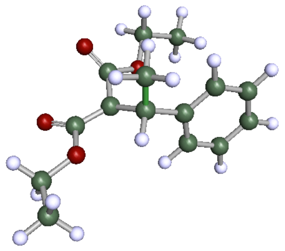


Total Energy = -843.43482106229 hartree
Enthalpy Correction = 0.296802 hartree
Entropy = 0.000223 hartree/K
LUMO Energy = -0.0775 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.55435482 | -3.22075618 | 0.91415096 | o | 8.000 | 0 |
| -3.45797122 | -3.34373672 | 1.83304010 | c | 6.000 | 0 |
| -1.50917312 | -1.39680809 | 1.38858193 | c | 6.000 | 0 |
| -2.48186097 | 0.89137513 | 0.05356273 | c | 6.000 | 0 |
| -1.59196699 | 1.05492452 | -2.27544134 | o | 8.000 | 0 |
| -2.29411416 | 3.27137967 | -3.69919312 | c | 6.000 | 0 |
| -0.96377714 | 3.13878892 | -6.20419773 | c | 6.000 | 0 |
| -3.90887306 | 2.39960857 | 0.99933226 | o | 8.000 | 0 |
| 0.91064253 | -1.72507887 | 2.07073329 | c | 6.000 | 0 |
| 3.03380409 | -0.01368559 | 1.72620224 | c | 6.000 | 0 |
| 5.45714435 | -1.06524671 | 1.63785366 | c | 6.000 | 0 |
| 7.55793601 | 0.44312662 | 1.23935047 | c | 6.000 | 0 |
| 7.27517057 | 3.03848300 | 0.97769970 | c | 6.000 | 0 |
| 4.88487706 | 4.11606011 | 1.13446466 | c | 6.000 | 0 |
| 2.78156994 | 2.60803524 | 1.50355145 | c | 6.000 | 0 |
| -2.68017743 | -5.22944175 | 3.28517942 | o | 8.000 | 0 |
| -4.44826948 | -7.25868907 | 3.68954523 | c | 6.000 | 0 |
| -3.18604249 | -9.17814735 | 5.35988631 | c | 6.000 | 0 |
| -4.34610155 | 3.28924108 | -3.90715431 | h | 1.000 | 0 |
| -1.73942142 | 4.93802430 | -2.61500219 | h | 1.000 | 0 |
| -1.45764007 | 4.79872594 | -7.32500362 | h | 1.000 | 0 |
| 1.08328367 | 3.11105750 | -5.95160601 | h | 1.000 | 0 |
| -1.52831523 | 1.45521974 | -7.25427137 | h | 1.000 | 0 |
| 1.36833536 | -3.51676432 | 2.95972385 | h | 1.000 | 0 |
| 5.67645475 | -3.09122839 | 1.85989880 | h | 1.000 | 0 |
| 9.41993533 | -0.40466971 | 1.14750430 | h | 1.000 | 0 |
| 8.91714121 | 4.22624430 | 0.68073140 | h | 1.000 | 0 |
| 4.66282740 | 6.14636586 | 0.98342299 | h | 1.000 | 0 |
| 0.94617511 | 3.49433101 | 1.69273670 | h | 1.000 | 0 |
| -4.96328030 | -8.05093818 | 1.85525417 | h | 1.000 | 0 |
| -6.14896722 | -6.47945372 | 4.55850569 | h | 1.000 | 0 |
| -4.48616905 | -10.74428316 | 5.69586056 | h | 1.000 | 0 |
| -1.48275947 | -9.92781294 | 4.47002422 | h | 1.000 | 0 |
| -2.67854340 | -8.35450616 | 7.18202555 | h | 1.000 | 0 |

Diethyl 2-benzylidenemalonate Product:

The $CH_3$-CH-C-C(=O) Torsion Angle was constrained to 270°. The CH-C-C=O Torsion Angle was constrained to 247.87°.

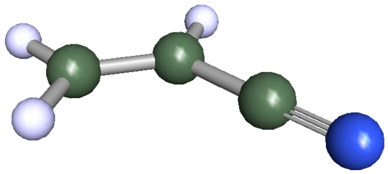


Total Energy = -883.43466728384 hartree
Enthalpy Correction = 0.334634 hartree
Entropy = 0.000225 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.18867554 | -3.52568225 | 0.06889957 | o | 8.000 | 0 |
| 1.71261428 | -2.13762723 | -1.12584538 | c | 6.000 | 0 |
| 0.39632875 | -0.02211933 | -0.22589702 | c | 6.000 | 0 |
| -1.05415463 | 1.66435804 | -2.04375789 | c | 6.000 | 0 |
| 0.60669815 | 3.79388666 | -3.05667369 | c | 6.000 | 0 |
| -3.56996577 | 2.56604965 | -1.01483786 | c | 6.000 | 0 |
| -5.38455582 | 0.77388215 | -0.34566136 | c | 6.000 | 0 |
| -7.71634452 | 1.48137837 | 0.60438354 | c | 6.000 | 0 |
| -8.29657182 | 4.02779598 | 0.91908700 | c | 6.000 | 0 |
| -6.51978241 | 5.83075750 | 0.25142486 | c | 6.000 | 0 |
| -4.18501670 | 5.10249954 | -0.71541802 | c | 6.000 | 0 |
| 1.33113848 | 1.12106280 | 2.07456120 | c | 6.000 | 0 |
| -0.57582026 | 2.07649169 | 3.50150940 | o | 8.000 | 0 |
| 0.08633911 | 3.81294711 | 5.44906796 | c | 6.000 | 0 |
| -2.33588773 | 4.77750824 | 6.59482183 | c | 6.000 | 0 |
| 3.52270497 | 1.52167132 | 2.70394242 | o | 8.000 | 0 |
| 1.17554277 | -2.74078577 | -3.59855032 | o | 8.000 | 0 |
| 2.18453047 | -5.04373669 | -4.51526828 | c | 6.000 | 0 |
| 1.30669205 | -5.36255059 | -7.20716058 | c | 6.000 | 0 |
| -1.51894276 | 0.44966920 | -3.64781852 | h | 1.000 | 0 |
| 2.28999694 | 2.97937256 | -3.92728654 | h | 1.000 | 0 |
| -0.36992424 | 4.93598760 | -4.47824630 | h | 1.000 | 0 |
| 1.23140576 | 5.05720495 | -1.54348849 | h | 1.000 | 0 |
| -4.91852295 | -1.21397243 | -0.55079459 | h | 1.000 | 0 |
| -9.09189092 | 0.04671928 | 1.10940310 | h | 1.000 | 0 |
| -10.11652249 | 4.59149439 | 1.67386408 | h | 1.000 | 0 |
| -6.94177702 | 7.82371376 | 0.48591726 | h | 1.000 | 0 |
| -2.82485770 | 6.54961282 | -1.21278581 | h | 1.000 | 0 |
| 1.26524827 | 2.86630572 | 6.85796805 | h | 1.000 | 0 |
| 1.20403771 | 5.35192001 | 4.63765901 | h | 1.000 | 0 |
| -1.91726139 | 6.16487285 | 8.06445724 | h | 1.000 | 0 |
| -3.51442153 | 5.66753805 | 5.15397943 | h | 1.000 | 0 |
| -3.41099146 | 3.23475219 | 7.44626359 | h | 1.000 | 0 |
| 4.24970627 | -5.00604230 | -4.40913825 | h | 1.000 | 0 |
| 1.54130669 | -6.61655595 | -3.33423980 | h | 1.000 | 0 |
| 1.96725355 | -3.80069873 | -8.38474035 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -0.75455574 | -5.42613682 | -7.30635076 | h | 1.000 | 0 |
| 2.04931228 | -7.12314457 | -7.98843743 | h | 1.000 | 0 |

Acrylonitrile (MAA* = 167.2 kJ/mol, E = -19.05):

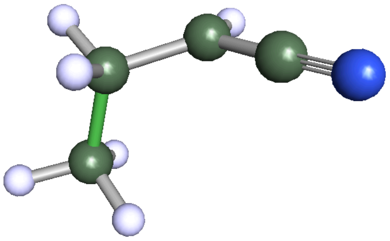


Total Energy = -170.69899164142 hartree
Enthalpy Correction = 0.056275 hartree
Entropy = 0.000103 hartree/K
LUMO Energy = -0.0544 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.96000850 | -0.28741046 | 0.00000000 | c | 6.000 | 0 |
| 0.26355478 | 0.88662273 | 0.00000000 | c | 6.000 | 0 |
| 2.58590807 | -0.46725481 | 0.00000000 | c | 6.000 | 0 |
| 4.48837296 | -1.52883955 | 0.00000000 | n | 7.000 | 0 |
| -2.10252414 | -2.32989844 | 0.00000000 | h | 1.000 | 0 |
| -3.69577214 | 0.79641875 | 0.00000000 | h | 1.000 | 0 |
| 0.42046896 | 2.93036178 | 0.00000000 | h | 1.000 | 0 |

Acrylonitrile Product:

The $CH_3$-C-C-C Torsion Angle was constrained to 270°.

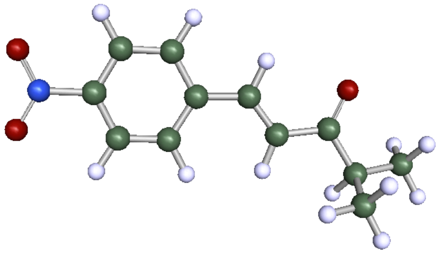


Total Energy = -210.69521770500 hartree
Enthalpy Correction = 0.095688 hartree
Entropy = 0.000119 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.12529684 | 1.26438535 | -0.65313027 | c | 6.000 | 0 |
| -0.82530493 | -0.90536099 | 0.74317812 | c | 6.000 | 0 |
| 1.74560903 | -1.61329795 | -0.25236837 | c | 6.000 | 0 |
| 2.02591799 | -3.38887634 | -2.09656332 | c | 6.000 | 0 |
| 2.25930754 | -4.98579338 | -3.64945736 | n | 7.000 | 0 |
| -2.41597963 | 0.77767481 | -2.64118945 | h | 1.000 | 0 |
| -3.96813575 | 1.72519596 | 0.17436350 | h | 1.000 | 0 |
| -0.95844441 | 2.97016313 | -0.59303228 | h | 1.000 | 0 |
| -0.69133049 | -0.39218704 | 2.74968506 | h | 1.000 | 0 |
| -2.06301908 | -2.56621855 | 0.68231173 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 3.29855701 | -0.29626969 | 0.01715778 | h | 1.000 | 0 |

(*E*)-4-Methyl-1-(4-nitrophenyl)pent-1-en-3-one (MAA* = 165.6 kJ/mol, E = -19.17):

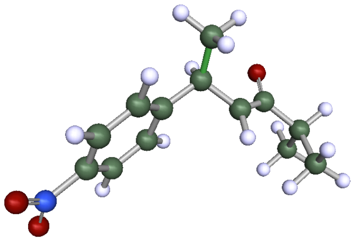


Total Energy = -744.90363611370 hartree
Enthalpy Correction = 0.24817 hartree
Entropy = 0.000199 hartree/K
LUMO Energy = -0.1108 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.73727689 | -2.69183633 | 2.09650393 | o | 8.000 | 0 |
| -4.35319798 | -1.01590150 | 0.56626868 | c | 6.000 | 0 |
| -6.46951651 | 0.50563518 | -0.59269672 | c | 6.000 | 0 |
| -6.39126955 | 3.18234530 | 0.50849636 | c | 6.000 | 0 |
| -9.02856239 | -0.72271139 | -0.21835608 | c | 6.000 | 0 |
| -1.76970115 | -0.31664313 | -0.23795868 | c | 6.000 | 0 |
| 0.25643441 | -1.46866761 | 0.73848558 | c | 6.000 | 0 |
| 2.88866263 | -0.98097967 | 0.11456583 | c | 6.000 | 0 |
| 4.75003619 | -2.42487744 | 1.31308398 | c | 6.000 | 0 |
| 7.28285144 | -2.04895274 | 0.80487794 | c | 6.000 | 0 |
| 7.94380736 | -0.19980420 | -0.92399658 | c | 6.000 | 0 |
| 10.60574753 | 0.21927228 | -1.47272412 | n | 7.000 | 0 |
| 12.15470886 | -1.07721126 | -0.37969525 | o | 8.000 | 0 |
| 11.15350021 | 1.84684801 | -2.99827258 | o | 8.000 | 0 |
| 6.14970550 | 1.27038752 | -2.15008658 | c | 6.000 | 0 |
| 3.63073193 | 0.87120837 | -1.62414260 | c | 6.000 | 0 |
| -6.04832288 | 0.64744555 | -2.61821911 | h | 1.000 | 0 |
| -6.76878735 | 3.13483715 | 2.53876073 | h | 1.000 | 0 |
| -4.56404073 | 4.09496410 | 0.21371916 | h | 1.000 | 0 |
| -7.83721133 | 4.34634502 | -0.39125905 | h | 1.000 | 0 |
| -9.48894643 | -0.86049903 | 1.78870721 | h | 1.000 | 0 |
| -9.07246425 | -2.62652134 | -1.01193241 | h | 1.000 | 0 |
| -10.49302858 | 0.40076491 | -1.14100734 | h | 1.000 | 0 |
| -1.59947130 | 1.14922022 | -1.65950432 | h | 1.000 | 0 |
| -0.07571454 | -2.92695373 | 2.14704196 | h | 1.000 | 0 |
| 4.19357673 | -3.86188006 | 2.66178823 | h | 1.000 | 0 |
| 8.72470093 | -3.16295958 | 1.72810729 | h | 1.000 | 0 |
| 6.73313635 | 2.69921007 | -3.48838005 | h | 1.000 | 0 |
| 2.22991178 | 2.01791533 | -2.57657727 | h | 1.000 | 0 |

(*E*)-4-Methyl-1-(4-nitrophenyl)pent-1-en-3-one Product:

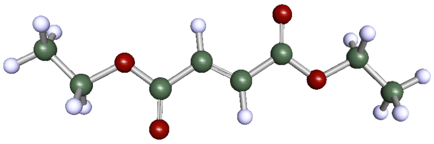
The $CH_3$-CH-CH-C Torsion Angle was constrained to 270°.



Total Energy = -784.90034890151 hartree
Enthalpy Correction = 0.287193 hartree
Entropy = 0.00021 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.17335167 | -5.04339570 | 0.22886197 | o | 8.000 | 0 |
| -3.84484754 | -2.85683861 | 1.23293304 | c | 6.000 | 0 |
| -6.26911662 | -1.48029015 | 1.99686087 | c | 6.000 | 0 |
| -7.83207826 | -0.93751240 | -0.36426262 | c | 6.000 | 0 |
| -5.93693273 | 0.91174531 | 3.54977181 | c | 6.000 | 0 |
| -1.54229205 | -1.73691992 | 1.59789347 | c | 6.000 | 0 |
| 0.85464834 | -3.03470270 | 0.79799797 | c | 6.000 | 0 |
| 1.99875973 | -4.69769693 | 2.85451329 | c | 6.000 | 0 |
| 2.64540567 | -1.12260644 | -0.29517735 | c | 6.000 | 0 |
| 4.96762104 | -0.52283090 | 0.80001154 | c | 6.000 | 0 |
| 6.51977995 | 1.31422903 | -0.22894331 | c | 6.000 | 0 |
| 5.74216595 | 2.56162380 | -2.39435392 | c | 6.000 | 0 |
| 7.35114849 | 4.47947920 | -3.47881719 | n | 7.000 | 0 |
| 9.38074373 | 4.91194442 | -2.47642870 | o | 8.000 | 0 |
| 6.61602206 | 5.59276873 | -5.35790270 | o | 8.000 | 0 |
| 3.44429239 | 2.00424411 | -3.54924266 | c | 6.000 | 0 |
| 1.92362259 | 0.18310724 | -2.48249995 | c | 6.000 | 0 |
| -7.33160954 | -2.84968135 | 3.14170670 | h | 1.000 | 0 |
| -8.06280082 | -2.65458928 | -1.48343817 | h | 1.000 | 0 |
| -9.70541310 | -0.20745458 | 0.11924694 | h | 1.000 | 0 |
| -6.87926936 | 0.47631645 | -1.53790217 | h | 1.000 | 0 |
| -4.84899553 | 0.56410198 | 5.27004017 | h | 1.000 | 0 |
| -4.95703572 | 2.37254075 | 2.46390658 | h | 1.000 | 0 |
| -7.77887068 | 1.67307372 | 4.10055255 | h | 1.000 | 0 |
| -1.39528709 | 0.11886368 | 2.44714705 | h | 1.000 | 0 |
| 0.30391480 | -4.29498914 | -0.75890411 | h | 1.000 | 0 |
| 2.47173299 | -3.59877302 | 4.54042875 | h | 1.000 | 0 |
| 3.70877572 | -5.67929240 | 2.22105982 | h | 1.000 | 0 |
| 0.60492504 | -6.11533853 | 3.40204718 | h | 1.000 | 0 |
| 5.58615454 | -1.49815073 | 2.48817674 | h | 1.000 | 0 |
| 8.31368876 | 1.78063464 | 0.63205267 | h | 1.000 | 0 |
| 2.88433584 | 2.99477498 | -5.24668409 | h | 1.000 | 0 |
| 0.10970031 | -0.25256180 | -3.32960271 | h | 1.000 | 0 |

Diethyl fumarate (MAA* = 165.0 kJ/mol, E = -17.79):

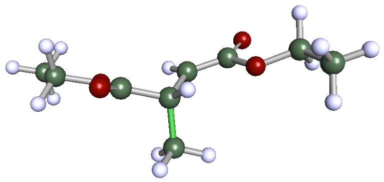


Total Energy = -612.56223352005 hartree
Enthalpy Correction = 0.21059 hartree
Entropy = 0.000184 hartree/K
LUMO Energy = -0.0866 hartree

```
              atomic coordinates              atom    charge  isotop
   4.21680667    2.52431209    0.15111784     o       8.000     0
   3.59121730    0.41734785    0.77957549     c       6.000     0
   0.94981698   -0.46398020    1.01991626     c       6.000     0
  -0.97177304    1.07091885    0.52192371     c       6.000     0
  -3.61330656    0.18983669    0.76158112     c       6.000     0
  -5.22034026    2.02165176    0.17524742     o       8.000     0
  -7.86936716    1.40978531    0.32888671     c       6.000     0
  -9.33750943    3.72678417   -0.40620326     c       6.000     0
  -4.23963905   -1.91273825    1.40368087     o       8.000     0
   5.19892242   -1.41945952    1.34784115     o       8.000     0
   7.84786168   -0.80818080    1.18974976     c       6.000     0
   9.31717382   -3.13637266    1.88594945     c       6.000     0
   0.63715176   -2.39882870    1.61394616     h       1.000     0
  -0.65889839    3.00542204   -0.07313044     h       1.000     0
  -8.24245633   -0.17692086   -0.93618501     h       1.000     0
  -8.28552990    0.80977947    2.25862983     h       1.000     0
  -8.89092260    4.30543919   -2.33523598     h       1.000     0
  -8.93384460    5.29544977    0.87126163     h       1.000     0
 -11.35564104    3.31112625   -0.30500976     h       1.000     0
   8.25555371   -0.18199951   -0.73342761     h       1.000     0
   8.22842812    0.76062136    2.47487670     h       1.000     0
   8.90769573   -4.68609786    0.58738526     h       1.000     0
   8.87749520   -3.74269299    3.80805828     h       1.000     0
  11.33519663   -2.72047925    1.78331225     h       1.000     0
```

Diethyl fumarate Product:

The $CH_3$-CH-CH-C Torsion Angle was constrained to 270°.

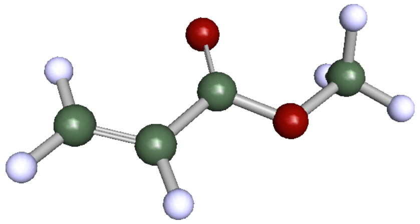


Total Energy = -652.55594987667 hartree
Enthalpy Correction = 0.249538 hartree
Entropy = 0.000204 hartree/K

```
              atomic coordinates              atom    charge  isotop
  -1.64245692    0.20900309    2.34492887     c       6.000     0
   0.24127638    0.03186131    0.13138289     c       6.000     0
  -1.24305919    0.33388155   -2.28027840     c       6.000     0
  -2.19099082   -1.83002582   -3.13851031     o       8.000     0
  -3.74050392   -1.69939114   -5.36034732     c       6.000     0
  -4.58945356   -4.34124567   -5.97731898     c       6.000     0
  -1.65725766    2.34426570   -3.30593207     o       8.000     0
   1.88483099   -2.27098541    0.16894618     c       6.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 4.19332962 | -2.37197759 | 1.35566597 | c | 6.000 | 0 |
| 4.96556549 | -0.07779604 | 2.40441872 | o | 8.000 | 0 |
| 7.39227200 | -0.03861975 | 3.52088177 | c | 6.000 | 0 |
| 7.83463948 | 2.58140674 | 4.55261426 | c | 6.000 | 0 |
| 5.65048675 | -4.23930618 | 1.59097039 | o | 8.000 | 0 |
| -2.90240587 | -1.42826177 | 2.35863313 | h | 1.000 | 0 |
| -2.79202451 | 1.92751599 | 2.25650191 | h | 1.000 | 0 |
| -0.57776725 | 0.21990108 | 4.11101956 | h | 1.000 | 0 |
| 1.43021737 | 1.71655061 | 0.22781328 | h | 1.000 | 0 |
| -5.33882197 | -0.44841017 | -4.98332687 | h | 1.000 | 0 |
| -2.63302485 | -0.87410437 | -6.89432876 | h | 1.000 | 0 |
| -2.97297332 | -5.56970810 | -6.34529622 | h | 1.000 | 0 |
| -5.69107521 | -5.14438943 | -4.42828348 | h | 1.000 | 0 |
| -5.77483968 | -4.30673952 | -7.66574412 | h | 1.000 | 0 |
| 1.13631478 | -4.02849736 | -0.56515629 | h | 1.000 | 0 |
| 7.51022962 | -1.45042484 | 5.02891316 | h | 1.000 | 0 |
| 8.83617259 | -0.52859364 | 2.12011887 | h | 1.000 | 0 |
| 6.41236564 | 3.06205031 | 5.97004889 | h | 1.000 | 0 |
| 9.69664602 | 2.69120661 | 5.43817999 | h | 1.000 | 0 |
| 7.75059043 | 3.99239418 | 3.04684597 | h | 1.000 | 0 |

Methyl acrylate (MAA* = 163.9 kJ/mol, E = -18.84):

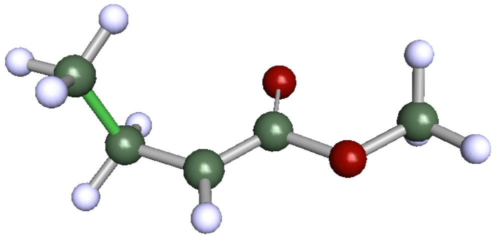


Total Energy = -306.25588994252 hartree
Enthalpy Correction = 0.103368 hartree
Entropy = 0.000125 hartree/K
LUMO Energy = -0.0520 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.70085040 | 0.38079333 | 0.17750918 | c | 6.000 | 0 |
| 2.39585550 | 1.22246603 | -0.33998945 | c | 6.000 | 0 |
| 0.14471843 | -0.34050745 | 0.17619658 | c | 6.000 | 0 |
| -1.96470827 | 0.86677661 | -0.48192688 | o | 8.000 | 0 |
| -4.27552484 | -0.46960736 | -0.06836605 | c | 6.000 | 0 |
| 0.16004769 | -2.44395862 | 1.07574056 | o | 8.000 | 0 |
| 6.35776274 | 1.52251320 | -0.19890730 | h | 1.000 | 0 |
| 4.97957871 | -1.47879998 | 0.99341788 | h | 1.000 | 0 |
| 2.07067260 | 3.07319496 | -1.15484310 | h | 1.000 | 0 |
| -4.29605833 | -2.21821183 | -1.15749176 | h | 1.000 | 0 |
| -4.50394065 | -0.90323616 | 1.93294146 | h | 1.000 | 0 |
| -5.76925400 | 0.78857727 | -0.70377664 | h | 1.000 | 0 |

Methyl acrylate Product:

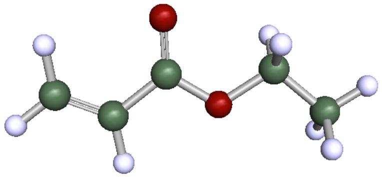
The $CH_3$-C-C-C Torsion Angle was constrained to 270°.



Total Energy = -346.24987539832 hartree
Enthalpy Correction = 0.142397 hartree
Entropy = 0.000143 hartree/K

```
                  atomic coordinates                atom    charge  isotop
         1.37822955    0.93352293    2.28837166     o       8.000     0
         1.32479402    0.50822392   -0.04850011     c       6.000     0
         3.63226674   -0.10668258   -1.22500723     o       8.000     0
         5.75562615   -0.17702803    0.37819875     c       6.000     0
        -0.68870342    0.57658484   -1.67929199     c       6.000     0
        -3.31975705    1.04061559   -0.75445646     c       6.000     0
        -4.78629102   -1.34647393   -0.04307761     c       6.000     0
         5.55328917   -1.59147184    1.87295654     h       1.000     0
         7.36384839   -0.67594403   -0.81242531     h       1.000     0
         6.11652639    1.65145196    1.27355237     h       1.000     0
        -0.37837329    0.06808200   -3.64267713     h       1.000     0
        -3.23723411    2.26705532    0.91431751     h       1.000     0
        -4.41721297    2.08062502   -2.17584750     h       1.000     0
        -6.69852754   -0.91850262    0.62999495     h       1.000     0
        -4.95560361   -2.61506048   -1.66778809     h       1.000     0
        -3.79320181   -2.37379526    1.44994265     h       1.000     0
```

Ethyl acrylate (MAA* = 161.0 kJ/mol, E = -19.07):



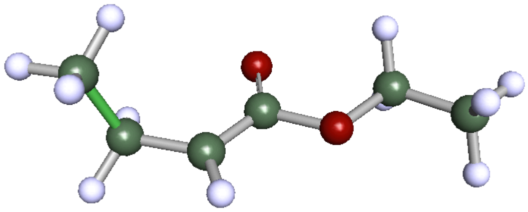
Total Energy = -345.54134835390 hartree
Enthalpy Correction = 0.132991 hartree
Entropy = 0.000136 hartree/K
LUMO Energy = -0.0512 hartree

```
                  atomic coordinates                atom    charge  isotop
         5.27779833    3.89834878   -1.25934534     c       6.000     0
         3.77342558    1.95172055   -0.77287856     c       6.000     0
         1.00365446    2.26898662   -0.65507467     c       6.000     0
        -0.13702104    0.08517207   -0.15059461     o       8.000     0
        -2.85058946    0.14053552    0.01333925     c       6.000     0
        -3.73964400   -2.49565364    0.59002450     c       6.000     0
        -0.12009037    4.23813371   -0.97059971     o       8.000     0
         4.50024496    5.76751314   -1.58026360     h       1.000     0
         7.31081451    3.67551365   -1.34863209     h       1.000     0
         4.50408306    0.06649431   -0.44552866     h       1.000     0
```

| | | | | | |
|---|---|---|---|---|---|
| -3.38945196 | 1.47585106 | 1.49158605 | h | 1.000 | 0 |
| -3.59991112 | 0.83069079 | -1.78093284 | h | 1.000 | 0 |
| -3.17861986 | -3.80920459 | -0.89885544 | h | 1.000 | 0 |
| -5.79866003 | -2.50583899 | 0.72044834 | h | 1.000 | 0 |
| -2.97334754 | -3.15937869 | 2.38666507 | h | 1.000 | 0 |

Ethyl acrylate Product:

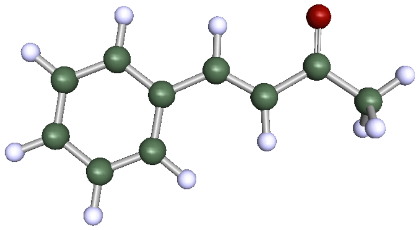
The CH$_3$-C-C-C Torsion Angle was constrained to 270°.



Total Energy = -385.53459186311 hartree
Enthalpy Correction = 0.172076 hartree
Entropy = 0.000153 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.16604464 | -2.71841153 | -0.79067860 | o | 8.000 | 0 |
| 0.07176220 | -0.66188667 | 0.37758242 | c | 6.000 | 0 |
| 2.32044924 | 0.70645428 | 0.00021015 | o | 8.000 | 0 |
| 4.06489833 | -0.33925639 | -1.72990345 | c | 6.000 | 0 |
| 6.31486330 | 1.40781892 | -1.87093073 | c | 6.000 | 0 |
| -1.56692475 | 0.47112345 | 2.03690608 | c | 6.000 | 0 |
| -4.12069111 | -0.61931965 | 2.56635991 | c | 6.000 | 0 |
| -6.22209416 | 0.33294589 | 0.82400855 | c | 6.000 | 0 |
| 4.64517319 | -2.22977076 | -1.11808778 | h | 1.000 | 0 |
| 3.18935280 | -0.55296912 | -3.59443465 | h | 1.000 | 0 |
| 7.21974874 | 1.59594579 | -0.02397345 | h | 1.000 | 0 |
| 7.70936275 | 0.66449740 | -3.20022050 | h | 1.000 | 0 |
| 5.75036433 | 3.28826621 | -2.51164031 | h | 1.000 | 0 |
| -1.07136784 | 2.30974451 | 2.80108529 | h | 1.000 | 0 |
| -4.68015763 | -0.24243432 | 4.52887191 | h | 1.000 | 0 |
| -4.01993734 | -2.68173736 | 2.38642029 | h | 1.000 | 0 |
| -8.05703632 | -0.51819144 | 1.27303535 | h | 1.000 | 0 |
| -6.42258063 | 2.38612815 | 0.97159389 | h | 1.000 | 0 |
| -5.77131072 | -0.10968147 | -1.14384227 | h | 1.000 | 0 |

(*E*)-4-Phenylbut-3-en-2-one (MAA* = 156.0 kJ/mol, E = -23.01):



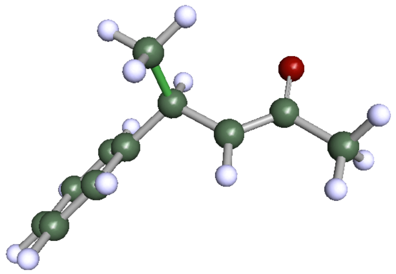
Total Energy = -461.94832585933 hartree

Enthalpy Correction = 0.183251 hartree
Entropy = 0.000157 hartree/K
LUMO Energy = -0.0787 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 7.57694891 | 1.39348885 | 0.41740065 | c | 6.000 | 0 |
| 5.59529801 | -0.54744067 | -0.14532423 | c | 6.000 | 0 |
| 2.95835731 | 0.30189226 | 0.10585718 | c | 6.000 | 0 |
| 1.02487111 | -1.26212664 | -0.37049769 | c | 6.000 | 0 |
| -1.65728060 | -0.69758629 | -0.20787740 | c | 6.000 | 0 |
| -2.58809923 | 1.66841739 | 0.52512800 | c | 6.000 | 0 |
| -5.16142780 | 2.10140710 | 0.64766676 | c | 6.000 | 0 |
| -6.85936727 | 0.18601485 | 0.04090612 | c | 6.000 | 0 |
| -5.96476916 | -2.16852847 | -0.68901042 | c | 6.000 | 0 |
| -3.38491701 | -2.60379639 | -0.81030085 | c | 6.000 | 0 |
| 6.15046233 | -2.69868732 | -0.77259699 | o | 8.000 | 0 |
| 9.46137003 | 0.60834880 | 0.16733478 | h | 1.000 | 0 |
| 7.32133985 | 3.02950537 | -0.82053185 | h | 1.000 | 0 |
| 7.34792116 | 2.07725614 | 2.35530347 | h | 1.000 | 0 |
| 2.66154423 | 2.24481512 | 0.68708544 | h | 1.000 | 0 |
| 1.49918442 | -3.17768704 | -0.94859167 | h | 1.000 | 0 |
| -1.29066563 | 3.17880627 | 1.00318061 | h | 1.000 | 0 |
| -5.85679313 | 3.94134139 | 1.21905181 | h | 1.000 | 0 |
| -8.87550277 | 0.53501069 | 0.13920402 | h | 1.000 | 0 |
| -7.27758629 | -3.66721899 | -1.16380494 | h | 1.000 | 0 |
| -2.68088848 | -4.44323242 | -1.37958278 | h | 1.000 | 0 |

(*E*)-4-Phenylbut-3-en-2-one Product:

The $CH_3$-CH-CH-C Torsion Angle was constrained to 270°.

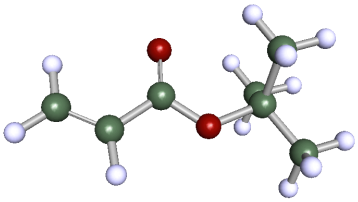


Total Energy = -501.94316924799 hartree
Enthalpy Correction = 0.222555 hartree
Entropy = 0.000168 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 6.87879747 | 2.12125816 | -1.41820981 | c | 6.000 | 0 |
| 4.90105597 | 1.55551562 | 0.57772393 | c | 6.000 | 0 |
| 2.71306933 | 0.38757704 | -0.15621844 | c | 6.000 | 0 |
| 0.66692279 | -0.30196568 | 1.68912781 | c | 6.000 | 0 |
| 1.01336416 | -2.95961615 | 2.79109412 | c | 6.000 | 0 |
| -1.92199401 | 0.01929705 | 0.54174978 | c | 6.000 | 0 |
| -2.72458341 | -1.49904641 | -1.46036975 | c | 6.000 | 0 |
| -5.08658141 | -1.17246804 | -2.54951008 | c | 6.000 | 0 |
| -6.71372334 | 0.68359534 | -1.65103983 | c | 6.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -5.94860388 | 2.20153560 | 0.34589332 | c | 6.000 | 0 |
| -3.57810271 | 1.86513595 | 1.42460798 | c | 6.000 | 0 |
| 5.45111383 | 2.25000512 | 2.84213314 | o | 8.000 | 0 |
| 7.26676416 | 4.15438246 | -1.46356836 | h | 1.000 | 0 |
| 8.65915544 | 1.18620412 | -0.92563981 | h | 1.000 | 0 |
| 6.31383734 | 1.51250082 | -3.30856415 | h | 1.000 | 0 |
| 2.46575429 | -0.14673305 | -2.12239976 | h | 1.000 | 0 |
| 0.81375900 | 1.02667739 | 3.27115004 | h | 1.000 | 0 |
| 0.94715072 | -4.39306769 | 1.30301168 | h | 1.000 | 0 |
| 2.85834378 | -3.08373269 | 3.70863207 | h | 1.000 | 0 |
| -0.44849585 | -3.41408957 | 4.18472362 | h | 1.000 | 0 |
| -1.47632116 | -2.95446124 | -2.18794323 | h | 1.000 | 0 |
| -5.66297849 | -2.37194765 | -4.10924771 | h | 1.000 | 0 |
| -8.56084933 | 0.94019847 | -2.50002514 | h | 1.000 | 0 |
| -7.20103906 | 3.65399090 | 1.07048902 | h | 1.000 | 0 |
| -2.99525770 | 3.06311270 | 2.98575225 | h | 1.000 | 0 |

*tert*-Butyl acrylate (MAA* = 152.154974 kJ/mol, E = -20.22):

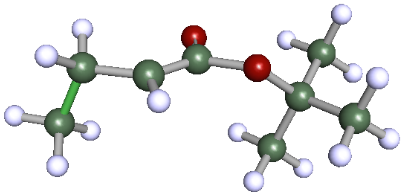


Total Energy = -424.10728586192 hartree
Enthalpy Correction = 0.190966 hartree
Entropy = 0.000154 hartree/K
LUMO Energy = -0.0489 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 6.98689533 | 1.59633299 | 0.05298140 | c | 6.000 | 0 |
| 4.84503586 | 0.87919596 | 1.14183503 | c | 6.000 | 0 |
| 2.48085611 | 0.64558066 | -0.33768731 | c | 6.000 | 0 |
| 0.59681758 | -0.08540533 | 1.15240500 | o | 8.000 | 0 |
| -1.97543103 | -0.47682076 | 0.20127418 | c | 6.000 | 0 |
| -1.99038257 | -2.58065524 | -1.74871562 | c | 6.000 | 0 |
| -3.40808754 | -1.27508389 | 2.55201301 | c | 6.000 | 0 |
| -3.02722920 | 1.98503333 | -0.82942807 | c | 6.000 | 0 |
| 2.31071714 | 1.06501351 | -2.58105322 | o | 8.000 | 0 |
| 7.04961609 | 2.02693058 | -1.95035310 | h | 1.000 | 0 |
| 8.72067927 | 1.77082596 | 1.12769034 | h | 1.000 | 0 |
| 4.73666785 | 0.44018188 | 3.13932903 | h | 1.000 | 0 |
| -0.99872618 | -2.02947968 | -3.46464522 | h | 1.000 | 0 |
| -1.11395158 | -4.28173771 | -0.97550664 | h | 1.000 | 0 |
| -3.94590623 | -3.02797366 | -2.23213028 | h | 1.000 | 0 |
| -2.60368472 | -3.00346379 | 3.34039407 | h | 1.000 | 0 |
| -5.38279958 | -1.62848355 | 2.07387079 | h | 1.000 | 0 |
| -3.33608863 | 0.20693539 | 3.98623751 | h | 1.000 | 0 |
| -5.02599720 | 1.72289838 | -1.26948700 | h | 1.000 | 0 |
| -2.87084063 | 3.47942671 | 0.58583234 | h | 1.000 | 0 |
| -2.04816016 | 2.57074828 | -2.54084417 | h | 1.000 | 0 |

*tert*-Butyl acrylate Product:

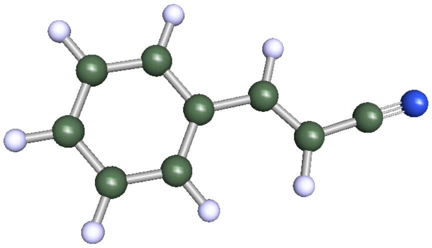
The $CH_3$-C-C-C Torsion Angle was constrained to 90°.



Total Energy = -464.09703849061 hartree
Enthalpy Correction = 0.229944 hartree
Entropy = 0.000171 hartree/K

```
                  atomic coordinates            atom    charge  isotop
  1.11883146   -1.95976381    2.16562911     o       8.000      0
  1.16388012   -0.06931391    0.71741598     c       6.000      0
 -1.06651412    1.37877542    0.48202659     o       8.000      0
 -3.40615229    0.09207839    0.01156844     c       6.000      0
 -3.06463704   -1.93322345   -2.00106194     c       6.000      0
 -5.16099709    2.15132308   -0.95709400     c       6.000      0
 -4.48347443   -1.03370796    2.43417203     c       6.000      0
  3.15856178    0.89911961   -0.60939161     c       6.000      0
  5.70699586   -0.31996390   -0.55017027     c       6.000      0
  6.10551770   -2.31260725   -2.60507926     c       6.000      0
 -2.25438712   -1.11099405   -3.71238045     h       1.000      0
 -1.80394660   -3.41647773   -1.32444571     h       1.000      0
 -4.89000418   -2.77374965   -2.47589896     h       1.000      0
 -4.42604867    2.95985357   -2.70855047     h       1.000      0
 -5.33129086    3.66193433    0.44129393     h       1.000      0
 -7.04419061    1.38793183   -1.32161408     h       1.000      0
 -4.67746888    0.43882622    3.87083771     h       1.000      0
 -6.35394944   -1.83799986    2.07785157     h       1.000      0
 -3.22692565   -2.49446628    3.15379682     h       1.000      0
  2.81307108    2.45714100   -1.89512597     h       1.000      0
  7.20808808    1.10412064   -0.71541164     h       1.000      0
  5.97202205   -1.22972743    1.29325304     h       1.000      0
  7.98203522   -3.18445839   -2.50005409     h       1.000      0
  4.68547459   -3.80278299   -2.42662614     h       1.000      0
  5.89623848   -1.47685618   -4.48494713     h       1.000      0
```

Cinnamonitrile (MAA* = 140.9 kJ/mol, E = -24.6):



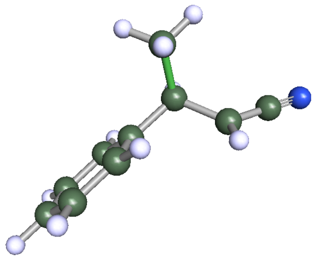
Total Energy = -401.58165588114 hartree

Enthalpy Correction = 0.142846 hartree
Entropy = 0.000144 hartree/K
LUMO Energy = -0.0767 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 9.38698374 | -0.23346015 | 0.00000000 | n | 7.000 | 0 |
| 7.24112826 | -0.63045241 | 0.00000000 | c | 6.000 | 0 |
| 4.62406624 | -1.16861763 | 0.00000000 | c | 6.000 | 0 |
| 2.90028087 | 0.69339811 | 0.00000000 | c | 6.000 | 0 |
| 0.17366317 | 0.38338726 | 0.00000000 | c | 6.000 | 0 |
| -1.00897371 | -1.98228176 | 0.00000000 | c | 6.000 | 0 |
| -3.61504560 | -2.15597516 | 0.00000000 | c | 6.000 | 0 |
| -5.08952483 | 0.02247726 | 0.00000000 | c | 6.000 | 0 |
| -3.94066965 | 2.37935896 | 0.00000000 | c | 6.000 | 0 |
| -1.32809870 | 2.55646239 | 0.00000000 | c | 6.000 | 0 |
| 4.12387666 | -3.15514157 | 0.00000000 | h | 1.000 | 0 |
| 3.57012627 | 2.63375227 | 0.00000000 | h | 1.000 | 0 |
| 0.10929435 | -3.69795418 | 0.00000000 | h | 1.000 | 0 |
| -4.51107988 | -3.99776674 | 0.00000000 | h | 1.000 | 0 |
| -7.13257349 | -0.12473877 | 0.00000000 | h | 1.000 | 0 |
| -5.07951313 | 4.08127914 | 0.00000000 | h | 1.000 | 0 |
| -0.42394055 | 4.39627299 | 0.00000000 | h | 1.000 | 0 |

Cinnamonitrile Product:

The $CH_3$-CH-CH-C Torsion Angle was constrained to 270°.

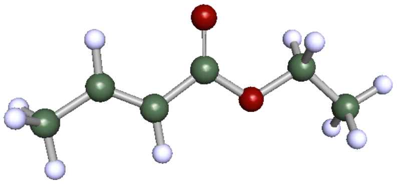


Total Energy = -441.56797330947 hartree
Enthalpy Correction = 0.222555 hartree
Entropy = 0.000168 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.87549946 | -3.16965725 | 1.26301199 | c | 6.000 | 0 |
| 2.39776397 | -0.36118160 | 0.72228463 | c | 6.000 | 0 |
| 3.89919954 | 0.64494790 | -1.49072448 | c | 6.000 | 0 |
| 6.24198727 | 1.65428814 | -1.15384363 | c | 6.000 | 0 |
| 8.24998354 | 2.59042887 | -0.83135831 | n | 7.000 | 0 |
| -0.39359772 | 0.13292923 | 0.37699418 | c | 6.000 | 0 |
| -1.70409775 | 1.72496329 | 2.01160208 | c | 6.000 | 0 |
| -4.26700564 | 2.19982917 | 1.68795164 | c | 6.000 | 0 |
| -5.57496048 | 1.07688340 | -0.28823236 | c | 6.000 | 0 |
| -4.29392153 | -0.52455748 | -1.93073854 | c | 6.000 | 0 |
| -1.73669792 | -0.99124891 | -1.59490657 | c | 6.000 | 0 |
| 4.87982485 | -3.47457195 | 1.65535363 | h | 1.000 | 0 |
| 2.36964050 | -4.32348488 | -0.37527664 | h | 1.000 | 0 |
| 1.77845525 | -3.84264640 | 2.88538204 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 2.97895933 | 0.69302073 | 2.40731334 | h | 1.000 | 0 |
| 3.39310209 | 0.01542541 | -3.37717732 | h | 1.000 | 0 |
| -0.69713856 | 2.61112967 | 3.56471493 | h | 1.000 | 0 |
| -5.24372725 | 3.44819439 | 2.98802806 | h | 1.000 | 0 |
| -7.57467723 | 1.44074251 | -0.54727562 | h | 1.000 | 0 |
| -5.29595805 | -1.41587025 | -3.48134632 | h | 1.000 | 0 |
| -0.76602667 | -2.24358243 | -2.89676832 | h | 1.000 | 0 |

Ethyl (*E*)-but-2-enoate (MAA* = 140.6 kJ/mol, E = -23.59):

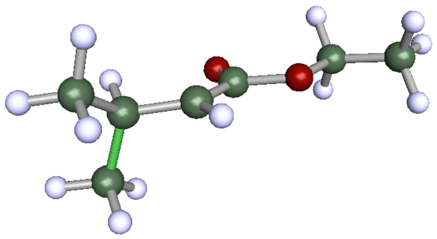


Total Energy = -384.83057081376 hartree
Enthalpy Correction = 0.162521 hartree
Entropy = 0.000148 hartree/K
LUMO Energy = -0.0424 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.97499631 | -2.89494580 | -3.46966224 | o | 8.000 | 0 |
| -0.12203477 | -1.48802058 | -1.87245990 | c | 6.000 | 0 |
| -1.56839686 | -0.00430453 | -0.43565179 | o | 8.000 | 0 |
| -4.24720309 | -0.13213986 | -0.86646199 | c | 6.000 | 0 |
| -5.50217690 | 1.65660165 | 0.95039336 | c | 6.000 | 0 |
| 2.56425191 | -1.17081034 | -1.25035059 | c | 6.000 | 0 |
| 4.34384537 | -2.47079163 | -2.46818551 | c | 6.000 | 0 |
| 7.09355949 | -2.28314869 | -1.98279432 | c | 6.000 | 0 |
| -4.62305888 | 0.37861627 | -2.83050270 | h | 1.000 | 0 |
| -4.86878821 | -2.07914115 | -0.58077581 | h | 1.000 | 0 |
| -4.85628450 | 3.59264588 | 0.64800937 | h | 1.000 | 0 |
| -5.10927836 | 1.12290656 | 2.90430350 | h | 1.000 | 0 |
| -7.54427804 | 1.60222705 | 0.66167530 | h | 1.000 | 0 |
| 3.02715524 | 0.16386791 | 0.23466477 | h | 1.000 | 0 |
| 3.73951144 | -3.77594769 | -3.93762340 | h | 1.000 | 0 |
| 7.85335007 | -4.13548771 | -1.46218057 | h | 1.000 | 0 |
| 8.08481882 | -1.71767869 | -3.70832258 | h | 1.000 | 0 |
| 7.52810936 | -0.93456015 | -0.48645921 | h | 1.000 | 0 |

Ethyl (*E*)-but-2-enoate Product:

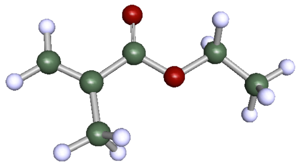
The $CH_3$-CH-CH-C Torsion Angle was constrained to 90°



Total Energy = -424.81632258057 hartree
Enthalpy Correction = 0.201436 hartree
Entropy = 0.000163 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.92220258 | 3.05674222 | -1.12108808 | o | 8.000 | 0 |
| 0.87204814 | 0.83343208 | -0.27701663 | c | 6.000 | 0 |
| 3.19762780 | -0.44252935 | -0.05759685 | o | 8.000 | 0 |
| 5.36643484 | 0.91486942 | -0.81884348 | c | 6.000 | 0 |
| 7.63388318 | -0.77622717 | -0.44957695 | c | 6.000 | 0 |
| -1.15876919 | -0.57207083 | 0.50223522 | c | 6.000 | 0 |
| -3.81270263 | 0.39977384 | 0.33702065 | c | 6.000 | 0 |
| -5.42762158 | -0.54752962 | 2.52883808 | c | 6.000 | 0 |
| -5.09227026 | -0.24601468 | -2.17708704 | c | 6.000 | 0 |
| 5.19947598 | 1.48892150 | -2.80127505 | h | 1.000 | 0 |
| 5.56116960 | 2.64989248 | 0.29413476 | h | 1.000 | 0 |
| 7.46528891 | -2.49474479 | -1.58243895 | h | 1.000 | 0 |
| 7.83227889 | -1.32281296 | 1.53217999 | h | 1.000 | 0 |
| 9.35570005 | 0.20870983 | -1.02313781 | h | 1.000 | 0 |
| -0.84671094 | -2.50307386 | 1.12745187 | h | 1.000 | 0 |
| -3.72564245 | 2.46975641 | 0.45172345 | h | 1.000 | 0 |
| -7.37001446 | 0.15487085 | 2.41195980 | h | 1.000 | 0 |
| -5.51138462 | -2.61654915 | 2.52078942 | h | 1.000 | 0 |
| -4.63388825 | 0.03704408 | 4.34479634 | h | 1.000 | 0 |
| -5.23397843 | -2.29879751 | -2.40521505 | h | 1.000 | 0 |
| -7.00550642 | 0.54129036 | -2.30249430 | h | 1.000 | 0 |
| -3.98465331 | 0.48952598 | -3.75767002 | h | 1.000 | 0 |

Ethyl 3-methylbut-2-enoate (MAA* = 139.2 kJ/mol, E = -22.77):



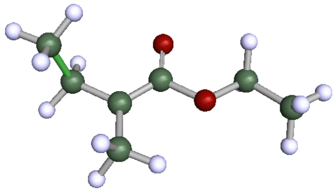
Total Energy = -384.82648007672 hartree
Enthalpy Correction = 0.16241 hartree
Entropy = 0.000147 hartree/K
LUMO Energy = -0.0450 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.06750177 | -1.79108461 | -0.42867989 | c | 6.000 | 0 |
| 3.06450231 | -0.30305452 | -0.74703987 | c | 6.000 | 0 |
| 3.17063301 | 2.22906300 | -1.99005056 | c | 6.000 | 0 |
| 0.58565008 | -1.24701204 | 0.20139537 | c | 6.000 | 0 |
| -1.26198492 | 0.40094188 | -0.21309314 | o | 8.000 | 0 |
| -3.74430931 | -0.32101856 | 0.62360127 | c | 6.000 | 0 |
| -5.53575892 | 1.77237142 | -0.06814360 | c | 6.000 | 0 |
| 0.25374965 | -3.26656046 | 1.22999730 | o | 8.000 | 0 |
| 6.92414491 | -1.21690962 | -1.07550563 | h | 1.000 | 0 |
| 4.88444529 | -3.61330527 | 0.48641558 | h | 1.000 | 0 |
| 1.94128782 | 2.29252890 | -3.64772402 | h | 1.000 | 0 |
| 2.52093015 | 3.71160835 | -0.70826000 | h | 1.000 | 0 |
| 5.09799447 | 2.65839874 | -2.57741155 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -3.68134227 | -0.63937686 | 2.66171010 | h | 1.000 | 0 |
| -4.25173564 | -2.10134500 | -0.28820057 | h | 1.000 | 0 |
| -5.57198822 | 2.06977159 | -2.10926847 | h | 1.000 | 0 |
| -4.99965185 | 3.53983683 | 0.85103551 | h | 1.000 | 0 |
| -7.44059270 | 1.27266997 | 0.54813391 | h | 1.000 | 0 |

Ethyl 3-methylbut-2-enoate Product:

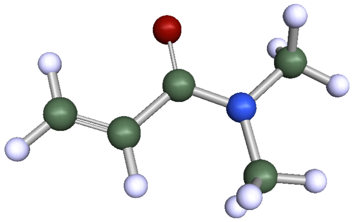
The $CH_3$-$CH_2$-C-C Torsion Angle was constrained to 270°.



Total Energy = -424.81126600739 hartree
Enthalpy Correction = 0.201352 hartree
Entropy = 0.000164 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.21832748 | -0.30639035 | 1.02922530 | o | 8.000 | 0 |
| 0.33384343 | -1.61628008 | 1.69923180 | c | 6.000 | 0 |
| 0.71656366 | -3.34220967 | 3.69167606 | o | 8.000 | 0 |
| 3.23268434 | -3.63418953 | 4.52186437 | c | 6.000 | 0 |
| 3.24048836 | -5.54292913 | 6.64177460 | c | 6.000 | 0 |
| -2.06987441 | -1.58602613 | 0.73417782 | c | 6.000 | 0 |
| -4.19620073 | -3.14375010 | 1.76346571 | c | 6.000 | 0 |
| -2.71055405 | 0.33680577 | -1.24628646 | c | 6.000 | 0 |
| -3.71280988 | 2.83442399 | -0.18935157 | c | 6.000 | 0 |
| 4.44045446 | -4.27438193 | 2.96385803 | h | 1.000 | 0 |
| 3.99982761 | -1.82311765 | 5.16582307 | h | 1.000 | 0 |
| 2.51911442 | -7.36722707 | 5.99670024 | h | 1.000 | 0 |
| 2.06369365 | -4.90144926 | 8.21332887 | h | 1.000 | 0 |
| 5.16257006 | -5.81880184 | 7.34464226 | h | 1.000 | 0 |
| -3.52618116 | -4.52644609 | 3.13777174 | h | 1.000 | 0 |
| -5.19425649 | -4.18594014 | 0.26503358 | h | 1.000 | 0 |
| -5.65917943 | -2.00606612 | 2.71587800 | h | 1.000 | 0 |
| -4.13094533 | -0.44258411 | -2.54935396 | h | 1.000 | 0 |
| -1.02975443 | 0.74350882 | -2.38445504 | h | 1.000 | 0 |
| -5.38797866 | 2.52302618 | 0.98310209 | h | 1.000 | 0 |
| -4.23254520 | 4.16855039 | -1.68594884 | h | 1.000 | 0 |
| -2.27505855 | 3.72802027 | 0.99595123 | h | 1.000 | 0 |

*N*,*N*-Dimethylacrylamide (MAA* = 138.3 kJ/mol, E = -23.54):

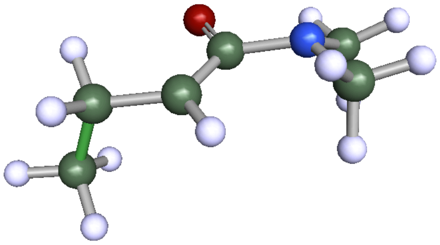


Total Energy = -325.67104839501 hartree
Enthalpy Correction = 0.229966 hartree
Entropy = 0.000171 hartree/K
LUMO Energy = -0.0426 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.19379439 | -1.09573343 | 0.94635710 | c | 6.000 | 0 |
| 3.02506792 | 0.12090653 | 0.61256685 | c | 6.000 | 0 |
| 0.66944376 | -1.29105282 | 0.02721973 | c | 6.000 | 0 |
| -1.46242863 | 0.05857455 | -0.28554242 | n | 7.000 | 0 |
| -3.74657225 | -1.34256900 | -0.85746708 | c | 6.000 | 0 |
| -1.57095537 | 2.79576943 | -0.08278459 | c | 6.000 | 0 |
| 0.66175737 | -3.61663156 | -0.16656360 | o | 8.000 | 0 |
| 6.92357863 | -0.08676810 | 1.37300213 | h | 1.000 | 0 |
| 5.27677096 | -3.13832828 | 0.79726585 | h | 1.000 | 0 |
| 2.95851193 | 2.15962238 | 0.76474712 | h | 1.000 | 0 |
| -5.31120067 | -0.02505310 | -1.04897077 | h | 1.000 | 0 |
| -3.53752971 | -2.40277663 | -2.61668779 | h | 1.000 | 0 |
| -4.17694108 | -2.68998043 | 0.64595203 | h | 1.000 | 0 |
| -1.02671186 | 3.44524855 | 1.79841397 | h | 1.000 | 0 |
| -3.50692022 | 3.39365849 | -0.42159698 | h | 1.000 | 0 |
| -0.36966518 | 3.71511342 | -1.48591157 | h | 1.000 | 0 |

*N*,*N*-dimethylacrylamide Product:

The $CH_3$-C-C-C Torsion Angle was constrained to 90°.

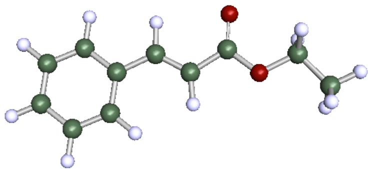


Total Energy = -365.65674560727 hartree
Enthalpy Correction = 0.184435 hartree
Entropy = 0.000151 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.37169513 | 3.83856567 | -0.39395355 | o | 8.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 0.59664801 | 1.45172672 | -0.10101853 | c | 6.000 | 0 |
| 3.09984785 | 0.58666507 | 0.44295992 | n | 7.000 | 0 |
| 5.06479543 | 1.80550162 | -1.01037420 | c | 6.000 | 0 |
| 3.51906139 | -2.08818540 | 0.69508996 | c | 6.000 | 0 |
| -1.37118985 | -0.24962001 | -0.19428379 | c | 6.000 | 0 |
| -4.02125221 | 0.62644474 | -0.65428508 | c | 6.000 | 0 |
| -4.77520455 | 0.72067935 | -3.44254168 | c | 6.000 | 0 |
| 5.20246522 | 1.04351422 | -2.94971711 | h | 1.000 | 0 |
| 6.89788514 | 1.53043485 | -0.09685255 | h | 1.000 | 0 |
| 4.66490014 | 3.81754004 | -1.13387307 | h | 1.000 | 0 |
| 5.46892205 | -2.41238798 | 1.29442990 | h | 1.000 | 0 |
| 2.26542029 | -2.88587971 | 2.12472695 | h | 1.000 | 0 |
| 3.21699195 | -3.13805619 | -1.08178802 | h | 1.000 | 0 |
| -1.02835632 | -2.26280342 | -0.07063972 | h | 1.000 | 0 |
| -5.37435908 | -0.58838648 | 0.34696062 | h | 1.000 | 0 |
| -4.24339621 | 2.52876431 | 0.13671811 | h | 1.000 | 0 |
| -3.51576971 | 1.99616456 | -4.47057812 | h | 1.000 | 0 |
| -6.72193542 | 1.37879498 | -3.70835104 | h | 1.000 | 0 |
| -4.61483287 | -1.15054773 | -4.30909461 | h | 1.000 | 0 |

Ethyl cinnamate (MAA* = 134.0 kJ/mol, E = -24.52):



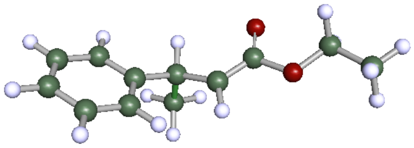
Total Energy = -576.42403160838 hartree
Enthalpy Correction 0.219618 hartree
Entropy = 0.000175 hartree/K
LUMO Energy = -0.0726 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.79038909 | -0.67776038 | -0.02523101 | o | 8.000 | 0 |
| 3.49585834 | -1.76381380 | 1.52612589 | c | 6.000 | 0 |
| 4.46205449 | -3.11759842 | 3.42110772 | o | 8.000 | 0 |
| 7.17197205 | -3.24270295 | 3.56331192 | c | 6.000 | 0 |
| 7.85196209 | -4.83037413 | 5.81989493 | c | 6.000 | 0 |
| 0.72582183 | -1.78316775 | 1.59656262 | c | 6.000 | 0 |
| -0.60262964 | -0.52586422 | -0.14825878 | c | 6.000 | 0 |
| -3.33743007 | -0.35010166 | -0.34684497 | c | 6.000 | 0 |
| -4.98297118 | -1.53774660 | 1.34967962 | c | 6.000 | 0 |
| -7.57010707 | -1.30366977 | 1.07073538 | c | 6.000 | 0 |
| -8.56839742 | 0.11846464 | -0.90395594 | c | 6.000 | 0 |
| -6.95958664 | 1.30558643 | -2.60044405 | c | 6.000 | 0 |
| -4.36570634 | 1.07134833 | -2.32147812 | c | 6.000 | 0 |
| 7.91125338 | -1.32267045 | 3.72490637 | h | 1.000 | 0 |
| 7.88549242 | -4.05843781 | 1.80704961 | h | 1.000 | 0 |
| 7.12390101 | -3.99508767 | 7.56026084 | h | 1.000 | 0 |
| 9.90573009 | -4.95521364 | 5.97151859 | h | 1.000 | 0 |
| 7.09917916 | -6.74233904 | 5.63508558 | h | 1.000 | 0 |
| -0.14893834 | -2.84855920 | 3.10965475 | h | 1.000 | 0 |
| 0.46169626 | 0.48532481 | -1.58630913 | h | 1.000 | 0 |
| -4.23593435 | -2.65159094 | 2.89733823 | h | 1.000 | 0 |
| -8.82403740 | -2.23276467 | 2.39738860 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -10.59813639 | 0.29693084 | -1.11403625 | h | 1.000 | 0 |
| -7.72529418 | 2.41533847 | -4.14227622 | h | 1.000 | 0 |
| -3.10400199 | 1.99820803 | -3.64551563 | h | 1.000 | 0 |

Ethyl cinnamate Product:

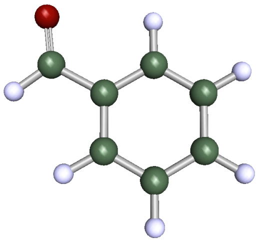
The $CH_3$-CH-CH-C Torsion Angle was constrained to 90°.



Total Energy = -616.40707426947 hartree
Enthalpy Correction = 0.25821 hartree
Entropy = 0.00019 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.59154822 | -0.47284375 | -0.36558781 | o | 8.000 | 0 |
| 3.26980839 | -0.83173523 | 1.57573355 | c | 6.000 | 0 |
| 4.54446764 | -1.16184113 | 3.88074827 | o | 8.000 | 0 |
| 7.17032968 | -0.67062540 | 3.86035846 | c | 6.000 | 0 |
| 8.17251278 | -1.15211401 | 6.48621728 | c | 6.000 | 0 |
| 0.68760348 | -0.94077868 | 1.80363253 | c | 6.000 | 0 |
| -0.96096687 | -0.99285418 | -0.49367619 | c | 6.000 | 0 |
| -1.49908502 | -3.69867849 | -1.41848352 | c | 6.000 | 0 |
| -3.43775390 | 0.41645403 | -0.24841246 | c | 6.000 | 0 |
| -4.61040268 | 1.37200198 | -2.40893084 | c | 6.000 | 0 |
| -6.91362790 | 2.61848350 | -2.27944653 | c | 6.000 | 0 |
| -8.11377434 | 2.92781670 | 0.03562118 | c | 6.000 | 0 |
| -6.97705303 | 1.98334209 | 2.20223232 | c | 6.000 | 0 |
| -4.66386610 | 0.74683570 | 2.05728770 | c | 6.000 | 0 |
| 8.11956064 | -1.88259248 | 2.47880870 | h | 1.000 | 0 |
| 7.52856807 | 1.28957640 | 3.29200483 | h | 1.000 | 0 |
| 7.25592033 | 0.08086784 | 7.86631437 | h | 1.000 | 0 |
| 10.20479859 | -0.79211880 | 6.54820887 | h | 1.000 | 0 |
| 7.84657619 | -3.11203272 | 7.04965888 | h | 1.000 | 0 |
| -0.09147358 | -1.43256217 | 3.63398472 | h | 1.000 | 0 |
| 0.09910560 | -0.06368717 | -2.01246044 | h | 1.000 | 0 |
| -2.62550408 | -3.72226456 | -3.15481993 | h | 1.000 | 0 |
| 0.28505951 | -4.67342647 | -1.77857620 | h | 1.000 | 0 |
| -2.53110958 | -4.75627489 | 0.02854327 | h | 1.000 | 0 |
| -3.68846463 | 1.13979150 | -4.22818545 | h | 1.000 | 0 |
| -7.77149462 | 3.35764668 | -3.98850198 | h | 1.000 | 0 |
| -9.91234187 | 3.90303154 | 0.14842355 | h | 1.000 | 0 |
| -7.89008672 | 2.21685039 | 4.02303240 | h | 1.000 | 0 |
| -3.79423227 | 0.04515819 | 3.77293349 | h | 1.000 | 0 |

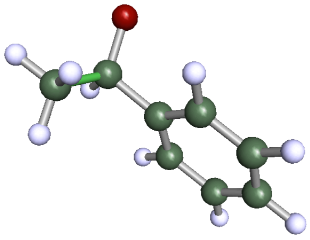
Benzaldehyde (MAA* = 123.9 kJ/mol, E = -19.5):



Total Energy = -345.31694700657 hartree
Enthalpy Correction = 0.118048 hartree
Entropy = 0.000126 hartree/K
LUMO Energy = -0.0708 hartree

```
               atomic coordinates              atom    charge  isotop
 5.90918969    1.26557531    0.00000000     o       8.000     0
 4.38836696   -0.44893484    0.00000000     c       6.000     0
 1.63567227   -0.13038791    0.00000000     c       6.000     0
 0.53629470    2.26725455    0.00000000     c       6.000     0
-2.06505767    2.49970346    0.00000000     c       6.000     0
-3.57701993    0.34457467    0.00000000     c       6.000     0
-2.49167219   -2.04430018    0.00000000     c       6.000     0
 0.11683939   -2.28084098    0.00000000     c       6.000     0
 5.03653602   -2.43723953    0.00000000     h       1.000     0
 1.74280361    3.92249218    0.00000000     h       1.000     0
-2.93107481    4.35556710    0.00000000     h       1.000     0
-5.61684654    0.53548777    0.00000000     h       1.000     0
-3.67706087   -3.71363047    0.00000000     h       1.000     0
 0.99302936   -4.13532114    0.00000000     h       1.000     0
```

Benzaldehyde Product:

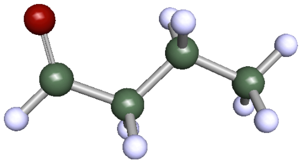


Total Energy = -385.29741668848 hartree
Enthalpy Correction = 0.157026 hartree
Entropy = 0.000138 hartree/K

```
               atomic coordinates              atom    charge  isotop
 3.16472462    1.98563446    3.44235987     o       8.000     0
 2.92615613    0.16560879    1.65410913     c       6.000     0
 4.70550671    0.57805901   -0.60586630     c       6.000     0
 0.22050852   -0.07668120    0.68371514     c       6.000     0
-1.11735276   -2.33197562    0.86083083     c       6.000     0
-3.60175619   -2.51876783    0.01849366     c       6.000     0
-4.78773957   -0.43328032   -1.03743670     c       6.000     0
```

```
-3.47391644    1.83912595   -1.22378954     c       6.000      0
-1.00626307    2.01032433   -0.36018192     c       6.000      0
 3.39729758   -1.76840400    2.37752859     h       1.000      0
 6.65521885    0.66333255    0.07775927     h       1.000      0
 4.26849508    2.37869647   -1.52773447     h       1.000      0
 4.56744786   -0.93077184   -2.01867153     h       1.000      0
-0.19699233   -3.97188600    1.68753168     h       1.000      0
-4.61133274   -4.29533949    0.19297814     h       1.000      0
-6.72154856   -0.56796222   -1.70269217     h       1.000      0
-4.38743161    3.47937277   -2.04959083     h       1.000      0
-0.00102207    3.79491419   -0.46934284     h       1.000      0
```

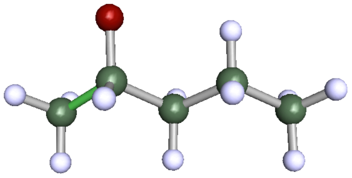
Butyraldehyde (MAA* = 119.3 kJ/mol, E = -18.7):



Total Energy = -232.28643293859 hartree
Enthalpy Correction = 0.120401 hartree
Entropy = 0.000122 hartree/K
LUMO Energy = -0.0267 hartree

```
                   atomic coordinates              atom    charge   isotop
-2.81024253   -0.83683159   -0.26233802     c       6.000      0
-0.91581017    1.23094797   -0.87616536     c       6.000      0
 1.40433407    1.09648904    0.79471231     c       6.000      0
 3.35524159    3.06731459    0.32873615     c       6.000      0
 3.20613430    4.71736010   -1.24510882     o       8.000      0
-3.45145136   -0.69885206    1.69772008     h       1.000      0
-1.97408705   -2.70972554   -0.51665543     h       1.000      0
-4.47142295   -0.71457367   -1.48125632     h       1.000      0
-0.33600421    1.09477142   -2.85620356     h       1.000      0
-1.80055488    3.08725477   -0.66137170     h       1.000      0
 2.36988876   -0.73488175    0.62587560     h       1.000      0
 0.91033792    1.22930001    2.80820146     h       1.000      0
 5.04460297    2.94770163    1.55947911     h       1.000      0
```

Butyraldehyde Product:

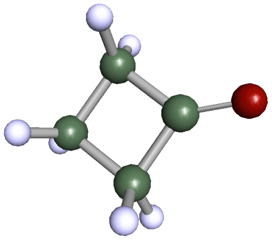


Total Energy = -272.26591890365 hartree
Enthalpy Correction = 0.159537 hartree
Entropy = 0.000132 hartree/K

```
                   atomic coordinates              atom    charge   isotop
```

```
-2.94070407   -4.00997631    1.84043220    c       6.000      0
-1.38859285   -1.62755779    1.43632640    c       6.000      0
 0.06290321   -1.60851443   -1.03333296    c       6.000      0
 1.65170648    0.79744483   -1.39688445    c       6.000      0
 2.92414900    0.69830160   -3.99966278    c       6.000      0
 3.33578756    1.19429436    0.49421299    o       8.000      0
-1.73808462   -5.69265043    1.81353460    h       1.000      0
-3.93978047   -3.98137573    3.64966701    h       1.000      0
-4.35441931   -4.23984454    0.34777617    h       1.000      0
-2.63695422    0.02903237    1.49684389    h       1.000      0
-0.02973462   -1.37816711    2.97519738    h       1.000      0
-1.26115322   -1.83403655   -2.61924453    h       1.000      0
 1.34929838   -3.24194521   -1.08721953    h       1.000      0
 0.21274321    2.36163996   -1.53841478    h       1.000      0
 4.00910407    2.43038089   -4.31586244    h       1.000      0
 4.24545651   -0.89720861   -4.06472711    h       1.000      0
 1.56742632    0.48412458   -5.55217833    h       1.000      0
```

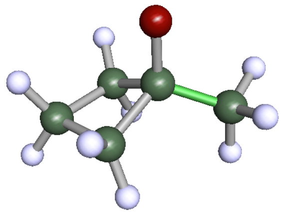
Cyclobutanone (MAA* = 109.3 kJ/mol, E = -17.5):



Total Energy = -231.06477844932 hartree
Enthalpy Correction = 0.097055 hartree
Entropy = 0.000114 hartree/K
LUMO Energy = -0.0250 hartree

```
                   atomic coordinates              atom    charge  isotop
 3.02797663    3.22828325    0.00000000    o       8.000      0
 1.47243576    1.57099330    0.00000000    c       6.000      0
 0.12469657    0.13478879   -2.07896251    c       6.000      0
-1.28169828   -1.37171242    0.00000000    c       6.000      0
 0.12469657    0.13478879    2.07896251    c       6.000      0
 1.40336779   -0.94851160   -3.28499929    h       1.000      0
-1.04372729    1.34243802   -3.27866325    h       1.000      0
-3.32100811   -1.09803134    0.00000000    h       1.000      0
-0.86676102   -3.38692894    0.00000000    h       1.000      0
-1.04372729    1.34243802    3.27866325    h       1.000      0
 1.40336779   -0.94851160    3.28499929    h       1.000      0
```

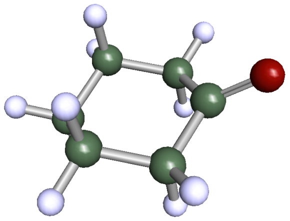
Cyclobutanone Product:



Total Energy = -271.03688800920 hartree
Enthalpy Correction = 0.13609 hartree
Entropy = 0.000122 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.47749980 | 3.52099855 | 0.25268876 | c | 6.000 | 0 |
| -1.15956596 | 0.95516860 | 0.20072309 | c | 6.000 | 0 |
| -2.79283046 | -0.98011479 | 0.50662606 | o | 8.000 | 0 |
| 1.24060410 | 0.77813221 | 1.95339537 | c | 6.000 | 0 |
| 2.68259330 | -0.47475199 | -0.23644875 | c | 6.000 | 0 |
| 0.70967696 | 0.58643022 | -2.08669698 | c | 6.000 | 0 |
| 0.96435633 | -0.32686640 | 3.67830093 | h | 1.000 | 0 |
| 2.03658343 | 2.62563941 | 2.44146152 | h | 1.000 | 0 |
| 4.65208240 | 0.08012741 | -0.52146352 | h | 1.000 | 0 |
| 2.59373156 | -2.53291103 | -0.12690818 | h | 1.000 | 0 |
| 1.33166726 | 2.37043203 | -2.93305819 | h | 1.000 | 0 |
| 0.01012991 | -0.67034159 | -3.57097849 | h | 1.000 | 0 |
| -3.89558722 | 3.60110844 | -1.25489473 | h | 1.000 | 0 |
| -3.46319574 | 3.75477113 | 2.05909616 | h | 1.000 | 0 |
| -1.17524246 | 5.11156586 | 0.00787620 | h | 1.000 | 0 |

Cyclohexanone (MAA* = 67.6 kJ/mol, E = -19.9):

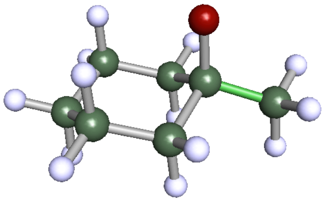


Total Energy = -309.66427501086 hartree
Enthalpy Correction = 0.158985 hartree
Entropy = 0.000126 hartree/K
LUMO Energy = -0.0187 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.78228934 | 1.78481393 | 0.00000000 | o | 8.000 | 0 |
| 2.83884704 | 0.55854517 | 0.00000000 | c | 6.000 | 0 |
| 1.55775577 | -0.25001024 | -2.39954797 | c | 6.000 | 0 |
| -1.26235612 | 0.39470059 | -2.36801996 | c | 6.000 | 0 |
| -2.54214285 | -0.61081785 | 0.00000000 | c | 6.000 | 0 |
| -1.26235612 | 0.39470059 | 2.36801996 | c | 6.000 | 0 |
| 1.55775577 | -0.25001024 | 2.39954797 | c | 6.000 | 0 |
| 2.53210075 | 0.59584535 | -4.00757839 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 1.77394526 | -2.30905534 | -2.52849205 | h | 1.000 | 0 |
| -2.15195687 | -0.37100289 | -4.06670443 | h | 1.000 | 0 |
| -1.48753813 | 2.45157974 | -2.45027626 | h | 1.000 | 0 |
| -2.46505646 | -2.68181359 | 0.00000000 | h | 1.000 | 0 |
| -4.53981877 | -0.08334362 | 0.00000000 | h | 1.000 | 0 |
| -2.15195687 | -0.37100289 | 4.06670443 | h | 1.000 | 0 |
| -1.48753813 | 2.45157974 | 2.45027626 | h | 1.000 | 0 |
| 1.77394526 | -2.30905534 | 2.52849205 | h | 1.000 | 0 |
| 2.53210075 | 0.59584535 | 4.00757839 | h | 1.000 | 0 |

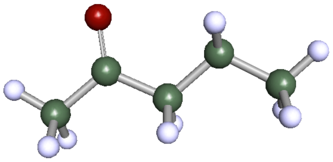
Cyclohexanone product:



Total Energy = -349.63467347747 hartree
Enthalpy Correction = 0.197193 hartree
Entropy = 0.000134 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.62417422 | -1.47265181 | 3.08780928 | o | 8.000 | 0 |
| 1.75359821 | -0.65123589 | 0.65189010 | c | 6.000 | 0 |
| 4.43997027 | -0.92852923 | -0.40806808 | c | 6.000 | 0 |
| -0.06051110 | -2.15967768 | -1.07859221 | c | 6.000 | 0 |
| -2.79551283 | -1.80249694 | -0.28095459 | c | 6.000 | 0 |
| -3.53660974 | 0.97719340 | -0.35328923 | c | 6.000 | 0 |
| -1.74269208 | 2.55877252 | 1.24792718 | c | 6.000 | 0 |
| 0.98284015 | 2.16250832 | 0.43548571 | c | 6.000 | 0 |
| 5.75695329 | 0.16437555 | 0.75657945 | h | 1.000 | 0 |
| 4.61397826 | -0.28270220 | -2.37011146 | h | 1.000 | 0 |
| 5.01274753 | -2.91597182 | -0.32375944 | h | 1.000 | 0 |
| 0.16811451 | -1.57369523 | -3.05915316 | h | 1.000 | 0 |
| 0.46995323 | -4.16051703 | -0.96527107 | h | 1.000 | 0 |
| -2.98657391 | -2.50128525 | 1.65896235 | h | 1.000 | 0 |
| -4.06935107 | -2.92071534 | -1.47057148 | h | 1.000 | 0 |
| -3.46547536 | 1.64833566 | -2.31705891 | h | 1.000 | 0 |
| -5.49018672 | 1.22461671 | 0.28640843 | h | 1.000 | 0 |
| -1.90680080 | 1.96878911 | 3.22589077 | h | 1.000 | 0 |
| -2.26338302 | 4.56070265 | 1.15311218 | h | 1.000 | 0 |
| 1.23211091 | 2.83794970 | -1.51388893 | h | 1.000 | 0 |
| 2.26265603 | 3.26623480 | 1.63665311 | h | 1.000 | 0 |

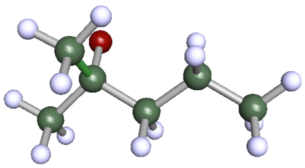
Pentan-2-one (MAA* = 89.0 kJ/mol, E = -22.3):



Total Energy = -271.57961568903 hartree
Enthalpy Correction = 0.149911 hartree
Entropy = 0.000135 hartree/K
LUMO Energy = -0.0121 hartree

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.57819273 | 1.61587850 | 2.02530822 | c | 6.000 | 0 |
| -2.69596911 | 1.15982320 | -0.04253411 | c | 6.000 | 0 |
| -0.01027383 | 0.71960367 | 0.77043296 | c | 6.000 | 0 |
| 1.84782373 | 0.29040341 | -1.36410342 | c | 6.000 | 0 |
| 4.51565525 | -0.15003160 | -0.40021328 | c | 6.000 | 0 |
| -3.31565444 | 1.15076333 | -2.25305911 | o | 8.000 | 0 |
| -4.56604987 | 0.03061425 | 3.35030281 | h | 1.000 | 0 |
| -6.46617543 | 1.86570520 | 1.24670742 | h | 1.000 | 0 |
| -4.03577521 | 3.29573595 | 3.09968976 | h | 1.000 | 0 |
| 0.55358120 | 2.34058305 | 1.93485406 | h | 1.000 | 0 |
| -0.02330987 | -0.88975144 | 2.07927381 | h | 1.000 | 0 |
| 1.22737694 | -1.32783977 | -2.49095339 | h | 1.000 | 0 |
| 1.81453065 | 1.92164531 | -2.63361875 | h | 1.000 | 0 |
| 4.59732436 | -1.80751837 | 0.83201191 | h | 1.000 | 0 |
| 5.19083681 | 1.47207448 | 0.68864782 | h | 1.000 | 0 |
| 5.83354311 | -0.45691966 | -1.95909464 | h | 1.000 | 0 |

Pentan-2-one Product:

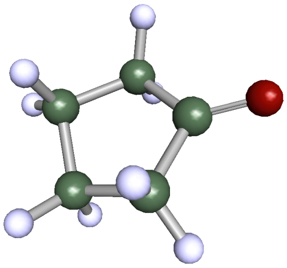


Total Energy = -311.54810271162 hartree
Enthalpy Correction = 0.188691 hartree
Entropy = 0.000142 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.90303329 | 1.77708423 | 1.28634605 | c | 6.000 | 0 |
| -1.88022182 | -0.30667267 | 1.09676534 | c | 6.000 | 0 |
| -1.43668100 | -1.36760122 | 3.39877651 | o | 8.000 | 0 |
| -2.85441844 | -2.29187825 | -0.80014294 | c | 6.000 | 0 |
| 0.52888308 | 0.95243967 | 0.00537036 | c | 6.000 | 0 |
| 2.77650589 | -0.80838776 | -0.24404370 | c | 6.000 | 0 |
| 5.22350683 | 0.55953838 | -0.87100718 | c | 6.000 | 0 |
| -5.65832680 | 0.96803964 | 2.02507604 | h | 1.000 | 0 |
| -4.31610138 | 2.68475202 | -0.53082072 | h | 1.000 | 0 |
| -3.26348686 | 3.23276784 | 2.61092121 | h | 1.000 | 0 |
| -1.49211953 | -3.83553884 | -0.97440206 | h | 1.000 | 0 |
| -4.62465107 | -3.09145892 | -0.08790556 | h | 1.000 | 0 |
| -3.20514893 | -1.51538845 | -2.68930489 | h | 1.000 | 0 |
| 0.12437358 | 1.83916964 | -1.82959287 | h | 1.000 | 0 |
| 1.03944351 | 2.48832283 | 1.30705378 | h | 1.000 | 0 |
| 2.96015944 | -1.83412266 | 1.54365398 | h | 1.000 | 0 |
| 2.40102487 | -2.23183743 | -1.69987935 | h | 1.000 | 0 |
| 5.06724624 | 1.59161210 | -2.65748188 | h | 1.000 | 0 |

```
         6.81509203   -0.74834782   -1.04364908     h       1.000      0
         5.69795365    1.93750768    0.59667894     h       1.000      0
```

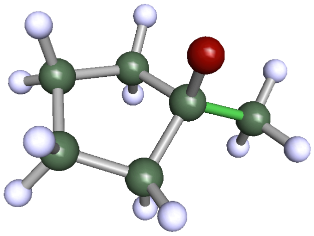
Cyclopentanone (MAA* = 88.9 kJ/mol, E = -21.0):



Total Energy = -270.37865937257 hartree
Enthalpy Correction = 0.128251 hartree
Entropy = 0.000116 hartree/K
LUMO Energy = -0.0202 hartree

```
                   atomic coordinates               atom     charge  isotop
         0.00000000    0.00000000    4.81847390     o       8.000      0
         0.00000000    0.00000000    2.52976651     c       6.000      0
         2.28689974   -0.39034339    0.86830157     c       6.000      0
         1.40747321    0.34150767   -1.77626745     c       6.000      0
        -1.40747321   -0.34150767   -1.77626745     c       6.000      0
        -2.28689974    0.39034339    0.86830157     c       6.000      0
         2.73782579   -2.41256774    0.96209085     h       1.000      0
         3.92239914    0.63612045    1.59060713     h       1.000      0
         2.46040378   -0.61216319   -3.26859037     h       1.000      0
         1.63206321    2.37865883   -2.05037673     h       1.000      0
        -1.63206321   -2.37865883   -2.05037673     h       1.000      0
        -2.46040378    0.61216319   -3.26859037     h       1.000      0
        -2.73782579    2.41256774    0.96209085     h       1.000      0
        -3.92239914   -0.63612045    1.59060713     h       1.000      0
```

Cyclopentanone Product:

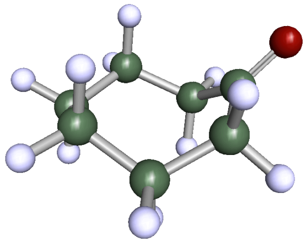


Total Energy = -310.34489374945 hartree
Enthalpy Correction = 0.167199 hartree
Entropy = 0.000131 hartree/K

```
                   atomic coordinates               atom     charge  isotop
         1.62529798    0.47076726   -3.16966459     o       8.000      0
         1.41729713    0.13657851   -0.62646747     c       6.000      0
         4.00843460    0.07448709    0.66192355     c       6.000      0
```

```
-0.31653494    2.16129908    0.57607673    c      6.000      0
-2.97664108    1.39183489   -0.25933915    c      6.000      0
-2.86390424   -1.50915993   -0.62214635    c      6.000      0
-0.14114146   -2.25497935    0.00982175    c      6.000      0
 5.14148697   -1.46502203   -0.13234984    h      1.000      0
 5.01186017    1.84611682    0.28907143    h      1.000      0
 3.89564249   -0.19080982    2.71332894    h      1.000      0
 0.22266924    4.05049957   -0.06767390    h      1.000      0
-0.17126872    2.12336090    2.64491113    h      1.000      0
-3.45497335    2.30909130   -2.04497384    h      1.000      0
-4.42009213    1.94848058    1.11069769    h      1.000      0
-4.23983830   -2.49405297    0.56438226    h      1.000      0
-3.30026007   -1.99484441   -2.57928763    h      1.000      0
 0.53482880   -3.87084484   -1.08924181    h      1.000      0
 0.02713692   -2.73280265    2.02093110    h      1.000      0
```

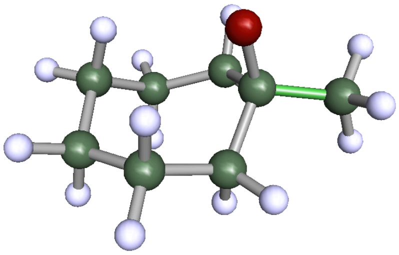
Cycloheptanone (MAA* = 72.6 kJ/mol, E = -22.1):



Total Energy = -348.94031426878 hartree
Enthalpy Correction = 0.188926 hartree
Entropy = 0.000135 hartree/K
LUMO Energy = -0.0189 hartree

```
                  atomic coordinates              atom     charge  isotop
-0.52443261    5.08905869   -1.71754066    o      8.000      0
-0.58089076    3.16627414   -0.45561573    c      6.000      0
 1.66255154    2.38427235    1.08893032    c      6.000      0
 3.11364374    0.21399077   -0.18254596    c      6.000      0
 1.97155896   -2.39413356    0.19893088    c      6.000      0
-0.69989269   -2.75485550   -0.80781734    c      6.000      0
-2.69920118   -1.14952762    0.51380079    c      6.000      0
-2.92028482    1.54345968   -0.46350958    c      6.000      0
 2.88457971    4.03408101    1.27780762    h      1.000      0
 1.05400130    1.79282308    2.97565953    h      1.000      0
 3.30448196    0.61754096   -2.20510385    h      1.000      0
 5.03009326    0.21395252    0.58821168    h      1.000      0
 3.21818882   -3.78227894   -0.69461976    h      1.000      0
 1.97492651   -2.82846417    2.22613076    h      1.000      0
-1.20034801   -4.74840898   -0.58654426    h      1.000      0
-0.74353610   -2.37177797   -2.84555146    h      1.000      0
-2.33942911   -1.14503131    2.55230615    h      1.000      0
-4.55019833   -2.03455521    0.26915426    h      1.000      0
-3.64805021    1.56204907   -2.39914278    h      1.000      0
-4.30776197    2.59153101    0.66705940    h      1.000      0
```

Cycloheptanone product:

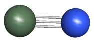


Total Energy = -388.90177012134 hartree
Enthalpy Correction = 0.188926 hartree
Entropy = 0.000135 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.88995551 | -0.25921208 | -3.26902602 | o | 8.000 | 0 |
| 2.19516734 | -0.24586225 | -0.71393170 | c | 6.000 | 0 |
| 5.02805215 | -0.32184946 | -0.03369123 | c | 6.000 | 0 |
| 0.99771676 | -2.62455544 | 0.53259813 | c | 6.000 | 0 |
| -1.81322757 | -2.56889889 | 1.17994395 | c | 6.000 | 0 |
| -3.52578131 | -1.18156742 | -0.68340732 | c | 6.000 | 0 |
| -3.70043122 | 1.64457586 | -0.15999873 | c | 6.000 | 0 |
| -1.31386594 | 3.13780541 | -0.74238389 | c | 6.000 | 0 |
| 1.10420417 | 2.20772149 | 0.49925742 | c | 6.000 | 0 |
| 5.84735796 | -2.11849804 | -0.65616791 | h | 1.000 | 0 |
| 5.38658293 | -0.11598457 | 1.99871089 | h | 1.000 | 0 |
| 6.00005853 | 1.20730614 | -1.03161763 | h | 1.000 | 0 |
| 2.02654260 | -3.11535134 | 2.26721410 | h | 1.000 | 0 |
| 1.36564904 | -4.14976144 | -0.81952320 | h | 1.000 | 0 |
| -2.46628571 | -4.52426037 | 1.38658368 | h | 1.000 | 0 |
| -2.07440909 | -1.70291665 | 3.04618774 | h | 1.000 | 0 |
| -2.82408232 | -1.47982185 | -2.60600005 | h | 1.000 | 0 |
| -5.43199730 | -1.98401224 | -0.57566980 | h | 1.000 | 0 |
| -4.20822100 | 1.90388710 | 1.83659842 | h | 1.000 | 0 |
| -5.26440131 | 2.44895006 | -1.25737579 | h | 1.000 | 0 |
| -1.63920155 | 5.12021004 | -0.23218002 | h | 1.000 | 0 |
| -0.96252135 | 3.06640751 | -2.77980269 | h | 1.000 | 0 |
| 2.53723292 | 3.69022638 | 0.26766623 | h | 1.000 | 0 |
| 0.84590574 | 1.96546204 | 2.54601545 | h | 1.000 | 0 |

## Energies and Coordinates of Molecules with E* values Calculated at the PBE0(disp)/def2-TZVP COSMO (∞) level of theory.

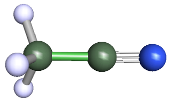
Ammoniaylidynemethylium (MAA* = 1372.8 kJ/mol, E* = 110.7):



Total Energy = -92.19926715790 hartree
Enthalpy Correction = 0.008174 hartree
Entropy = 0.000075 hartree/K

```
                  atomic  coordinates              atom    charge  isotop
         0.00000000    0.00000000    1.10201057     c      6.000     0
         0.00000000    0.00000000   -1.10201057     n      7.000     0
```

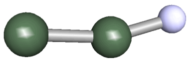
Ammoniaylidynemethylium Product:



Total Energy = -132.65591304898 hartree
Enthalpy Correction = 0.05 hartree
Entropy = 0.000095 hartree/K

```
                  atomic  coordinates              atom    charge  isotop
         3.97948994   -0.02524300    0.02076553     n      7.000     0
         1.80555292   -0.01155162    0.00929517     c      6.000     0
        -0.92517085    0.00591296   -0.00481155     c      6.000     0
        -1.62213826   -1.38084386   -1.36130381     h      1.000     0
        -1.63256247   -0.46590161    1.87294112     h      1.000     0
        -1.60517128    1.87762713   -0.53688646     h      1.000     0
```

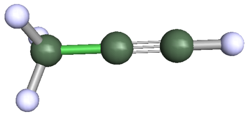
Ethylium (MAA* = 1157.3 kJ/mol, E* = 87.4):



Total Energy = -76.17641274576 hartree
Enthalpy Correction = 0.015928 hartree
Entropy = 0.000081 hartree/K

```
                  atomic  coordinates              atom    charge  isotop
         2.22661290   -0.68531729    0.00058072     c      6.000     0
        -0.03400970    0.49445529   -0.00146488     c      6.000     0
        -2.07349430    0.81959864   -0.00116728     h      1.000     0
```

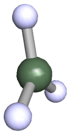
Ethylium Product:



Total Energy = -116.55607039460 hartree
Enthalpy Correction = 0.06078 hartree
Entropy = 0.000094 hartree/K

```
                  atomic coordinates            atom    charge  isotop
         0.00000000    0.00000000   -1.79924677     c      6.000     0
         0.00000000    0.00000000    0.94208765     c      6.000     0
         0.00000000    0.00000000    3.21500787     c      6.000     0
        -0.96516509   -1.67171497   -2.53011081     h      1.000     0
        -0.96516509    1.67171497   -2.53011081     h      1.000     0
         1.93033017    0.00000000   -2.53011081     h      1.000     0
         0.00000000    0.00000000    5.23136919     h      1.000     0
```

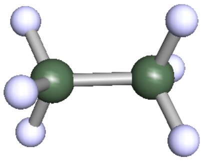
Methylium (MAA* = 670.1 kJ/mol, E* = 34.8):



Total Energy = -39.56351567695 hartree
Enthalpy Correction 0.035423 hartree
Entropy = 0.000071 hartree/K

```
                  atomic coordinates            atom    charge  isotop
         0.00000000    0.00000000    0.00000000     c      6.000     0
        -1.02797367    1.78050263    0.00000000     h      1.000     0
        -1.02797367   -1.78050263    0.00000000     h      1.000     0
         2.05594735    0.00000000    0.00000000     h      1.000     0
```

Methylium Product:

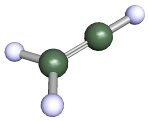


Total Energy = -79.75380002333 hartree
Enthalpy Correction = 0.078264 hartree
Entropy = 0.00009 hartree/K

```
                  atomic coordinates            atom    charge  isotop
        -1.43527362    0.02028181   -0.03067898     c      6.000     0
         1.43526354   -0.02029273    0.03066817     c      6.000     0
        -2.23002227   -0.18340800    1.86492451     h      1.000     0
```

| | | | | | |
|---|---|---|---|---|---|
| -2.14473570 | 1.79375978 | -0.81633950 | h | 1.000 | 0 |
| -2.18338182 | -1.51785119 | -1.18854365 | h | 1.000 | 0 |
| 2.18331691 | 1.51748698 | 1.18903065 | h | 1.000 | 0 |
| 2.23007046 | 0.18401880 | -1.86484407 | h | 1.000 | 0 |
| 2.14476250 | -1.79399544 | 0.81578286 | h | 1.000 | 0 |

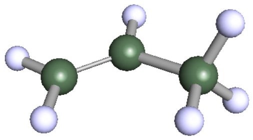
Vinyl cation (MAA* = 631.4 kJ/mol, E* = 30.6):



Total Energy = -77.62701087149 hartree
Enthalpy Correction = 0.040006 hartree
Entropy = 0.000085 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | 1.43184446 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -0.92701887 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 3.47470964 | h | 1.000 | 0 |
| -1.78454251 | 0.00000000 | -1.98954046 | h | 1.000 | 0 |
| 1.78454251 | 0.00000000 | -1.98954046 | h | 1.000 | 0 |

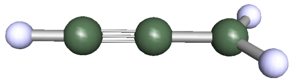
Vinyl cation Product:



Total Energy = -117.80340555820 hartree
Enthalpy Correction 0.083968 hartree
Entropy = 0.000105 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.23562385 | -3.34189366 | 0.31741743 | c | 6.000 | 0 |
| -1.99055928 | -1.64577120 | 0.22530262 | c | 6.000 | 0 |
| -4.35658880 | -4.49455285 | -1.39617711 | h | 1.000 | 0 |
| -5.98541584 | -2.24209682 | 0.40734464 | h | 1.000 | 0 |
| -4.16811811 | -4.60085652 | 1.95099824 | h | 1.000 | 0 |
| -1.91719780 | -0.32566438 | -1.35173167 | h | 1.000 | 0 |
| -0.11820056 | -1.63691882 | 1.89586052 | c | 6.000 | 0 |
| -0.11091655 | -2.92016261 | 3.49914780 | h | 1.000 | 0 |
| 1.46807880 | -0.35074475 | 1.72024758 | h | 1.000 | 0 |

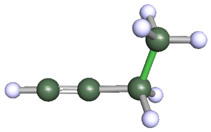
Prop-2-yn-1-ylium (MAA* = 568.0 kJ/mol, E* = 23.7):



Total Energy = -115.68392653716 hartree
Enthalpy Correction = 0.048621 hartree
Entropy = 0.000094 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -2.02633352 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 0.50407207 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 2.81268369 | c | 6.000 | 0 |
| 1.77387421 | 0.00000000 | -3.06673781 | h | 1.000 | 0 |
| -1.77387421 | 0.00000000 | -3.06673781 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 4.84293065 | h | 1.000 | 0 |

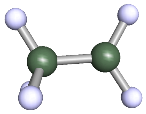
Prop-2-yn-1-ylium Product:



Total Energy = -155.83593078687 hartree
Enthalpy Correction = 0.090876 hartree
Entropy = 0.000109 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.33111070 | -0.13528981 | 0.00000000 | c | 6.000 | 0 |
| 2.11397591 | -0.64027594 | 0.00000000 | c | 6.000 | 0 |
| -0.57597729 | -1.20806230 | 0.00000000 | c | 6.000 | 0 |
| -2.22375922 | 1.16058264 | 0.00000000 | c | 6.000 | 0 |
| 6.29867839 | 0.30600935 | 0.00000000 | h | 1.000 | 0 |
| -1.00897217 | -2.37018946 | -1.65520807 | h | 1.000 | 0 |
| -1.00897217 | -2.37018946 | 1.65520807 | h | 1.000 | 0 |
| -1.85636161 | 2.31199433 | 1.67126569 | h | 1.000 | 0 |
| -1.85636161 | 2.31199433 | -1.67126569 | h | 1.000 | 0 |
| -4.21704576 | 0.63051771 | 0.00000000 | h | 1.000 | 0 |

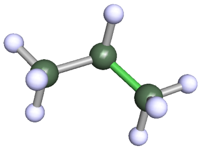
Ethyl cation (MAA* = 539.1 kJ/mol, E* = 20.6):



Total Energy = -78.89076821155 hartree
Enthalpy Correction = 0.064305 hartree
Entropy = 0.000089 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.51211596 | 0.03750064 | 0.00000000 | c | 6.000 | 0 |
| -1.12344615 | 0.17740474 | 0.00000000 | c | 6.000 | 0 |
| 2.71696293 | 1.70301150 | 0.00000000 | h | 1.000 | 0 |
| 2.43484539 | -1.79894576 | 0.00000000 | h | 1.000 | 0 |
| -1.98204164 | 2.03426410 | 0.00000000 | h | 1.000 | 0 |
| -1.77921824 | -1.07661761 | -1.55560516 | h | 1.000 | 0 |
| -1.77921824 | -1.07661761 | 1.55560516 | h | 1.000 | 0 |

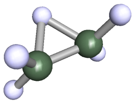
Ethyl cation Product:



Total Energy = -119.03468196859 hartree
Enthalpy Correction = 0.108878 hartree
Entropy = 0.000102 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 2.38856802 | -0.43043981 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.16284726 | c | 6.000 | 0 |
| 0.00000000 | -2.38856802 | -0.43043981 | c | 6.000 | 0 |
| 0.00000000 | 4.08787193 | 0.74341345 | h | 1.000 | 0 |
| 1.66818101 | 2.46467538 | -1.65010934 | h | 1.000 | 0 |
| -1.66818101 | 2.46467538 | -1.65010934 | h | 1.000 | 0 |
| 1.65493827 | 0.00000000 | 2.40605137 | h | 1.000 | 0 |
| -1.65493827 | 0.00000000 | 2.40605137 | h | 1.000 | 0 |
| 0.00000000 | -4.08787193 | 0.74341345 | h | 1.000 | 0 |
| 1.66818101 | -2.46467538 | -1.65010934 | h | 1.000 | 0 |
| -1.66818101 | -2.46467538 | -1.65010934 | h | 1.000 | 0 |

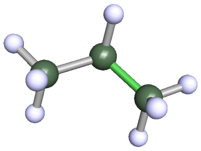
Ethyl cation (bridged) (MAA* = 518.4 kJ/mol, E* = 18.4):



Total Energy = -78.90115337706 hartree
Enthalpy Correction = 0.066221 hartree
Entropy = 0.000087 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 1.29324185 | -0.30007999 | c | 6.000 | 0 |
| 0.00000000 | -1.29324185 | -0.30007999 | c | 6.000 | 0 |
| 1.77001994 | 2.32795273 | -0.30165845 | h | 1.000 | 0 |
| -1.77001994 | 2.32795273 | -0.30165845 | h | 1.000 | 0 |
| 1.77001994 | -2.32795273 | -0.30165845 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 1.80698651 | h | 1.000 | 0 |
| -1.77001994 | -2.32795273 | -0.30165845 | h | 1.000 | 0 |

Ethyl cation (bridged) Product:

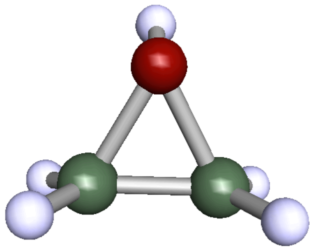


Total Energy = -119.03468196859 hartree

Enthalpy Correction = 0.108878 hartree
Entropy = 0.000102 hartree/K

```
                   atomic coordinates             atom    charge  isotop
         0.00000000    2.38856802   -0.43043981     c       6.000     0
         0.00000000    0.00000000    1.16284726     c       6.000     0
         0.00000000   -2.38856802   -0.43043981     c       6.000     0
         0.00000000    4.08787193    0.74341345     h       1.000     0
         1.66818101    2.46467538   -1.65010934     h       1.000     0
        -1.66818101    2.46467538   -1.65010934     h       1.000     0
         1.65493827    0.00000000    2.40605137     h       1.000     0
        -1.65493827    0.00000000    2.40605137     h       1.000     0
         0.00000000   -4.08787193    0.74341345     h       1.000     0
         1.66818101   -2.46467538   -1.65010934     h       1.000     0
        -1.66818101   -2.46467538   -1.65010934     h       1.000     0
```

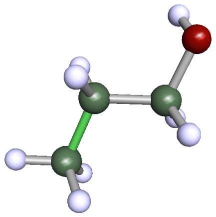
Protonated oxirane (MAA* = 497.7 kJ/mol, E* = 16.1):



Total Energy = -154.09343855965 hartree
Enthalpy Correction = 0.075464 hartree
Entropy = 0.000096 hartree/K

```
                   atomic coordinates             atom    charge  isotop
        -0.48075865    1.51327868   -1.05861502     o       8.000     0
         1.47731957   -0.26017645   -0.04813829     c       6.000     0
        -1.16916619   -0.91523069    0.21797508     c       6.000     0
        -0.72440590    2.95202138    0.06681804     h       1.000     0
         2.56140427   -1.02519972   -1.60079034     h       1.000     0
         2.48651627    0.51837409    1.54872224     h       1.000     0
        -2.04761353   -2.16612498   -1.13669148     h       1.000     0
        -2.10329584   -0.61694230    2.01071976     h       1.000     0
```

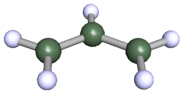
Protonated oxirane Product:



Total Energy = -194.21392029309 hartree
Enthalpy Correction = 0.112679 hartree
Entropy = 0.00011 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.40758345 | -0.13534415 | 1.22934870 | o | 8.000 | 0 |
| 1.93173576 | 0.82095657 | 0.83794371 | c | 6.000 | 0 |
| -0.06025134 | -1.23122384 | 0.72930088 | c | 6.000 | 0 |
| -2.67968931 | -0.15753556 | 0.24814853 | c | 6.000 | 0 |
| 4.43309464 | -0.98134807 | 2.83935369 | h | 1.000 | 0 |
| 1.99598032 | 1.84114380 | -0.95833557 | h | 1.000 | 0 |
| 1.44578093 | 2.19572074 | 2.31473366 | h | 1.000 | 0 |
| -0.04414508 | -2.27591115 | 2.51837088 | h | 1.000 | 0 |
| 0.44882225 | -2.57669820 | -0.75751777 | h | 1.000 | 0 |
| -3.22905736 | 1.16374735 | 1.73915885 | h | 1.000 | 0 |
| -2.74656736 | 0.86045589 | -1.54931391 | h | 1.000 | 0 |
| -4.09942949 | -1.65321961 | 0.17753044 | h | 1.000 | 0 |

Allylium (MAA* = 492.7 kJ/mol, E* = 15.6):

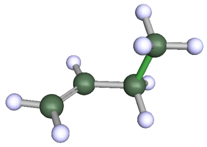


Total Energy = -116.96080936701 hartree
Enthalpy Correction = 0.074052 hartree
Entropy = 0.000096 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.21951097 | 0.00000000 | 0.31437416 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -1.02688603 | c | 6.000 | 0 |
| -4.03970930 | 0.00000000 | -0.62953453 | h | 1.000 | 0 |
| -2.20195401 | 0.00000000 | 2.36544098 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | -3.07277340 | h | 1.000 | 0 |
| 2.21951097 | 0.00000000 | 0.31437416 | c | 6.000 | 0 |
| 2.20195401 | 0.00000000 | 2.36544098 | h | 1.000 | 0 |
| 4.03970930 | 0.00000000 | -0.62953453 | h | 1.000 | 0 |

Allylium Product:

The $CH_3$-C-C-C Torsion Angle was constrained to 270°.

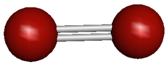


Total Energy = -157.08210258916 hartree
Enthalpy Correction = 0.114855 hartree
Entropy = 0.000113 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.68556087 | -3.04238164 | 0.66411584 | c | 6.000 | 0 |
| -2.38097254 | -2.10140697 | 0.34916275 | c | 6.000 | 0 |
| -6.12106477 | -2.88017939 | -0.79000246 | h | 1.000 | 0 |
| -5.21015853 | -4.02815342 | 2.38828112 | h | 1.000 | 0 |
| -1.94701539 | -1.10791210 | -1.40055746 | h | 1.000 | 0 |
| -0.34789962 | -2.12669715 | 2.31522049 | c | 6.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -0.57459143 | -3.79404345 | 3.51808879 | h | 1.000 | 0 |
| 1.50300559 | -2.28012595 | 1.40710593 | h | 1.000 | 0 |
| -0.41874398 | 0.23690042 | 3.96891167 | c | 6.000 | 0 |
| 1.11535809 | 0.21530761 | 5.35129555 | h | 1.000 | 0 |
| -2.21065701 | 0.35124068 | 4.98709740 | h | 1.000 | 0 |
| -0.22605625 | 1.95108719 | 2.83123048 | h | 1.000 | 0 |

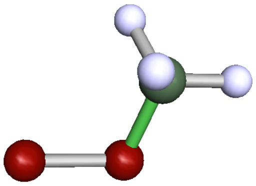
Oxygen (singlet) (MAA* = 489.0 kJ/mol, E* =15.2):



Total Energy = -150.12342893447 hartree
Enthalpy Correction = 0.007301 hartree
Entropy = 0.000075 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | 1.12858925 | o | 8.000 | 0 |
| 0.00000000 | 0.00000000 | -1.12858925 | o | 8.000 | 0 |

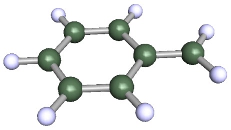
Oxygen (singlet) Product:



Total Energy = -190.23999654676 hartree
Enthalpy Correction = 0.046880 hartree
Entropy = 0.000099 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.22169382 | -1.56318462 | 0.45215993 | c | 6.000 | 0 |
| -0.15836558 | 1.02743598 | 0.31443783 | o | 8.000 | 0 |
| -0.06494302 | -2.47796225 | -1.39372596 | h | 1.000 | 0 |
| -1.06764027 | -2.45393544 | 1.81992602 | h | 1.000 | 0 |
| 2.17694977 | -1.87551014 | 1.06438444 | h | 1.000 | 0 |
| -2.73920951 | 1.43575396 | -0.49493545 | o | 8.000 | 0 |

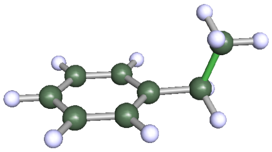
Phenylmethylium (MAA* = 470.4 kJ/mol, E* =13.2):



Total Energy = -270.51271181930 hartree
Enthalpy Correction = 0.12506 hartree
Entropy = 0.000117 hartree/K

```
                   atomic coordinates            atom    charge  isotop
    0.00000000    0.00000000    4.27415291      c      6.000     0
    0.00000000    0.00000000    1.69928793      c      6.000     0
    2.33721956    0.00000000    0.34775767      c      6.000     0
    2.31818498    0.00000000   -2.23584616      c      6.000     0
    0.00000000    0.00000000   -3.51037132      c      6.000     0
   -2.31818498    0.00000000   -2.23584616      c      6.000     0
   -2.33721956    0.00000000    0.34775767      c      6.000     0
    1.75666652    0.00000000    5.33017685      h      1.000     0
   -1.75666652    0.00000000    5.33017685      h      1.000     0
    4.09116475    0.00000000    1.40376897      h      1.000     0
    4.06541603    0.00000000   -3.29778002      h      1.000     0
    0.00000000    0.00000000   -5.55936328      h      1.000     0
   -4.06541603    0.00000000   -3.29778002      h      1.000     0
   -4.09116475    0.00000000    1.40376897      h      1.000     0
```

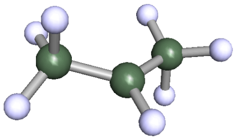
Phenylmethylium Product:



Total Energy = -310.62565146176 hartree
Enthalpy Correction = 0.165718 hartree
Entropy = 0.000133 hartree/K

```
                   atomic coordinates            atom    charge  isotop
   -4.09601715    0.56074183    2.94375465      c      6.000     0
   -3.10690686    1.02389881    0.27536969      c      6.000     0
   -0.30621924    0.61240030    0.08463310      c      6.000     0
    1.38212720    2.57161078    0.58117574      c      6.000     0
    3.97393114    2.17753666    0.48706311      c      6.000     0
    4.92516158   -0.19511829   -0.10870338      c      6.000     0
    3.26354088   -2.16313030   -0.61193815      c      6.000     0
    0.67326715   -1.75722387   -0.51468509      c      6.000     0
   -6.13500434    0.87203565    3.03945086      h      1.000     0
   -3.71256950   -1.37850604    3.54183875      h      1.000     0
   -3.18764213    1.83171568    4.29490717      h      1.000     0
   -4.07766285   -0.23652266   -1.04409981      h      1.000     0
   -3.55713718    2.95877462   -0.29511479      h      1.000     0
    0.65327533    4.43369416    1.04084612      h      1.000     0
    5.25550955    3.72980631    0.87272035      h      1.000     0
    6.94873769   -0.50609880   -0.18844013      h      1.000     0
    3.98670226   -4.02045342   -1.08923382      h      1.000     0
   -0.61369146   -3.30369088   -0.91711443      h      1.000     0
```

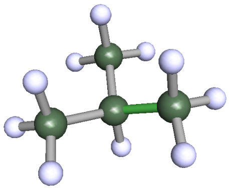
Propan-2-ylium (MAA* = 458.5 kJ/mol, E* = 11.9):



Total Energy = -118.20397115353 hartree
Enthalpy Correction = 0.094845 hartree
Entropy = 0.000103 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.40170703 | 0.16986633 | 0.07493960 | c | 6.000 | 0 |
| -0.09764547 | 0.07745998 | -0.91631245 | c | 6.000 | 0 |
| -2.33713205 | -0.21986043 | 0.54403810 | c | 6.000 | 0 |
| 2.58432675 | -0.36986538 | 2.04885516 | h | 1.000 | 0 |
| 3.81558578 | -0.63409420 | -1.19221585 | h | 1.000 | 0 |
| 2.73758524 | 2.25008477 | -0.06548506 | h | 1.000 | 0 |
| -0.31345718 | 0.24709064 | -2.95672700 | h | 1.000 | 0 |
| -3.97384326 | 0.74525379 | -0.25597923 | h | 1.000 | 0 |
| -2.71979863 | -2.25857818 | 0.14551979 | h | 1.000 | 0 |
| -2.09732820 | -0.00735733 | 2.57336695 | h | 1.000 | 0 |

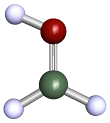
Propan-2-ylium Product:



Total Energy = -158.31738849101 hartree
Enthalpy Correction = 0.138137 hartree
Entropy = 0.000111 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.36855902 | -2.37041376 | 0.12334826 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -0.76273919 | c | 6.000 | 0 |
| 1.36855902 | 2.37041376 | 0.12334826 | c | 6.000 | 0 |
| -2.73711804 | 0.00000000 | 0.12334826 | c | 6.000 | 0 |
| 3.32068613 | -2.40693406 | -0.55323321 | h | 1.000 | 0 |
| 1.41467185 | -2.45028352 | 2.19104853 | h | 1.000 | 0 |
| 0.42412297 | -4.07926558 | -0.55323321 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | -2.83639523 | h | 1.000 | 0 |
| 1.41467185 | 2.45028352 | 2.19104853 | h | 1.000 | 0 |
| 3.32068613 | 2.40693406 | -0.55323321 | h | 1.000 | 0 |
| 0.42412297 | 4.07926558 | -0.55323321 | h | 1.000 | 0 |
| -3.74480910 | 1.67233152 | -0.55323321 | h | 1.000 | 0 |
| -3.74480910 | -1.67233152 | -0.55323321 | h | 1.000 | 0 |
| -2.82934370 | 0.00000000 | 2.19104853 | h | 1.000 | 0 |

Methyleneoxonium (MAA* = 446.9 kJ/mol, E* = 10.7):

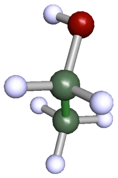


Total Energy = -114.82947809046 hartree
Enthalpy Correction = 0.045448 hartree

Entropy = 0.000087 hartree/K

```
                   atomic coordinates            atom    charge  isotop
         -0.76340845   -0.05378986    0.00000000    c      6.000     0
          1.42417994   -0.88367673    0.00000000    o      8.000     0
         -2.26491951   -1.45626109    0.00000000    h      1.000     0
         -1.13132993    1.97068362    0.00000000    h      1.000     0
          2.73547794    0.42304406    0.00000000    h      1.000     0
```

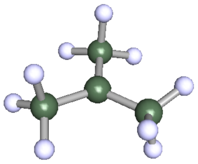
Methyleneoxonium Product:



Total Energy = -154.93324444517 hartree
Enthalpy Correction = 0.085598 hartree
Entropy = 0.000102 hartree/K

```
                   atomic coordinates            atom    charge  isotop
         -2.89900190   -0.82657714   -0.30454771    o      8.000     0
         -0.87564972    0.91536889   -0.01002121    c      6.000     0
          1.68701340   -0.32956595   -0.21618943    c      6.000     0
         -2.77707626   -2.05665334    1.02985458    h      1.000     0
         -1.04583991    1.90968260    1.80110794    h      1.000     0
         -1.12010284    2.31401644   -1.50886363    h      1.000     0
          1.94683102   -1.72916257    1.28270733    h      1.000     0
          1.89682715   -1.27649881   -2.03896478    h      1.000     0
          3.18699905    1.07938988   -0.03508308    h      1.000     0
```

2-Methylpropan-2-ylium (MAA* = 404.4 kJ/mol, E* = 6.1):

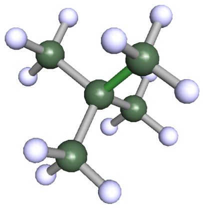


Total Energy = -157.50630163202 hartree
Enthalpy Correction = 0.124405 hartree
Entropy = 0.000115 hartree/K

```
                   atomic coordinates            atom    charge  isotop
         -1.52103662   -3.96899178    0.34517876    c      6.000     0
         -0.81203095   -1.33926260    0.08040480    c      6.000     0
         -1.46201005   -5.61111884   -1.83725313    c      6.000     0
         -2.21181008   -4.98682953    2.78892235    c      6.000     0
         -3.02707464   -3.58981518    4.05867523    h      1.000     0
         -3.31674046   -6.71854851    2.65270060    h      1.000     0
         -0.36774685   -5.54317041    3.60463906    h      1.000     0
         -0.22871126   -4.93793815   -3.34046053    h      1.000     0
```

```
  -1.18523919   -7.59403713   -1.35847189     h      1.000     0
  -3.42234844   -5.45198187   -2.55636363     h      1.000     0
   1.26119845   -1.37499850    0.35204833     h      1.000     0
  -1.60242487   -0.11661583    1.53092129     h      1.000     0
  -1.10194637   -0.63355180   -1.83360458     h      1.000     0
```

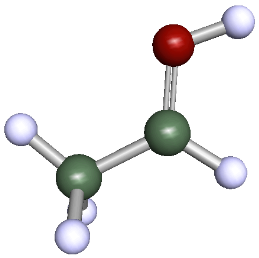
2-Methylpropan-2-ylium Product:



Total Energy = -197.60069206148 hartree
Enthalpy Correction = 0.167177 hartree
Entropy = 0.000116 hartree/K

```
                 atomic coordinates              atom    charge  isotop
   0.00000000    0.00000000    0.00000000     c      6.000     0
   1.66601954   -1.66601954    1.66601954     c      6.000     0
  -1.66601954    1.66601954    1.66601954     c      6.000     0
  -1.66601954   -1.66601954   -1.66601954     c      6.000     0
   1.66601954    1.66601954   -1.66601954     c      6.000     0
   2.88022673   -0.51465145    2.88022673     h      1.000     0
   2.88022673   -2.88022673    0.51465145     h      1.000     0
   0.51465145   -2.88022673    2.88022673     h      1.000     0
  -0.51465145   -2.88022673   -2.88022673     h      1.000     0
  -2.88022673   -0.51465145   -2.88022673     h      1.000     0
  -2.88022673   -2.88022673   -0.51465145     h      1.000     0
  -2.88022673    0.51465145    2.88022673     h      1.000     0
  -0.51465145    2.88022673    2.88022673     h      1.000     0
  -2.88022673    2.88022673    0.51465145     h      1.000     0
   0.51465145    2.88022673   -2.88022673     h      1.000     0
   2.88022673    0.51465145   -2.88022673     h      1.000     0
   2.88022673    2.88022673   -0.51465145     h      1.000     0
```

Protonated acetaldehyde (MAA* = 386.1 kJ/mol, E* = 4.1):

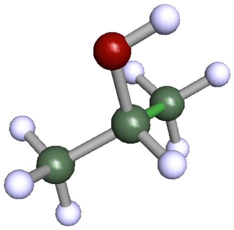


Total Energy = -154.13816473682 hartree
Enthalpy Correction = 0.073128 hartree
Entropy = 0.000097 hartree/K

```
                 atomic coordinates              atom    charge  isotop
```

| | | | | | |
|---|---|---|---|---|---|
| -1.76963169 | -0.11130672 | -0.15605044 | c | 6.000 | 0 |
| 0.92764404 | -0.27116235 | 0.13868593 | c | 6.000 | 0 |
| 2.27745467 | 1.66916806 | -0.05286989 | o | 8.000 | 0 |
| -2.43291576 | 1.79384585 | -0.53708468 | h | 1.000 | 0 |
| -2.62435025 | -0.90734494 | 1.55882119 | h | 1.000 | 0 |
| -2.30140187 | -1.43679164 | -1.66166736 | h | 1.000 | 0 |
| 1.84683941 | -2.07250731 | 0.53092033 | h | 1.000 | 0 |
| 4.07636143 | 1.33609905 | 0.17924492 | h | 1.000 | 0 |

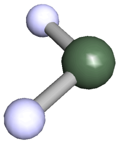
Protonated acetaldehyde Product:



Total Energy = -194.2192876 hartree
Enthalpy Correction = 0.113789 hartree
Entropy = 0.000112 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.22423957 | -0.87315394 | -0.20699511 | c | 6.000 | 0 |
| 0.13228703 | 0.49676331 | 0.64214836 | c | 6.000 | 0 |
| 2.51462022 | -0.62996874 | -0.47792174 | c | 6.000 | 0 |
| -0.15134808 | 3.07641872 | -0.09357347 | o | 8.000 | 0 |
| -3.90892830 | -0.00501082 | 0.61006159 | h | 1.000 | 0 |
| -2.38602510 | -0.81247627 | -2.26663441 | h | 1.000 | 0 |
| -2.15828241 | -2.84879301 | 0.38320972 | h | 1.000 | 0 |
| 0.25478644 | 0.40108113 | 2.71317901 | h | 1.000 | 0 |
| 2.74740059 | -2.59019998 | 0.12844043 | h | 1.000 | 0 |
| 2.42725531 | -0.58739248 | -2.54214802 | h | 1.000 | 0 |
| 4.18376218 | 0.42597960 | 0.13025662 | h | 1.000 | 0 |
| 1.34859288 | 3.97208462 | 0.41331017 | h | 1.000 | 0 |

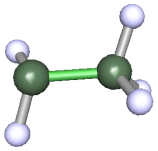
Carbene (MAA* = 382.6 kJ/mol, E* = 3.7):



Total Energy = -39.09547814511 hartree
Enthalpy Correction = 0.020705 hartree
Entropy = 0.000072 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | 0.87206216 | c | 6.000 | 0 |
| 1.63238454 | 0.00000000 | -0.43611619 | h | 1.000 | 0 |
| -1.63238454 | 0.00000000 | -0.43611619 | h | 1.000 | 0 |

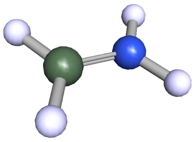
Carbene product:



Total Energy = -79.17647002479 hartree
Enthalpy Correction = 0.063738 hartree
Entropy = 0.000091 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.67907838 | -2.97628114 | 0.28682367 | c | 6.000 | 0 |
| -2.13226686 | -1.61226731 | 0.17184540 | c | 6.000 | 0 |
| -4.77800868 | -4.05733272 | 2.07217339 | h | 1.000 | 0 |
| -4.72197538 | -4.43871414 | -1.20519133 | h | 1.000 | 0 |
| -0.41768393 | -2.80417476 | 0.34702019 | h | 1.000 | 0 |
| -1.96306864 | -0.18129219 | 1.66642089 | h | 1.000 | 0 |
| -1.90198224 | -0.57258525 | -1.61003224 | h | 1.000 | 0 |

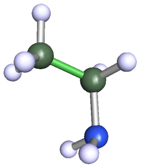
Methaniminium (MAA* = 323.3 kJ/mol, E* = -2.7):



Total Energy = -95.01575813041 hartree
Enthalpy Correction = 0.059325 hartree
Entropy = 0.000085 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | 1.19379788 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -1.19342352 | n | 7.000 | 0 |
| -1.78417348 | 0.00000000 | 2.19767394 | h | 1.000 | 0 |
| 1.78417348 | 0.00000000 | 2.19767394 | h | 1.000 | 0 |
| -1.63272798 | 0.00000000 | -2.19773611 | h | 1.000 | 0 |
| 1.63272798 | 0.00000000 | -2.19773611 | h | 1.000 | 0 |

Methaniminium Product:

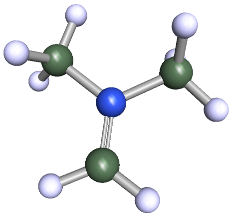


Total Energy = -135.07093869583 hartree
Enthalpy Correction = 0.098531 hartree
Entropy = 0.000102 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|

```
 -2.79182384   -0.06599630    0.00000000    n      7.000     0
 -0.34049662    1.19943734    0.00000000    c      6.000     0
  1.93526134   -0.55133808    0.00000000    c      6.000     0
 -2.91038046   -1.22088774    1.52701111    h      1.000     0
 -2.91038046   -1.22088774   -1.52701111    h      1.000     0
 -0.26382150    2.43730465    1.65529490    h      1.000     0
 -0.26382150    2.43730465   -1.65529490    h      1.000     0
  3.70332392    0.51968815    0.00000000    h      1.000     0
  1.92399999   -1.76638758    1.67275268    h      1.000     0
  1.92399999   -1.76638758   -1.67275268    h      1.000     0
```

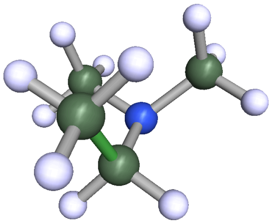
*N*-Methyl-*N*-methylenemethanaminium (MAA* = 295.0 kJ/mol, E* = -5.7):



Total Energy = -173.56548862941 hartree
Enthalpy Correction = 0.116798 hartree
Entropy = 0.000107 hartree/K

```
                 atomic coordinates             atom    charge  isotop
  1.49175403    2.33970533   -0.09706876    c      6.000     0
  0.21951911    0.31359820   -0.01583132    n      7.000     0
  1.38107744   -2.15903920   -0.32879200    c      6.000     0
 -2.52067213    0.34892239    0.40173238    c      6.000     0
  0.53940672    4.13570170    0.14635241    h      1.000     0
  3.51190936    2.25463559   -0.40854570    h      1.000     0
  1.00743029   -3.26800823    1.36629021    h      1.000     0
  3.40143936   -1.94302192   -0.62113296    h      1.000     0
  0.50724810   -3.08257320   -1.94920001    h      1.000     0
 -3.41698366    1.40879927   -1.11540733    h      1.000     0
 -3.21054146   -1.58312667    0.40549101    h      1.000     0
 -2.91158717    1.23440676    2.21611207    h      1.000     0
```

*N*-Methyl-*N*-methylenemethanaminium Product:

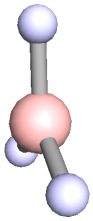


Total Energy = -213.61059106097 hartree
Enthalpy Correction = 0.156702 hartree
Entropy = 0.000124 hartree/K

```
                 atomic coordinates             atom    charge  isotop
 -2.17906186    1.47804084    1.24884502    c      6.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -0.96197623 | -0.13190031 | -0.59339911 | n | 7.000 | 0 |
| -2.54998087 | -2.24812578 | -1.27797787 | c | 6.000 | 0 |
| 1.58347926 | -0.87934998 | 0.13613929 | c | 6.000 | 0 |
| 1.83489761 | -2.51769627 | 2.49478928 | c | 6.000 | 0 |
| -2.64666251 | 0.50268500 | 3.03003721 | h | 1.000 | 0 |
| -3.94274019 | 2.21400629 | 0.46492671 | h | 1.000 | 0 |
| -0.95407853 | 3.07872707 | 1.69887165 | h | 1.000 | 0 |
| -4.31407065 | -1.55122709 | -2.09625936 | h | 1.000 | 0 |
| -1.59576112 | -3.41097844 | -2.69295370 | h | 1.000 | 0 |
| -3.04856003 | -3.47254161 | 0.33254881 | h | 1.000 | 0 |
| 2.68329240 | 0.85423940 | 0.39609702 | h | 1.000 | 0 |
| 2.41755734 | -1.87810830 | -1.47290412 | h | 1.000 | 0 |
| 0.84286915 | -4.31633974 | 2.28921567 | h | 1.000 | 0 |
| 3.82760691 | -2.93738150 | 2.83635611 | h | 1.000 | 0 |
| 1.09907849 | -1.56563375 | 4.17205287 | h | 1.000 | 0 |

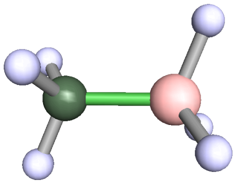
Borane (MAA* = 285.5 kJ/mol, E* = -6.8):



Total Energy = -26.56771537828 hartree
Enthalpy Correction = 0.029863 hartree
Entropy = 0.000072 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00009345 | -0.00002751 | 0.00001272 | b | 5.000 | 0 |
| -1.70696989 | -1.46881770 | -0.12507469 | h | 1.000 | 0 |
| -0.41516376 | 2.21665962 | -0.03326875 | h | 1.000 | 0 |
| 2.12204021 | -0.74781441 | 0.15833072 | h | 1.000 | 0 |

Borane Product:

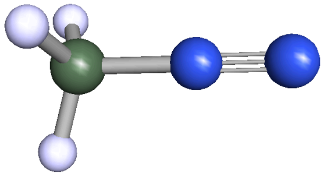


Total Energy = -66.60635772771 hartree
Enthalpy Correction = 0.06812 hartree
Entropy = 0.000093 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.54902660 | 0.15688302 | 0.15550769 | c | 6.000 | 0 |
| 1.49864993 | -0.15194751 | -0.15062735 | b | 5.000 | 0 |
| -2.41940893 | 1.12617902 | -1.45972492 | h | 1.000 | 0 |
| -2.07488847 | 1.25230670 | 1.83784574 | h | 1.000 | 0 |
| -2.52271719 | -1.66760152 | 0.32664369 | h | 1.000 | 0 |
| 2.05590383 | -1.39426675 | -2.05710584 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 2.44734225 | -1.24718930 | 1.69007809 | h | 1.000 | 0 |
| 2.56414518 | 1.92563635 | -0.34261709 | h | 1.000 | 0 |

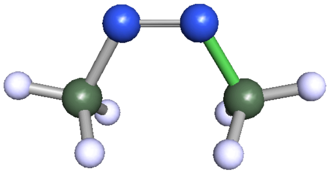
Methanediazonium (MAA* = 273.0 kJ/mol, E* = -8.1):



Total Energy = -149.08382944271 hartree
Enthalpy Correction = 0.050571 hartree
Entropy = 0.000092 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.94322016 | -0.01161607 | 0.00202460 | c | 6.000 | 0 |
| 1.73283004 | 0.02113486 | -0.00332095 | n | 7.000 | 0 |
| 3.78551579 | 0.04669553 | -0.00822470 | n | 7.000 | 0 |
| -1.52085109 | -0.03812983 | 1.97959321 | h | 1.000 | 0 |
| -1.54789254 | 1.70256456 | -0.96824647 | h | 1.000 | 0 |
| -1.50638205 | -1.72064905 | -1.00182569 | h | 1.000 | 0 |

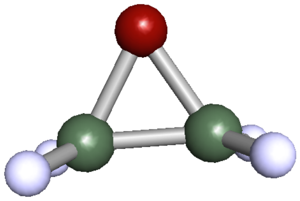
Methanediazonium Product:



Total Energy = -189.12051895056 hartree
Enthalpy Correction = 0.091041 hartree
Entropy = 0.000111 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.45472454 | -0.58800370 | 0.20732410 | c | 6.000 | 0 |
| 1.50375807 | 1.07675077 | -1.77655415 | n | 7.000 | 0 |
| -0.77539889 | 1.54498163 | -1.89413979 | n | 7.000 | 0 |
| -2.49549861 | 0.42828506 | -0.04876705 | c | 6.000 | 0 |
| 2.02212708 | 0.17457583 | 2.08089518 | h | 1.000 | 0 |
| 1.59263305 | -2.46311513 | 0.07193265 | h | 1.000 | 0 |
| 4.49126905 | -0.75088071 | -0.01370253 | h | 1.000 | 0 |
| -2.42683889 | -1.63734930 | -0.13204081 | h | 1.000 | 0 |
| -4.40030888 | 1.06950568 | -0.47727576 | h | 1.000 | 0 |
| -1.98930410 | 1.00143930 | 1.87312551 | h | 1.000 | 0 |

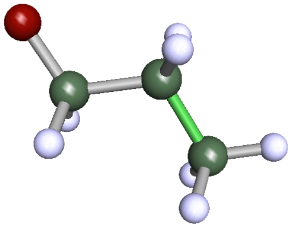
Oxirane (MAA* = 232.2 kJ/mol, E* = -12.5):



Total Energy = -153.68352130011 hartree
Enthalpy Correction = 0.061753 hartree
Entropy = 0.000092 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.37281215 | 0.10832964 | -0.08744827 | c | 6.000 | 0 |
| -1.37553309 | -0.04903052 | -0.09930207 | c | 6.000 | 0 |
| 0.02910907 | -0.67048051 | 2.11399833 | o | 8.000 | 0 |
| 2.27634181 | 1.94554232 | 0.05513392 | h | 1.000 | 0 |
| 2.47023374 | -1.36733686 | -0.99823669 | h | 1.000 | 0 |
| -2.48362422 | 1.67295676 | 0.03460599 | h | 1.000 | 0 |
| -2.28933946 | -1.63998083 | -1.01875121 | h | 1.000 | 0 |

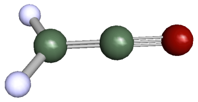
Oxirane Product:



Total Energy = -193.70192526485 hartree
Enthalpy Correction = 0.098901 hartree
Entropy = 0.000109 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.56972748 | -0.99366558 | 0.22354727 | o | 8.000 | 0 |
| 2.41784742 | 0.37652441 | 0.00043319 | c | 6.000 | 0 |
| -0.03794741 | -1.15263602 | 0.15621680 | c | 6.000 | 0 |
| -2.39381010 | 0.46714215 | -0.11443190 | c | 6.000 | 0 |
| 2.28711774 | 1.45578408 | -1.82300155 | h | 1.000 | 0 |
| 2.22397497 | 1.89459992 | 1.47257470 | h | 1.000 | 0 |
| -0.06242003 | -2.15935949 | 1.96926131 | h | 1.000 | 0 |
| 0.00791210 | -2.60651802 | -1.32291447 | h | 1.000 | 0 |
| -2.47703558 | 1.90684739 | 1.36972309 | h | 1.000 | 0 |
| -4.13044985 | -0.64552320 | 0.00001258 | h | 1.000 | 0 |
| -2.40491674 | 1.45680436 | -1.93142103 | h | 1.000 | 0 |

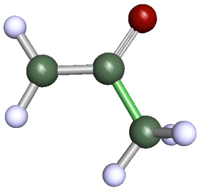
Ethenone (MAA* = 217.2 kJ/mol, E* = -14.1):



Total Energy = -152.49476330144 hartree
Enthalpy Correction = 0.036143 hartree
Entropy = 0.000092 hartree/K

```
                  atomic coordinates             atom    charge  isotop
  0.00000000    0.00000000    3.63114891      o      8.000     0
  0.00000000    0.00000000    1.43942377      c      6.000     0
  0.00000000    0.00000000   -1.02545565      c      6.000     0
 -1.78443034    0.00000000   -2.02258606      h      1.000     0
  1.78443034    0.00000000   -2.02258606      h      1.000     0
```

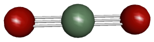
Ethenone Product:



Total Energy = -192.51167061006 hartree
Enthalpy Correction = 0.076895 hartree
Entropy = 0.000107 hartree/K

```
                  atomic coordinates             atom    charge  isotop
 -0.00528112    3.47693610    0.00000000      o      8.000     0
  0.33864597    1.07782832    0.00000000      c      6.000     0
 -2.04583591   -0.51947728    0.00000000      c      6.000     0
  2.62836082   -0.13490990    0.00000000      c      6.000     0
 -3.18911930   -0.05707703   -1.66129845      h      1.000     0
 -3.18911930   -0.05707703    1.66129845      h      1.000     0
 -1.66472700   -2.54756175    0.00000000      h      1.000     0
  4.37818657    0.94108015    0.00000000      h      1.000     0
  2.74888927   -2.17974158    0.00000000      h      1.000     0
```

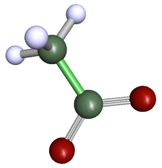
Carbon dioxide (MAA* = 208.8 kJ/mol, E* = -15.1):



Total Energy = -188.47073285971 hartree
Enthalpy Correction = 0.015427 hartree
Entropy = 0.000081 hartree/K

```
                  atomic coordinates             atom    charge  isotop
  0.00000000    0.00000000   -2.18520321      o      8.000     0
  0.00000000    0.00000000    0.00000000      c      6.000     0
  0.00000000    0.00000000    2.18520321      o      8.000     0
```

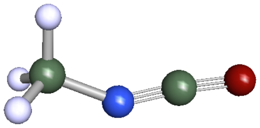
Carbon dioxide Product:



Total Energy = -228.47925678814 hartree
Enthalpy Correction = 0.054297 hartree
Entropy = 0.000107 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.74159096 | -2.08131959 | -0.09949829 | o | 8.000 | 0 |
| 1.64397437 | 0.01717983 | 0.01594357 | c | 6.000 | 0 |
| -1.23617942 | -0.00159141 | -0.05889393 | c | 6.000 | 0 |
| 2.71477687 | 2.11992191 | 0.24260602 | o | 8.000 | 0 |
| -1.93920558 | -1.54812347 | -1.22674654 | h | 1.000 | 0 |
| -1.98503191 | 1.79463775 | -0.73656608 | h | 1.000 | 0 |
| -1.93992529 | -0.30070502 | 1.86315526 | h | 1.000 | 0 |

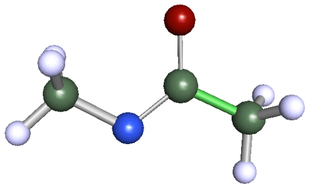
Isocyanatomethane (MAA* = 189.3 kJ/mol, E* = -17.2):



Total Energy = -207.84642111208 hartree
Enthalpy Correction = 0.05662 hartree
Entropy = 0.000108 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.15723405 | 0.32811103 | 0.21458391 | o | 8.000 | 0 |
| 2.98230115 | -0.01374903 | -0.10518279 | c | 6.000 | 0 |
| 0.85361661 | -0.50553281 | -0.59484374 | n | 7.000 | 0 |
| -1.73932647 | -0.03468046 | 0.01318225 | c | 6.000 | 0 |
| -1.89840012 | 1.31392333 | 1.56256729 | h | 1.000 | 0 |
| -2.70705682 | 0.71456497 | -1.64407994 | h | 1.000 | 0 |
| -2.64836840 | -1.80263703 | 0.55377303 | h | 1.000 | 0 |

Isocyanatomethane Product:

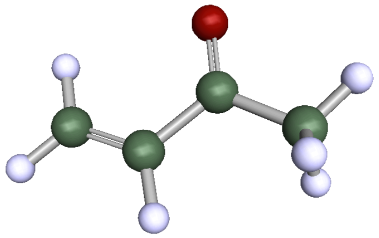


Total Energy = -207.84642111208 hartree
Enthalpy Correction = 0.095575 hartree

Entropy = 0.000118 hartree/K

```
                  atomic coordinates            atom    charge  isotop
   0.68456045   -1.18145774    1.88321882     o      8.000     0
   0.81634491   -0.18508556   -0.29619951     c      6.000     0
   3.43854530    0.31574495   -1.33357255     c      6.000     0
  -1.07975906    0.45890807   -1.74921476     n      7.000     0
  -3.53038518   -0.06357581   -0.65855519     c      6.000     0
   4.47033620    1.56307147   -0.04682007     h      1.000     0
   3.38153325    1.17450876   -3.20567627     h      1.000     0
   4.49880983   -1.45672823   -1.43229019     h      1.000     0
  -5.01908743    0.52351748   -1.96867413     h      1.000     0
  -3.84396157    0.93229609    1.14047051     h      1.000     0
  -3.81693669   -2.08119947   -0.24179850     h      1.000     0
```

But-3-en-2-one (MAA* = 186.0 kJ/mol, E* = -17.5):

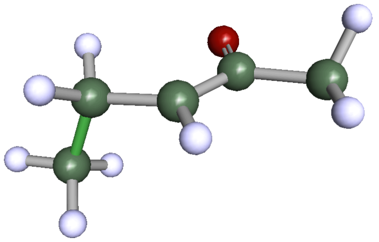


Total Energy = -231.06503253699 hartree
Enthalpy Correction = 0.096493 hartree
Entropy = 0.000118 hartree/K

```
                  atomic coordinates            atom    charge  isotop
  -3.57283416    2.92361005    0.05017362     c      6.000     0
  -1.82979296    1.11660441   -0.00042512     c      6.000     0
   0.90935638    1.69778598    0.17033982     c      6.000     0
   2.65330057   -0.52411647    0.08501596     c      6.000     0
   1.68571728    3.85485502    0.36749703     o      8.000     0
  -5.57051448    2.49156314   -0.07531604     h      1.000     0
  -3.02561066    4.89285863    0.21985044     h      1.000     0
  -2.35732972   -0.85806276   -0.17017193     h      1.000     0
   2.35299855   -1.57080128   -1.67284419     h      1.000     0
   4.61553831    0.07605294    0.22448513     h      1.000     0
   2.19441170   -1.82226726    1.62739109     h      1.000     0
```

But-3-en-2-one product:

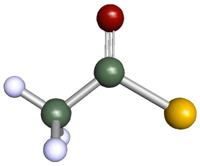
The $CH_3$-$CH_2$-CH-C Torsion Angle was constrained to 90°.



Total Energy = -271.06953423463 hartree
Enthalpy Correction = 0.136439 hartree
Entropy = 0.000132 hartree/K

```
                   atomic coordinates                 atom    charge  isotop
         4.15666455   -0.20465259   -0.02554535     o       8.000      0
         2.62489817    1.52104382    0.75003786     c       6.000      0
         3.85239744    3.87849844    1.82477669     c       6.000      0
         0.04217583    1.39681516    0.66471747     c       6.000      0
        -1.34227404   -0.88519614   -0.27021074     c       6.000      0
        -1.95351270   -2.81830695    1.78888522     c       6.000      0
         5.03852542    3.37339909    3.44530968     h       1.000      0
         5.10799199    4.72456241    0.41237902     h       1.000      0
         2.48154046    5.29956981    2.42846153     h       1.000      0
        -1.04679217    2.96320405    1.42718487     h       1.000      0
        -0.17649670   -1.81872708   -1.70699520     h       1.000      0
        -3.10899602   -0.33644866   -1.20877057     h       1.000      0
        -2.95262914   -4.46949096    1.03742352     h       1.000      0
        -0.21163661   -3.47315369    2.68678951     h       1.000      0
        -3.13801902   -1.97669247    3.26077686     h       1.000      0
```

Acetyl chloride (MAA* = 164.0 kJ/mol, E* = -19.9):

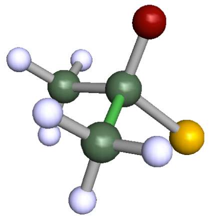


Total Energy = -613.21214664023 hartree
Enthalpy Correction = 0.053002 hartree
Entropy = 0.00011 hartree/K

```
                   atomic coordinates                 atom    charge  isotop
         0.89094006    0.25163184   -1.26928154     c       6.000      0
         2.14395316    2.02268132   -1.80457325     o       8.000      0
        -0.73241274   -0.13382251    0.97845929     c       6.000      0
         0.83480396   -2.42845081   -3.37135501     cl     17.000      0
        -2.67598459   -0.44976965    0.36262963     h       1.000      0
        -0.11643324   -1.82727114    1.98219955     h       1.000      0
        -0.61891323    1.51717884    2.19960221     h       1.000      0
```

Acetyl chloride Product:

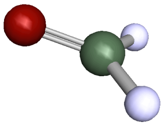
The C-Cl bond length was fixed at 1.8 Angstroms.



Total Energy = -653.20727912463 hartree
Enthalpy Correction = 0.09195 hartree
Entropy = 0.000124 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.26294821 | 4.99099997 | 3.55041188 | c | 6.000 | 0 |
| -0.74371639 | 2.81247575 | 2.50676866 | o | 8.000 | 0 |
| 0.54855064 | 5.69944502 | 5.70931614 | c | 6.000 | 0 |
| -0.92848121 | 7.52801004 | 1.30943945 | cl | 17.000 | 0 |
| -4.01119105 | 5.20539662 | 4.47054966 | c | 6.000 | 0 |
| 2.49146894 | 5.65087342 | 5.01441625 | h | 1.000 | 0 |
| 0.35111794 | 4.28252593 | 7.20225647 | h | 1.000 | 0 |
| 0.16637824 | 7.56450914 | 6.51081183 | h | 1.000 | 0 |
| -4.46317913 | 7.06373472 | 5.25095263 | h | 1.000 | 0 |
| -5.29018511 | 4.80578284 | 2.90068837 | h | 1.000 | 0 |
| -4.30856141 | 3.77839150 | 5.93675996 | h | 1.000 | 0 |

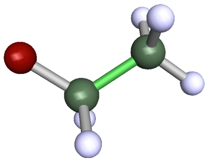
Formaldehyde (MAA* = 161.0 kJ/mol, E* = -20.2):



Total Energy = -114.42708201049 hartree
Enthalpy Correction = 0.030769 hartree
Entropy = 0.000083 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -0.02024812 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 2.25403608 | o | 8.000 | 0 |
| -1.77497720 | 0.00000000 | -1.11681804 | h | 1.000 | 0 |
| 1.77497720 | 0.00000000 | -1.11681804 | h | 1.000 | 0 |

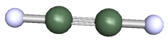
Formaldehyde Product:



Total Energy = -154.42122680407 hartree
Enthalpy Correction = 0.070787 hartree
Entropy = 0.0001 hartree/K

```
                   atomic coordinates            atom    charge  isotop
          2.58198367   -2.24125332    0.00000000    o       8.000     0
          1.44563811    0.05601624    0.00000000    c       6.000     0
         -1.44652355   -0.04856548    0.00000000    c       6.000     0
          1.98040326    1.25893148   -1.66156856    h       1.000     0
          1.98040326    1.25893148    1.66156856    h       1.000     0
         -2.29212733    1.84484025    0.00000000    h       1.000     0
         -2.12530962   -1.06226589   -1.67254776    h       1.000     0
         -2.12530962   -1.06226589    1.67254776    h       1.000     0
```

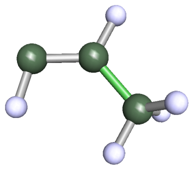
Ethyne (MAA* = 126.7 kJ/mol, E* = -23.9):



Total Energy = -77.26361121560 hartree
Enthalpy Correction = 0.031074 hartree
Entropy = 0.000076 hartree/K

```
                   atomic coordinates            atom    charge  isotop
          0.00000000    0.00000000   -1.13329062    c       6.000     0
          0.00000000    0.00000000    1.13329062    c       6.000     0
          0.00000000    0.00000000   -3.15150770    h       1.000     0
          0.00000000    0.00000000    3.15150770    h       1.000     0
```

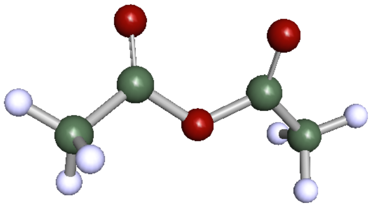
Ethyne Product:



Total Energy = -117.24249324763 hartree
Enthalpy Correction = 0.070652 hartree
Entropy = 0.000099 hartree/K

```
                   atomic coordinates            atom    charge  isotop
         -3.28533569    0.33925038   -0.57876925    c       6.000     0
         -0.86353185    1.11320958   -0.65113406    c       6.000     0
          1.49699419   -0.40974090   -0.16234516    c       6.000     0
         -3.30707387   -1.70782699   -0.08083085    h       1.000     0
         -0.43584423    3.09533531   -1.11287635    h       1.000     0
          1.02380845   -2.37391838    0.28049600    h       1.000     0
          2.59930236    0.35496994    1.42023490    h       1.000     0
          2.77168064   -0.41127893   -1.79901909    h       1.000     0
```

Acetic anhydride (MAA* =  124.2 kJ/mol, E* = -24.2):

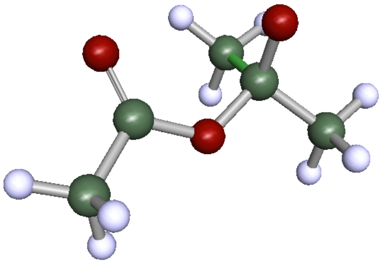


Total Energy = -381.48286805730 hartree
Enthalpy Correction = 0.105479 hartree
Entropy = 0.000134 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.34660390 | -1.05685680 | -0.11965604 | c | 6.000 | 0 |
| -2.30202808 | 0.78799088 | 0.42834503 | c | 6.000 | 0 |
| 0.01023941 | -0.20016488 | -0.23844134 | o | 8.000 | 0 |
| 2.22993549 | 0.62659573 | 0.83749589 | c | 6.000 | 0 |
| 4.39548343 | 0.10436237 | -0.87168589 | c | 6.000 | 0 |
| 2.31658649 | 1.54366731 | 2.89942148 | o | 8.000 | 0 |
| -2.54240688 | 2.87792749 | 1.24936249 | o | 8.000 | 0 |
| -4.13872590 | -2.67632096 | 1.14528631 | h | 1.000 | 0 |
| -4.16520470 | -1.75571079 | -2.05110789 | h | 1.000 | 0 |
| -6.18087351 | -0.17573714 | 0.15991395 | h | 1.000 | 0 |
| 6.16099727 | 0.56489122 | 0.07139116 | h | 1.000 | 0 |
| 4.18707101 | 1.23790155 | -2.58495777 | h | 1.000 | 0 |
| 4.37552988 | -1.87854599 | -1.43852502 | h | 1.000 | 0 |

Acetic anhydride Product:

The O-C(O)(CH$_3$)(CH$_3$) bond length was fixed at 1.395 Angstroms.

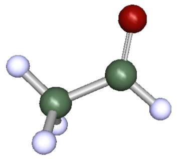


Total Energy = -421.46316815000 hartree
Enthalpy Correction = 0.144449 hartree
Entropy = 0.000147 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.06559404 | 0.90145643 | 4.11391715 | c | 6.000 | 0 |
| 1.61089019 | -0.43287688 | 3.61855442 | c | 6.000 | 0 |
| 0.23258917 | 0.82111353 | 1.95642597 | o | 8.000 | 0 |
| -2.26734266 | 0.22002481 | 1.37469273 | c | 6.000 | 0 |
| -2.30842178 | -2.37518045 | 0.03530366 | c | 6.000 | 0 |
| -2.93726651 | 2.26129988 | -0.59744601 | c | 6.000 | 0 |

```
 -3.76507589    0.32063283    3.38147422    o      8.000     0
  1.02069922   -2.39364559    4.64625831    o      8.000     0
  4.95831253    1.45981402    2.34183984    h      1.000     0
  3.68793647    2.62511961    5.18809258    h      1.000     0
  5.32532203   -0.31053472    5.19605730    h      1.000     0
 -1.88630432   -3.86378812    1.39242804    h      1.000     0
 -0.95727369   -2.48005855   -1.52942508    h      1.000     0
 -4.20301800   -2.68305203   -0.72362037    h      1.000     0
 -4.86551784    1.94229680   -1.25690705    h      1.000     0
 -1.66582721    2.25781189   -2.23025695    h      1.000     0
 -2.84878376    4.11387088    0.31337056    h      1.000     0
```

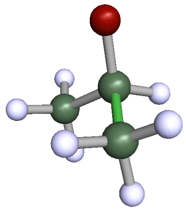
Acetaldehyde (MAA* = 123.0 kJ/mol, E* = -24.3):



Total Energy = -153.72471860799 hartree
Enthalpy Correction = 0.060556 hartree
Entropy = 0.000099 hartree/K

```
                 atomic coordinates              atom    charge  isotop
 -4.20573147   -3.95179949    0.30056586    c      6.000     0
 -2.20116989   -2.00604225    0.05131543    c      6.000     0
 -4.74622923   -4.10437266    2.29155493    h      1.000     0
 -5.84563190   -3.50785096   -0.86152308    h      1.000     0
 -3.41845343   -5.79016688   -0.22967687    h      1.000     0
 -2.33719607   -0.15494918   -1.28212453    o      8.000     0
 -0.48165598   -2.33682973    1.19733175    h      1.000     0
```

Acetaldehyde Product:

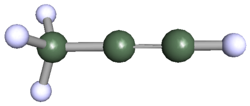


Total Energy = -193.70570377649 hartree
Enthalpy Correction = 0.100092 hartree
Entropy = 0.00011 hartree/K

```
                 atomic coordinates              atom    charge  isotop
  0.42924075    0.19974008   -2.36126063    c      6.000     0
 -1.11764951   -0.45152753    0.00000000    c      6.000     0
  0.95502691    2.20264144   -2.45410270    h      1.000     0
  2.16397668   -0.93344731   -2.39276601    h      1.000     0
 -0.66318603   -0.26198406   -4.05572571    h      1.000     0
 -2.73603010    0.92478077    0.00000000    h      1.000     0
```

```
 -1.91684529   -2.88768712    0.00000000    o      8.000     0
  0.42924075    0.19974008    2.36126063    c      6.000     0
 -0.66318603   -0.26198406    4.05572571    h      1.000     0
  2.16397668   -0.93344731    2.39276601    h      1.000     0
  0.95502691    2.20264144    2.45410270    h      1.000     0
```

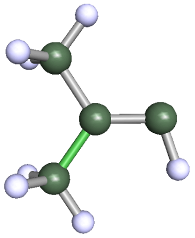
Propyne (MAA* = 105.6 kJ/mol, E* = -26.2):



Total Energy = -116.55607312831 hartree
Enthalpy Correction = 0.060787 hartree
Entropy = 0.000094 hartree/K

```
                 atomic coordinates               atom    charge  isotop
  3.21368729   -0.09671082   -0.00986831    c      6.000     0
  0.94177163   -0.02857947   -0.00313052    c      6.000     0
 -1.79834390    0.05417422    0.00540398    c      6.000     0
  5.22916939   -0.15727988   -0.01594941    h      1.000     0
 -2.53000106   -0.17035652    1.92240492    h      1.000     0
 -2.57886778   -1.45797875   -1.16280060    h      1.000     0
 -2.47741557    1.85673123   -0.73606004    h      1.000     0
```

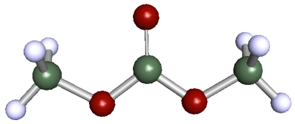
Propyne Product:



Total Energy = -156.52580356996 hartree
Enthalpy Correction = 0.09806 hartree
Entropy = 0.000113 hartree/K

```
                 atomic coordinates               atom    charge  isotop
  2.93839854   -1.65164239   -0.61246308    c      6.000     0
  0.80618453   -0.36046447   -0.08685165    c      6.000     0
  0.74607486    1.78623954    1.78981744    c      6.000     0
 -1.76085352   -0.84407434   -1.25047405    c      6.000     0
  2.48406904   -3.12429340   -2.04184455    h      1.000     0
 -0.58600397    1.41285623    3.33815939    h      1.000     0
  2.61766682    2.09929245    2.60069444    h      1.000     0
  0.10771300    3.55513447    0.90978453    h      1.000     0
 -3.18051061   -1.30658674    0.19174073    h      1.000     0
 -2.48442677    0.83487340   -2.23441727    h      1.000     0
 -1.68831191   -2.40133476   -2.60414591    h      1.000     0
```

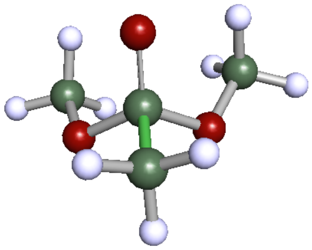
Dimethyl carbonate (MAA* = 94.2 kJ/mol, E* = -27.4):



Total Energy = -343.38866970069 hartree
Enthalpy Correction = 0.103902 hartree
Entropy = 0.000126 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.15973319 | -1.06922408 | 1.32217266 | o | 8.000 | 0 |
| -0.00176990 | -0.00032575 | -0.68510780 | c | 6.000 | 0 |
| -1.91950097 | 0.63399149 | -2.16109401 | o | 8.000 | 0 |
| -4.36836784 | -0.04530687 | -1.23636797 | c | 6.000 | 0 |
| 2.11871339 | 0.73842913 | -1.78838113 | o | 8.000 | 0 |
| 4.38874865 | 0.17759893 | -0.42983124 | c | 6.000 | 0 |
| -4.73686486 | 0.88379070 | 0.56445239 | h | 1.000 | 0 |
| -5.69458260 | 0.60764672 | -2.66185862 | h | 1.000 | 0 |
| -4.50660175 | -2.08787042 | -1.01145447 | h | 1.000 | 0 |
| 5.91741770 | 0.91458574 | -1.58620234 | h | 1.000 | 0 |
| 4.37055072 | 1.10419943 | 1.40911454 | h | 1.000 | 0 |
| 4.59199062 | -1.85751502 | -0.18670885 | h | 1.000 | 0 |

Dimethyl carbonate Product:

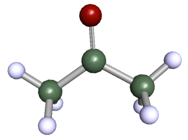


Total Energy = -383.35543256446 hartree
Enthalpy Correction = 0.141056 hartree
Entropy = 0.000139 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.48670569 | -2.67699988 | 3.43712417 | o | 8.000 | 0 |
| 0.07692638 | -1.32913456 | 1.50105295 | c | 6.000 | 0 |
| -1.79426432 | 0.65288468 | 0.92281656 | o | 8.000 | 0 |
| -2.40746626 | 2.18193690 | 2.99647771 | c | 6.000 | 0 |
| 0.32812977 | -2.72273150 | -1.01204778 | c | 6.000 | 0 |
| 2.51171724 | 0.05181478 | 1.73307291 | o | 8.000 | 0 |
| 3.44303241 | 0.37878438 | 4.18922312 | c | 6.000 | 0 |
| -4.19269483 | 3.13773736 | 2.58711959 | h | 1.000 | 0 |
| -2.62908619 | 1.04495156 | 4.71139181 | h | 1.000 | 0 |
| -0.96062310 | 3.62732015 | 3.34720662 | h | 1.000 | 0 |
| 0.87772859 | -1.45396400 | -2.54470243 | h | 1.000 | 0 |
| -1.47653923 | -3.60322099 | -1.48748399 | h | 1.000 | 0 |
| 1.75750741 | -4.19641673 | -0.81506249 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 2.73936670 | 2.11757517 | 5.08022212 | h | 1.000 | 0 |
| 5.50497605 | 0.50001365 | 4.08118018 | h | 1.000 | 0 |
| 2.91148818 | -1.21582837 | 5.39180240 | h | 1.000 | 0 |

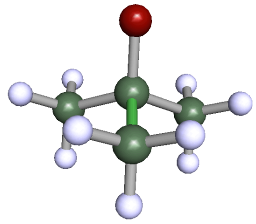
Propan-2-one (MAA* = 93.1 kJ/mol, E* = -27.5):



Total Energy = -193.01821589665 hartree
Enthalpy Correction = 0.090093 hartree
Entropy = 0.00011 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.03652265 | -1.29088722 | 0.28676364 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -1.19866461 | c | 6.000 | 0 |
| -3.52598872 | -1.97000633 | -0.95950653 | h | 1.000 | 0 |
| -1.21673010 | -2.88256279 | 1.32055587 | h | 1.000 | 0 |
| -2.81896777 | -0.00334236 | 1.69950058 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | -3.49553845 | o | 8.000 | 0 |
| 2.03652265 | 1.29088722 | 0.28676364 | c | 6.000 | 0 |
| 1.21673010 | 2.88256279 | 1.32055587 | h | 1.000 | 0 |
| 3.52598872 | 1.97000633 | -0.95950653 | h | 1.000 | 0 |
| 2.81896777 | 0.00334236 | 1.69950058 | h | 1.000 | 0 |

Propan-2-one Product:

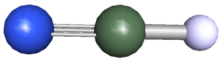


Total Energy = -232.98873477870 hartree
Enthalpy Correction = 0.129033 hartree
Entropy = 0.000116 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.35962832 | -2.35494532 | -0.18869690 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 0.84496615 | c | 6.000 | 0 |
| -1.41053822 | -2.44312386 | -2.25845856 | h | 1.000 | 0 |
| -3.30578668 | -2.37916478 | 0.51431583 | h | 1.000 | 0 |
| -0.40752380 | -4.05247763 | 0.51431583 | h | 1.000 | 0 |
| -1.35962832 | 2.35494532 | -0.18869690 | c | 6.000 | 0 |
| 2.71925663 | 0.00000000 | -0.18869690 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 3.41822316 | o | 8.000 | 0 |
| 2.82107644 | 0.00000000 | -2.25845856 | h | 1.000 | 0 |
| 3.71331047 | -1.67331285 | 0.51431583 | h | 1.000 | 0 |
| 3.71331047 | 1.67331285 | 0.51431583 | h | 1.000 | 0 |
| -3.30578668 | 2.37916478 | 0.51431583 | h | 1.000 | 0 |

```
        -1.41053822    2.44312386   -2.25845856     h       1.000      0
        -0.40752380    4.05247763    0.51431583     h       1.000      0
```

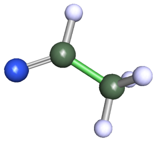
Hydrogen cyanide (MAA* = 81.6 kJ/mol, E* = -28.8):



Total Energy = -93.35645307915 hartree
Enthalpy Correction = 0.020142 hartree
Entropy = 0.000077 hartree/K

```
                   atomic coordinates            atom    charge  isotop
         0.00000000    0.00000000    2.11950366     n       7.000      0
         0.00000000    0.00000000   -0.04533030     c       6.000      0
         0.00000000    0.00000000   -2.07417336     h       1.000      0
```

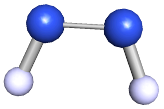
Hydrogen cyanide Product:



Total Energy = -133.31724583132 hartree
Enthalpy Correction = 0.058543 hartree
Entropy = 0.000099 hartree/K

```
                   atomic coordinates            atom    charge  isotop
         3.08188376   -1.60988062   -1.05880220     n       7.000      0
         1.65422725   -0.05525959   -0.01734416     c       6.000      0
        -1.22702850   -0.01138907   -0.02242315     c       6.000      0
         2.36007674    1.62122000    1.13222907     h       1.000      0
        -1.93081827    1.75965575   -0.84028536     h       1.000      0
        -1.96420266   -0.10005798    1.91395473     h       1.000      0
        -1.97413833   -1.60428850   -1.10732892     h       1.000      0
```

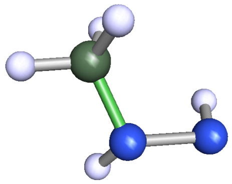
Diazene (MAA* = 78.8 kJ/mol, E* = -29.1):



Total Energy = -110.56395684706 hartree
Enthalpy Correction = 0.032422 hartree
Entropy = 0.000083 hartree/K

```
                   atomic coordinates            atom    charge  isotop
        -1.16242628    0.00000000   -0.90238875     n       7.000      0
         1.16242628    0.00000000   -0.90238875     n       7.000      0
        -1.90871059    0.00000000    0.90219218     h       1.000      0
         1.90871059    0.00000000    0.90219218     h       1.000      0
```

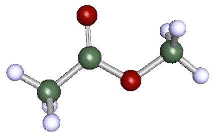
Diazene Product:



Total Energy = -150.52622771243 hartree
Enthalpy Correction = 0.071877 hartree
Entropy = 0.0001 hartree/K

```
                  atomic coordinates              atom    charge  isotop
     2.84884268   -0.18835273    1.28007345     n       7.000     0
     0.62692972   -1.42764364    0.32838621     n       7.000     0
    -1.47603300    0.28175458   -0.00952958     c       6.000     0
     3.16940668    1.29608961    0.05447287     h       1.000     0
     0.97720710   -2.21769924   -1.39431256     h       1.000     0
    -3.08664114   -0.69440337   -0.88110453     h       1.000     0
    -0.99243968    1.92691056   -1.20798524     h       1.000     0
    -2.06727235    1.02334423    1.82999938     h       1.000     0
```

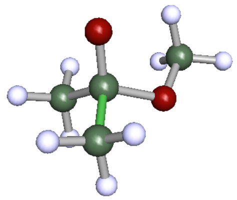
Methyl acetate (MAA* = 78.4 kJ/mol, E* = -29.1):



Total Energy = -268.20911119395 hartree
Enthalpy Correction = 0.097135 hartree
Entropy = 0.00012 hartree/K

```
                  atomic coordinates              atom    charge  isotop
    -4.10279627   -3.56603515    0.66292240     c       6.000     0
    -2.53097083   -1.43539387   -0.31142809     c       6.000     0
    -5.94852355   -3.51690584   -0.26124448     h       1.000     0
    -3.22466712   -5.37396294    0.20742782     h       1.000     0
    -4.34936797   -3.38035813    2.69415610     h       1.000     0
    -1.86710661   -1.78651932   -2.71427093     o       8.000     0
    -1.92849825    0.41595109    0.88542896     o       8.000     0
    -0.39693518    0.17847138   -3.84569833     c       6.000     0
    -0.04373246   -0.43068629   -5.77539956     h       1.000     0
    -1.44094491    1.95446521   -3.83424082     h       1.000     0
     1.38144128    0.41893672   -2.83364805     h       1.000     0
```

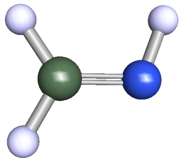
Methyl acetate Product:



Total Energy = -308.17162486468 hartree
Enthalpy Correction = 0.134875 hartree
Entropy = 0.00013 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.89497668 | -3.96735962 | 0.06416515 | c | 6.000 | 0 |
| -2.13513840 | -1.68190012 | 0.42488148 | c | 6.000 | 0 |
| -2.90598352 | -5.77272547 | 0.25889631 | h | 1.000 | 0 |
| -5.40473361 | -3.88856553 | 1.47331987 | h | 1.000 | 0 |
| -4.77234360 | -3.88534295 | -1.80337458 | h | 1.000 | 0 |
| -0.79084925 | -1.87200612 | 2.98203990 | c | 6.000 | 0 |
| -3.27910249 | 0.49596473 | 0.05501275 | o | 8.000 | 0 |
| 0.04386349 | -2.08051917 | -1.36818319 | o | 8.000 | 0 |
| -0.58603362 | -1.65545412 | -3.89659592 | c | 6.000 | 0 |
| 1.16287627 | -1.38501105 | -4.96593093 | h | 1.000 | 0 |
| -1.61134989 | -3.25261011 | -4.74731616 | h | 1.000 | 0 |
| -1.75973399 | 0.04106884 | -4.08407413 | h | 1.000 | 0 |
| 0.28026596 | -3.62807247 | 3.18998453 | h | 1.000 | 0 |
| -2.19049165 | -1.76997091 | 4.49818430 | h | 1.000 | 0 |
| 0.50188477 | -0.27275032 | 3.17582930 | h | 1.000 | 0 |

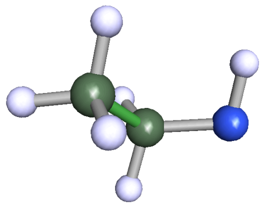
Methanimine (MAA* = 74.6 kJ/mol, E* = -29.5):



Total Energy = -94.56000533535 hartree
Enthalpy Correction = 0.04418 hartree
Entropy = 0.000087 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.53540932 | -0.86921504 | 0.00000000 | n | 7.000 | 0 |
| -0.73270488 | -0.11993917 | 0.00000000 | c | 6.000 | 0 |
| 2.74580417 | 0.63267540 | 0.00000000 | h | 1.000 | 0 |
| -1.29445893 | 1.86869696 | 0.00000000 | h | 1.000 | 0 |
| -2.25404969 | -1.51221815 | 0.00000000 | h | 1.000 | 0 |

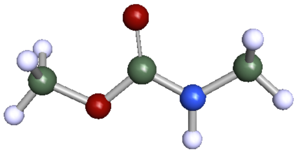
Methanimine Product:



Total Energy = -134.52073162067 hartree
Enthalpy Correction = 0.082786 hartree
Entropy = 0.000101 hartree/K

```
               atomic coordinates              atom    charge  isotop
  2.93658321    0.80226763    0.83160991       n      7.000     0
  0.93500989   -0.88145024    0.10182563       c      6.000     0
 -1.70867640    0.28934534   -0.02232579       c      6.000     0
  2.89774246    2.25050391   -0.44729810       h      1.000     0
  0.84854745   -2.45684220    1.46611501       h      1.000     0
  1.21342370   -1.84640688   -1.76074261       h      1.000     0
 -3.17044039   -1.08720935   -0.54896620       h      1.000     0
 -1.74079977    1.81184383   -1.42676856       h      1.000     0
 -2.21139016    1.11794796    1.80655073       h      1.000     0
```

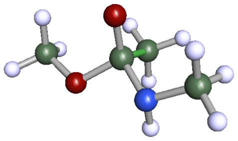
Methyl methylcarbamate (MAA* = 37.8 kJ/mol, E* = -33.5):



Total Energy = -323.53884685014 hartree
Enthalpy Correction = 0.116397 hartree
Entropy = 0.000131 hartree/K

```
               atomic coordinates              atom    charge  isotop
 -2.13490546   -2.29150169   -1.96301172       o      8.000     0
 -0.78739989   -0.98400510   -0.62703378       c      6.000     0
 -1.50301345   -0.07859976    1.63734364       o      8.000     0
 -3.99453001   -0.74338267    2.41579437       c      6.000     0
  1.56314877   -0.25484615   -1.21183818       n      7.000     0
  2.77510430   -1.04809131   -3.51914957       c      6.000     0
 -4.25437313    0.13685654    4.25476016       h      1.000     0
 -5.39266809   -0.02398661    1.08361145       h      1.000     0
 -4.18829998   -2.78879146    2.57685595       h      1.000     0
  2.53550109    0.76340781    0.06397845       h      1.000     0
  1.58547593   -0.62348059   -5.14946995       h      1.000     0
  4.54639637   -0.02063416   -3.70896212       h      1.000     0
  3.18009199   -3.07431701   -3.51512360       h      1.000     0
```

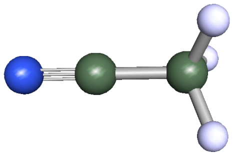
Methyl methylcarbamate Product:



Total Energy = -363.48644164270 hartree
Enthalpy Correction = 0.154098 hartree
Entropy = 0.000139 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.14512821 | 1.46415660 | 3.31235149 | o | 8.000 | 0 |
| -0.14769064 | 0.79341058 | 1.17133775 | c | 6.000 | 0 |
| -1.28592398 | -1.55624522 | 0.08651957 | o | 8.000 | 0 |
| -3.91184683 | -1.42314838 | -0.17154781 | c | 6.000 | 0 |
| -0.37590074 | 2.82456491 | -0.90793604 | c | 6.000 | 0 |
| 2.50405647 | -0.07584851 | 1.41284107 | n | 7.000 | 0 |
| 4.14007049 | 1.76412362 | 2.60831350 | c | 6.000 | 0 |
| -4.50195733 | -0.31225267 | -1.82662053 | h | 1.000 | 0 |
| -4.63592414 | -3.34444488 | -0.40744719 | h | 1.000 | 0 |
| -4.77619582 | -0.58648700 | 1.51490693 | h | 1.000 | 0 |
| 0.34136292 | 2.16514823 | -2.73234443 | h | 1.000 | 0 |
| -2.34854388 | 3.38627563 | -1.13555529 | h | 1.000 | 0 |
| 0.68791763 | 4.50364197 | -0.34780885 | h | 1.000 | 0 |
| 3.17227118 | -0.47069978 | -0.34032948 | h | 1.000 | 0 |
| 3.39200090 | 2.20166622 | 4.47884177 | h | 1.000 | 0 |
| 6.03355395 | 0.96977535 | 2.83676219 | h | 1.000 | 0 |
| 4.33177914 | 3.56022920 | 1.57288271 | h | 1.000 | 0 |

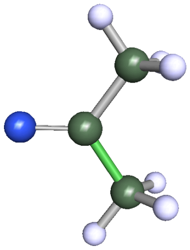
Acetonitrile (MAA* = 37.3 kJ/mol, E* = -33.6):



Total Energy = -132.65590935544 hartree
Enthalpy Correction 0.049993 hartree
Entropy = 0.000092 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -0.92556463 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.80542455 | c | 6.000 | 0 |
| -0.97039584 | 1.68077490 | -1.61984751 | h | 1.000 | 0 |
| -0.97039584 | -1.68077490 | -1.61984751 | h | 1.000 | 0 |
| 1.94079169 | 0.00000000 | -1.61984751 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 3.97941974 | n | 7.000 | 0 |

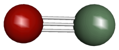
Acetonitrile Product:



Total Energy = -172.60099299059 hartree
Enthalpy Correction 0.08598 hartree
Entropy = 0.000102 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.06022756 | 3.39424988 | -1.48825628 | n | 7.000 | 0 |
| -0.02188199 | 1.22896918 | -0.53963578 | c | 6.000 | 0 |
| -2.38038574 | -0.29002665 | 0.20975423 | c | 6.000 | 0 |
| 2.39046967 | -0.28006321 | 0.03952227 | c | 6.000 | 0 |
| -2.47632435 | -2.09349552 | -0.80946539 | h | 1.000 | 0 |
| -4.07450329 | 0.80903213 | -0.21193946 | h | 1.000 | 0 |
| -2.36948189 | -0.76122514 | 2.22944464 | h | 1.000 | 0 |
| 2.52913466 | -0.74260685 | 2.05658016 | h | 1.000 | 0 |
| 4.04542072 | 0.82255484 | -0.50915642 | h | 1.000 | 0 |
| 2.41777978 | -2.08738866 | -0.97684797 | h | 1.000 | 0 |

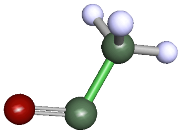
Carbon monoxide (MAA* = 32.8 kJ/mol, E* = -34.1):



Total Energy = -113.23230291133 hartree
Enthalpy Correction = 0.008413 hartree
Entropy = 0.000075 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | 1.06104216 | o | 8.000 | 0 |
| 0.00000000 | 0.00000000 | -1.06104216 | c | 6.000 | 0 |

Carbon monoxide Product:

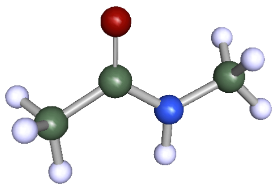


Total Energy = -153.17379906714 hartree
Enthalpy Correction = 0.045494 hartree
Entropy = 0.000095 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.50070988 | 0.51124731 | 0.00000000 | o | 8.000 | 0 |
| 1.85531663 | -1.17637135 | 0.00000000 | c | 6.000 | 0 |
| -0.84917387 | -0.06860244 | 0.00000000 | c | 6.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -1.09933620 | 1.13270241 | -1.67489969 | h | 1.000 | 0 |
| -1.09933620 | 1.13270241 | 1.67489969 | h | 1.000 | 0 |
| -2.30818024 | -1.53167833 | 0.00000000 | h | 1.000 | 0 |

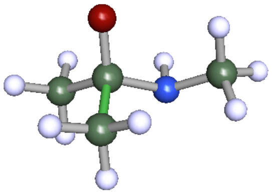
*N*-Methylacetamide (MAA* = 28.5 kJ/mol, E* = -34.5):



Total Energy = -248.35856689882 hartree
Enthalpy Correction = 0.110109 hartree
Entropy = 0.000121 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.21263602 | -4.22603218 | 0.03275306 | c | 6.000 | 0 |
| -1.95380333 | -2.59605499 | 0.58016056 | c | 6.000 | 0 |
| -4.48817923 | -5.52704205 | 1.60975775 | h | 1.000 | 0 |
| -4.02856621 | -5.30509788 | -1.71144662 | h | 1.000 | 0 |
| -5.88459058 | -3.02364023 | -0.08548912 | h | 1.000 | 0 |
| -1.85231177 | -1.24499748 | 2.47283165 | o | 8.000 | 0 |
| -0.06251675 | -2.69375485 | -1.09471638 | n | 7.000 | 0 |
| 2.21682704 | -1.22695211 | -0.80252507 | c | 6.000 | 0 |
| -0.24066778 | -3.81834206 | -2.61534987 | h | 1.000 | 0 |
| 1.80631642 | 0.79651206 | -0.82038534 | h | 1.000 | 0 |
| 3.15960122 | -1.67722793 | 0.97768738 | h | 1.000 | 0 |
| 3.48493872 | -1.66512298 | -2.36046321 | h | 1.000 | 0 |

*N*-Methylacetamide Product:

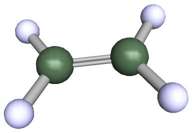


Total Energy = -288.30291234240 hartree
Enthalpy Correction = 0.148087 hartree
Entropy = 0.000129 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.93011255 | -4.15287734 | 0.19753738 | c | 6.000 | 0 |
| -2.63565995 | -2.37608679 | 0.35591366 | c | 6.000 | 0 |
| -5.54958468 | -4.28647101 | -1.77318198 | h | 1.000 | 0 |
| -6.48647302 | -3.35886059 | 1.29994449 | h | 1.000 | 0 |
| -4.52537675 | -6.05946255 | 0.89209281 | h | 1.000 | 0 |
| -1.72187103 | -2.30437178 | 3.11706146 | c | 6.000 | 0 |
| -3.19031766 | -0.05112477 | -0.50864300 | o | 8.000 | 0 |
| -0.61621181 | -3.70317111 | -1.14796443 | n | 7.000 | 0 |
| -0.08220291 | -1.06007370 | 3.28679896 | h | 1.000 | 0 |
| -1.21451256 | -4.17194661 | 3.84867988 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -3.22754062 | -1.52053853 | 4.29519634 | h | 1.000 | 0 |
| -1.38036159 | -3.90334770 | -2.89873117 | h | 1.000 | 0 |
| 1.65913276 | -2.19982515 | -1.44509979 | c | 6.000 | 0 |
| 2.83472005 | -3.00056096 | -2.94364559 | h | 1.000 | 0 |
| 1.24367000 | -0.21869520 | -1.91106972 | h | 1.000 | 0 |
| 2.78044248 | -2.22331965 | 0.29135537 | h | 1.000 | 0 |

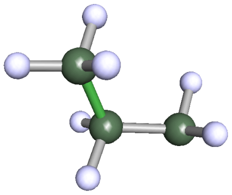
Ethene (MAA* = 28.3 kJ/mol, E* = -34.5):



Total Energy = -78.51691383717 hartree
Enthalpy Correction = 0.055139 hartree
Entropy = 0.000083 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.25196806 | 0.00000000 | 0.00000000 | c | 6.000 | 0 |
| 1.25196806 | 0.00000000 | 0.00000000 | c | 6.000 | 0 |
| -2.32724003 | -1.74679821 | 0.00000000 | h | 1.000 | 0 |
| -2.32724003 | 1.74679821 | 0.00000000 | h | 1.000 | 0 |
| 2.32724003 | -1.74679821 | 0.00000000 | h | 1.000 | 0 |
| 2.32724003 | 1.74679821 | 0.00000000 | h | 1.000 | 0 |

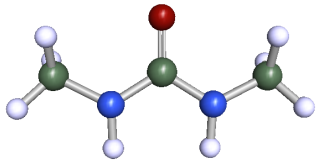
Ethene Product:



Total Energy = -118.45803494576 hartree
Enthalpy Correction = 0.093568 hartree
Entropy = 0.000103 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.76984228 | 0.02803723 | -0.92665290 | c | 6.000 | 0 |
| 0.27238372 | 1.23749716 | -0.15217370 | c | 6.000 | 0 |
| -1.84330900 | -0.57013822 | 0.64226459 | c | 6.000 | 0 |
| 2.37716619 | -1.33182383 | -2.46778293 | h | 1.000 | 0 |
| 3.42673028 | -1.16779611 | 0.66024928 | h | 1.000 | 0 |
| 0.58320875 | 2.57000914 | 1.41449353 | h | 1.000 | 0 |
| -0.45773451 | 2.41749863 | -1.70246998 | h | 1.000 | 0 |
| -3.59422860 | 0.40958822 | 1.17766326 | h | 1.000 | 0 |
| -2.29268904 | -1.87379155 | -0.90129960 | h | 1.000 | 0 |
| -1.24137008 | -1.71908067 | 2.25570848 | h | 1.000 | 0 |

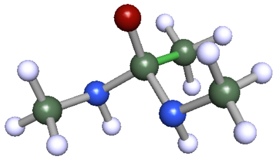
1,3-Dimethylurea (MAA* = -0.3 kJ/mol, E* = -37.6):



Total Energy = -303.68275738044 hartree
Enthalpy Correction = 0.129249 hartree
Entropy = 0.000133 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.86658209 | -2.19325184 | 0.23448710 | n | 7.000 | 0 |
| -0.07853112 | 0.14671937 | -0.46094905 | c | 6.000 | 0 |
| -0.73832199 | -4.28919550 | -1.50028387 | c | 6.000 | 0 |
| -1.03714488 | -2.58381144 | 2.08693865 | h | 1.000 | 0 |
| -0.06440073 | 1.91553837 | 1.39732539 | n | 7.000 | 0 |
| 0.50801274 | 0.65302900 | -2.66021955 | o | 8.000 | 0 |
| -0.27144034 | 1.34258359 | 3.19791581 | h | 1.000 | 0 |
| 0.98802255 | 4.39110059 | 0.96964328 | c | 6.000 | 0 |
| 0.48168035 | 5.60296381 | 2.55468945 | h | 1.000 | 0 |
| 3.05041477 | 4.35754423 | 0.79494014 | h | 1.000 | 0 |
| 0.20768012 | 5.20493110 | -0.75438239 | h | 1.000 | 0 |
| 1.20794972 | -4.86508072 | -1.90500987 | h | 1.000 | 0 |
| -1.64844461 | -3.79685152 | -3.28234643 | h | 1.000 | 0 |
| -1.73889552 | -5.88621611 | -0.67274909 | h | 1.000 | 0 |

1,3-Dimethylurea Product:

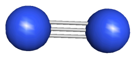


Total Energy = -343.61628626878 hartree
Enthalpy Correction = 0.166783 hartree
Entropy = 0.000139 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.43326998 | -3.65150211 | 0.22205269 | c | 6.000 | 0 |
| -1.45548693 | -1.62150020 | -0.08355436 | n | 7.000 | 0 |
| -3.07008581 | -5.65810759 | -1.86299089 | c | 6.000 | 0 |
| -5.72874931 | -2.67255084 | 0.23725337 | o | 8.000 | 0 |
| -2.82516591 | -4.98925039 | 2.63182525 | n | 7.000 | 0 |
| -1.91009151 | 0.06209779 | -2.18958195 | c | 6.000 | 0 |
| 0.24889049 | -2.46857519 | -0.32889303 | h | 1.000 | 0 |
| -1.00454782 | -5.59202111 | 2.55844211 | h | 1.000 | 0 |
| -3.15514604 | -3.42218759 | 4.85147845 | c | 6.000 | 0 |
| -4.51034055 | -7.12200325 | -1.64954256 | h | 1.000 | 0 |
| -1.20476181 | -6.55823936 | -1.79313958 | h | 1.000 | 0 |
| -3.30039297 | -4.78499765 | -3.72027544 | h | 1.000 | 0 |
| -0.48388621 | 1.56016950 | -2.21900282 | h | 1.000 | 0 |
| -3.76231364 | 0.93282962 | -1.94121549 | h | 1.000 | 0 |

```
  -1.89758733   -0.85128223   -4.06276380    h      1.000     0
  -5.10819267   -2.75978791    4.89578332    h      1.000     0
  -1.92727357   -1.74710559    4.89023699    h      1.000     0
  -2.80289423   -4.53597171    6.55697965    h      1.000     0
```

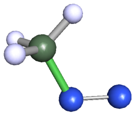
Dinitrogen (MAA* = -140.1 kJ/mol, E* = -52.7):



Total Energy = -109.44739867954 hartree
Enthalpy Correction = 0.008976 hartree
Entropy = 0.000073 hartree/K

```
                  atomic coordinates            atom    charge  isotop
   0.00000000    0.00000000    1.02891949    n      7.000     0
   0.00000000    0.00000000   -1.02891949    n      7.000     0
```

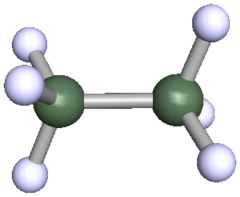
Dinitrogen Product:



Total Energy = -149.32260913327 hartree
Enthalpy Correction = 0.04712 hartree
Entropy = 0.000098 hartree/K

```
                  atomic coordinates            atom    charge  isotop
   3.41449903   -0.16585588    0.98614610    n      7.000     0
   1.89307608    0.69171138   -0.53990772    n      7.000     0
  -0.82525867   -0.01507771   -0.16199293    c      6.000     0
  -1.94480668    1.71157173    0.08033222    h      1.000     0
  -1.51699282   -0.97364666   -1.86376962    h      1.000     0
  -1.02051695   -1.24870287    1.49919195    h      1.000     0
```

Ethane (MAA* = -296.5 kJ/mol, E* = -69.6):

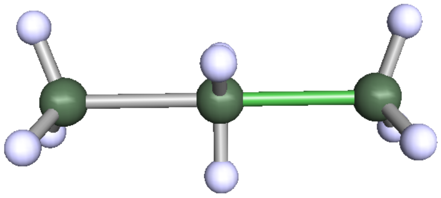


Total Energy = -79.75380173493 hartree
Enthalpy Correction = 0.078273 hartree
Entropy = 0.000091 hartree/K

```
                  atomic coordinates            atom    charge  isotop
  -1.42786266    0.08572643    0.12290490    c      6.000     0
   1.42786200   -0.08571380   -0.12293295    c      6.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.34551863 | -1.63044158 | -0.56914590 | h | 1.000 | 0 |
| -1.99761081 | 0.34714817 | 2.09088554 | h | 1.000 | 0 |
| -2.18088190 | 1.67513664 | -0.96017764 | h | 1.000 | 0 |
| 2.34556448 | 1.63012606 | 0.56986862 | h | 1.000 | 0 |
| 2.18074754 | -1.67557852 | 0.95957955 | h | 1.000 | 0 |
| 1.99769998 | -0.34640341 | -2.09098213 | h | 1.000 | 0 |

Ethane Product (transition state):

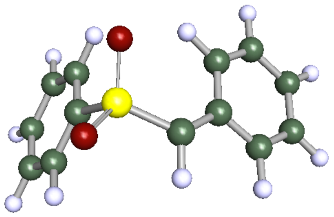


Total Energy = -119.55913196280 hartree
Enthalpy Correction = 0.106392 hartree
Entropy = 0.000117 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00640883 | -0.01669460 | -0.00675837 | c | 6.000 | 0 |
| 1.58024489 | 1.25081301 | -0.17120785 | h | 1.000 | 0 |
| 0.21632776 | 0.25336522 | 4.06929438 | c | 6.000 | 0 |
| 0.32343797 | -2.01589669 | 0.10896262 | h | 1.000 | 0 |
| -1.88390523 | 0.71454802 | 0.04102847 | h | 1.000 | 0 |
| -0.20072061 | -0.28192908 | -4.08370920 | c | 6.000 | 0 |
| -1.25716267 | -0.91872689 | 4.95382867 | h | 1.000 | 0 |
| 2.07314165 | -0.39866784 | 4.74324776 | h | 1.000 | 0 |
| -0.05338185 | 2.22445328 | 4.67697103 | h | 1.000 | 0 |
| 1.57960228 | -1.03223664 | -4.85515267 | h | 1.000 | 0 |
| -1.75156885 | -1.54615175 | -4.65333896 | h | 1.000 | 0 |
| -0.54071911 | 1.59518738 | -4.91365383 | h | 1.000 | 0 |

## Energies and Coordinates of Molecules with Experimental *Nu* Values Calculated at the PBE0(disp)/def2-TZVP COSMO (∞) level of theory.

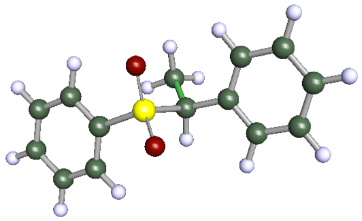
Sulfonyl Carbanion (MCA* = 509.6 kJ/mol, N = 25.77, $s_N$ = 0.56):



Total Energy = -1050.14803897502 hartree
Enthalpy Correction = 0.22223 hartree
Entropy = 0.000183 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.20476705 | -5.75323859 | 2.65381618 | o | 8.000 | 0 |
| -0.79157511 | -3.38506629 | 2.61333677 | s | 16.000 | 0 |
| 1.29120643 | -3.49828987 | 0.27208682 | c | 6.000 | 0 |
| 3.05040489 | -1.53185339 | -0.34772778 | c | 6.000 | 0 |
| 3.76243626 | 0.46028373 | 1.27810628 | c | 6.000 | 0 |
| 5.49731401 | 2.27566901 | 0.53628550 | c | 6.000 | 0 |
| 6.61810751 | 2.20876464 | -1.83930921 | c | 6.000 | 0 |
| 5.94682857 | 0.25882816 | -3.47397528 | c | 6.000 | 0 |
| 4.20933788 | -1.55537745 | -2.75432975 | c | 6.000 | 0 |
| -3.08744328 | -1.01139873 | 1.95206617 | c | 6.000 | 0 |
| -2.84665455 | 1.39796547 | 2.96794063 | c | 6.000 | 0 |
| -4.55449071 | 3.27362000 | 2.28879209 | c | 6.000 | 0 |
| -6.50053756 | 2.74427649 | 0.61389602 | c | 6.000 | 0 |
| -6.74160699 | 0.32518487 | -0.39002370 | c | 6.000 | 0 |
| -5.03587889 | -1.54751509 | 0.26623407 | c | 6.000 | 0 |
| 0.33759559 | -2.58894235 | 4.99913576 | o | 8.000 | 0 |
| 0.67016723 | -4.75389308 | -1.22296526 | h | 1.000 | 0 |
| 2.95769486 | 0.55280918 | 3.15580066 | h | 1.000 | 0 |
| 5.98675476 | 3.77307703 | 1.85103785 | h | 1.000 | 0 |
| 7.97777477 | 3.63300784 | -2.40277432 | h | 1.000 | 0 |
| 6.78461491 | 0.15611911 | -5.34399772 | h | 1.000 | 0 |
| 3.70846534 | -3.04788803 | -4.07089894 | h | 1.000 | 0 |
| -1.34879423 | 1.78912526 | 4.30423229 | h | 1.000 | 0 |
| -4.36733922 | 5.15165527 | 3.08633812 | h | 1.000 | 0 |
| -7.83719597 | 4.20733964 | 0.09556251 | h | 1.000 | 0 |
| -8.26992528 | -0.10098640 | -1.68629147 | h | 1.000 | 0 |
| -5.21249418 | -3.43327644 | -0.51286241 | h | 1.000 | 0 |

Sulfonyl Carbanion Product:

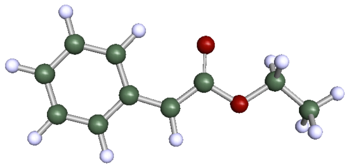


Total Energy = -1089.93136210722 hartree
Enthalpy Correction = 0.266073 hartree
Entropy = 0.000196 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.20642287 | 2.14524993 | -3.48456539 | o | 8.000 | 0 |
| -0.64682433 | -0.02322183 | -2.05901490 | s | 16.000 | 0 |
| 0.96260012 | 0.00011377 | 0.95289272 | c | 6.000 | 0 |
| -0.03331998 | -2.08511310 | 2.65127185 | c | 6.000 | 0 |
| 3.75703626 | -0.08071892 | 0.44279160 | c | 6.000 | 0 |
| 4.99062405 | -2.34691373 | -0.07800555 | c | 6.000 | 0 |
| 7.56904628 | -2.37342823 | -0.54992732 | c | 6.000 | 0 |
| 8.94312465 | -0.13833011 | -0.50652738 | c | 6.000 | 0 |
| 7.72471400 | 2.12802751 | 0.00675944 | c | 6.000 | 0 |
| 5.14512780 | 2.15370912 | 0.47028994 | c | 6.000 | 0 |
| -3.85328310 | 0.43496080 | -1.29283982 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -4.68836734 | 2.86078118 | -0.73178643 | c | 6.000 | 0 |
| -7.20524970 | 3.22037395 | -0.10745558 | c | 6.000 | 0 |
| -8.85099319 | 1.17444881 | -0.05380386 | c | 6.000 | 0 |
| -7.99333442 | -1.23924830 | -0.62355108 | c | 6.000 | 0 |
| -5.47679526 | -1.62477272 | -1.24237414 | c | 6.000 | 0 |
| -0.37292389 | -2.49631818 | -3.18640195 | o | 8.000 | 0 |
| 0.47196387 | 1.85185343 | 1.72840016 | h | 1.000 | 0 |
| 0.23082932 | -3.94459772 | 1.80592633 | h | 1.000 | 0 |
| 0.98949485 | -2.02727229 | 4.44011782 | h | 1.000 | 0 |
| -2.03867744 | -1.82685242 | 3.04824746 | h | 1.000 | 0 |
| 3.93968878 | -4.10267338 | -0.12224229 | h | 1.000 | 0 |
| 8.50855728 | -4.14937723 | -0.94961106 | h | 1.000 | 0 |
| 10.95946903 | -0.16397839 | -0.86680009 | h | 1.000 | 0 |
| 8.78440406 | 3.88059440 | 0.04935778 | h | 1.000 | 0 |
| 4.19537689 | 3.92585866 | 0.86963660 | h | 1.000 | 0 |
| -3.39438951 | 4.44545724 | -0.80615268 | h | 1.000 | 0 |
| -7.88552159 | 5.10161531 | 0.32711812 | h | 1.000 | 0 |
| -10.81945594 | 1.46630127 | 0.43059370 | h | 1.000 | 0 |
| -9.28464069 | -2.82731541 | -0.58681490 | h | 1.000 | 0 |
| -4.77580910 | -3.49262792 | -1.69536167 | h | 1.000 | 0 |

2-Ethoxy-2-oxo-1-phenylethan-1-ide Anion (MCA* = 495.5 kJ/mol, N = 27.54, $s_N$ = 0.57):



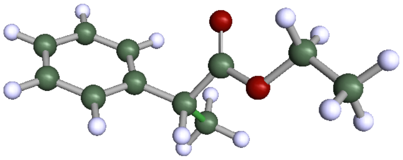
Total Energy = -537.86598583926 hartree
Enthalpy Correction = 0.199236 hartree
Entropy = 0.000165 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -6.84768549 | -5.45901892 | 1.20992054 | c | 6.000 | 0 |
| -4.36486751 | -6.20063226 | 0.87825489 | c | 6.000 | 0 |
| -2.45005899 | -4.48707362 | 0.13084507 | c | 6.000 | 0 |
| -3.23751904 | -1.95961347 | -0.25721173 | c | 6.000 | 0 |
| -5.73110582 | -1.23485015 | 0.08097107 | c | 6.000 | 0 |
| -7.57537092 | -2.95867434 | 0.81647147 | c | 6.000 | 0 |
| -8.24160513 | -6.85124066 | 1.78497541 | h | 1.000 | 0 |
| -3.85134502 | -8.16294987 | 1.19849975 | h | 1.000 | 0 |
| 0.08213748 | -5.37299165 | -0.17754525 | c | 6.000 | 0 |
| -1.83573554 | -0.58552078 | -0.82973863 | h | 1.000 | 0 |
| -6.24631585 | 0.72657456 | -0.23793636 | h | 1.000 | 0 |
| -9.52148239 | -2.37504699 | 1.07641118 | h | 1.000 | 0 |
| 0.43142605 | -7.35968509 | 0.18595672 | h | 1.000 | 0 |
| 2.16001104 | -3.92517872 | -0.90538495 | c | 6.000 | 0 |
| 2.27827898 | -1.63809832 | -1.43417575 | o | 8.000 | 0 |
| 4.35852607 | -5.35257331 | -1.02145336 | o | 8.000 | 0 |
| 6.58273237 | -4.05199026 | -1.76063489 | c | 6.000 | 0 |
| 6.95968075 | -2.49553295 | -0.45138299 | h | 1.000 | 0 |
| 8.72988284 | -5.92535530 | -1.76024978 | c | 6.000 | 0 |
| 6.32575397 | -3.22319151 | -3.63862080 | h | 1.000 | 0 |
| 10.48131880 | -4.98823212 | -2.32215099 | h | 1.000 | 0 |
| 9.00414328 | -6.73392196 | 0.11968117 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 8.36671891 | -7.46553005 | -3.08642017 | h | 1.000 | 0 |

2-Ethoxy-2-oxo-1-phenylethan-1-ide Anion Product:

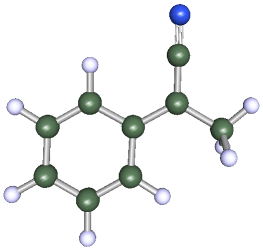
The $H_3C$-C-C=O Torsion Angle was constrained to 90°.



Total Energy = -577.64342207225 hartree
Enthalpy Correction = 0.243139 hartree
Entropy = 0.00018 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.90076660 | 1.12259751 | 3.23441854 | c | 6.000 | 0 |
| 0.67211932 | 0.15456471 | 0.85689019 | c | 6.000 | 0 |
| -1.26837640 | -1.62318303 | 0.92161665 | c | 6.000 | 0 |
| -2.36305359 | -2.48548639 | -1.29844282 | c | 6.000 | 0 |
| -1.53735238 | -1.58081158 | -3.62087082 | c | 6.000 | 0 |
| 0.39217014 | 0.19224800 | -3.70534059 | c | 6.000 | 0 |
| 1.48592381 | 1.04791873 | -1.47840914 | c | 6.000 | 0 |
| -1.92695695 | -2.35189074 | 2.71785727 | h | 1.000 | 0 |
| -3.87066907 | -3.87088635 | -1.21529148 | h | 1.000 | 0 |
| -2.39849985 | -2.25317392 | -5.35404130 | h | 1.000 | 0 |
| 1.04910449 | 0.91595985 | -5.50619876 | h | 1.000 | 0 |
| 2.99404756 | 2.43621858 | -1.55324539 | h | 1.000 | 0 |
| 3.55658979 | -0.86190359 | 4.46385658 | c | 6.000 | 0 |
| 3.13158528 | 2.70148005 | 2.73535330 | h | 1.000 | 0 |
| -0.00181067 | 2.05622070 | 5.20924025 | c | 6.000 | 0 |
| -1.23052743 | 0.52715248 | 5.84411876 | h | 1.000 | 0 |
| -1.17634227 | 3.54041708 | 4.39180432 | h | 1.000 | 0 |
| 0.97783295 | 2.82718328 | 6.85251644 | h | 1.000 | 0 |
| 5.54155024 | 0.18734674 | 5.58763436 | o | 8.000 | 0 |
| 3.12514443 | -3.10255055 | 4.50526085 | o | 8.000 | 0 |
| 7.19246670 | -1.48510701 | 6.96048901 | c | 6.000 | 0 |
| 9.25569947 | 0.09148254 | 8.11293701 | c | 6.000 | 0 |
| 6.08271610 | -2.46965417 | 8.39432877 | h | 1.000 | 0 |
| 7.93952412 | -2.88913111 | 5.64558629 | h | 1.000 | 0 |
| 8.47912626 | 1.48642055 | 9.41997318 | h | 1.000 | 0 |
| 10.54403498 | -1.13194770 | 9.16177151 | h | 1.000 | 0 |
| 10.33737779 | 1.07491181 | 6.65698707 | h | 1.000 | 0 |

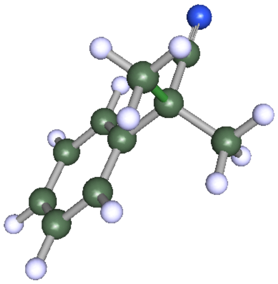
1-Cyano-1-phenylethan-1-ide Anion (MCA* = 489.6 kJ/mol, N = 28.95, $s_N$ = 0.58):



Total Energy = -402.30789539742 hartree
Enthalpy Correction = 0.152302 hartree
Entropy = 0.000145 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.02366029 | -3.63594278 | -0.32312419 | c | 6.000 | 0 |
| -2.93226487 | -1.89105954 | -1.91634285 | c | 6.000 | 0 |
| -2.98276402 | -6.28004837 | -0.27779942 | c | 6.000 | 0 |
| -1.99277625 | -0.41153314 | -3.28038978 | n | 7.000 | 0 |
| -1.40009220 | -6.46438506 | -1.58766933 | h | 1.000 | 0 |
| -2.29162070 | -6.82916312 | 1.60105362 | h | 1.000 | 0 |
| -4.39710747 | -7.69964261 | -0.81923118 | h | 1.000 | 0 |
| -6.10379421 | -2.91856698 | 1.23690460 | c | 6.000 | 0 |
| -7.13244591 | -0.44267559 | 1.24656486 | c | 6.000 | 0 |
| -9.14578328 | 0.20749541 | 2.77160345 | c | 6.000 | 0 |
| -10.26612649 | -1.55510938 | 4.38344007 | c | 6.000 | 0 |
| -9.29266104 | -3.99533257 | 4.41037140 | c | 6.000 | 0 |
| -7.27184494 | -4.67223841 | 2.88793321 | c | 6.000 | 0 |
| -6.30679952 | 0.97717978 | 0.01620523 | h | 1.000 | 0 |
| -9.86347211 | 2.12932565 | 2.70848571 | h | 1.000 | 0 |
| -11.84732354 | -1.03592059 | 5.57701797 | h | 1.000 | 0 |
| -10.12303855 | -5.41000838 | 5.64420109 | h | 1.000 | 0 |
| -6.57313376 | -6.59628443 | 2.96784894 | h | 1.000 | 0 |

1-Cyano-1-phenylethan-1-ide Anion Product:

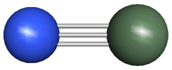


Total Energy = -442.08351838247 hartree
Enthalpy Correction = 0.195448 hartree
Entropy = 0.000156 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.78310143 | -4.04217608 | 0.35916874 | c | 6.000 | 0 |
| -1.84558115 | -2.06688521 | 0.31738716 | c | 6.000 | 0 |
| -3.44586108 | -5.63156198 | -2.05098811 | c | 6.000 | 0 |
| -3.30231691 | -5.67604698 | 2.71485008 | c | 6.000 | 0 |
| -1.40703194 | -6.48525047 | 2.65327399 | h | 1.000 | 0 |
| -4.66925763 | -7.21722973 | 2.75950691 | h | 1.000 | 0 |
| -3.50522611 | -4.56197372 | 4.43673649 | h | 1.000 | 0 |
| -4.80853505 | -7.17708664 | -2.04086386 | h | 1.000 | 0 |
| -3.75614135 | -4.48707075 | -3.73645638 | h | 1.000 | 0 |
| -1.54879310 | -6.43564688 | -2.12014420 | h | 1.000 | 0 |
| -0.26716354 | -0.57254063 | 0.28115338 | n | 7.000 | 0 |
| -6.41348482 | -2.86573746 | 0.45280948 | c | 6.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -6.80366888 | -0.26986796 | 0.51766101 | c | 6.000 | 0 |
| -9.23528458 | 0.71829246 | 0.60641249 | c | 6.000 | 0 |
| -11.30927894 | -0.88037335 | 0.63102067 | c | 6.000 | 0 |
| -10.93531671 | -3.47827958 | 0.56735364 | c | 6.000 | 0 |
| -8.50982249 | -4.46077164 | 0.47957687 | c | 6.000 | 0 |
| -5.20556573 | 1.01201655 | 0.49949132 | h | 1.000 | 0 |
| -9.49819164 | 2.74937501 | 0.65625210 | h | 1.000 | 0 |
| -13.20691362 | -0.11249375 | 0.69955541 | h | 1.000 | 0 |
| -12.54105941 | -4.75013510 | 0.58598048 | h | 1.000 | 0 |
| -8.26073559 | -6.49346164 | 0.43220488 | h | 1.000 | 0 |

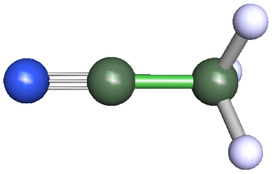
Cyanide Anion (MCA* = 480.4 kJ/mol, N = 16.27, $s_N$ = 0.70):



Total Energy = -92.8879207095hartree
Enthalpy Correction = 0.008273 hartree
Entropy = 0.000075 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.10291015 | 0.00000000 | 0.00000000 | c | 6.000 | 0 |
| -1.10291015 | 0.00000000 | 0.00000000 | n | 7.000 | 0 |

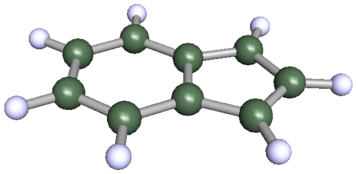
Cyanide Anion Product:



Total Energy = -132.6559133127 hartree
Enthalpy Correction = 0.050008 hartree
Entropy = 0.000095 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.97909847 | -0.02327460 | 0.06115790 | n | 7.000 | 0 |
| 1.80539758 | -0.01064140 | 0.02746605 | c | 6.000 | 0 |
| -0.92507378 | 0.00550055 | -0.01432033 | c | 6.000 | 0 |
| -1.65035419 | -0.22623424 | 1.90123616 | h | 1.000 | 0 |
| -1.61122167 | -1.54088339 | -1.19197252 | h | 1.000 | 0 |
| -1.59784641 | 1.79553308 | -0.78356725 | h | 1.000 | 0 |

Indenyl Anion (MCA* = 479.3 kJ/mol, N = 24.16, $s_N$ = 0.68):

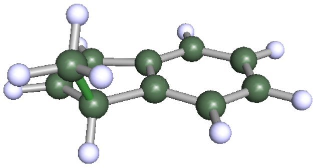


Total Energy = -346.99576158974 hartree
Enthalpy Correction = 0.135042 hartree
Entropy = 0.000125 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.54130896 | -1.38705892 | -0.12345354 | c | 6.000 | 0 |
| -1.82265428 | -2.60071724 | -0.11103980 | c | 6.000 | 0 |
| -4.01452373 | -1.19635689 | 0.08267945 | c | 6.000 | 0 |
| -3.91665654 | 1.46322833 | 0.27102508 | c | 6.000 | 0 |
| -1.62709194 | 2.71672481 | 0.26479488 | c | 6.000 | 0 |
| 0.64195250 | 1.34725283 | 0.07018590 | c | 6.000 | 0 |
| 3.21655294 | 2.06499633 | 0.01383951 | c | 6.000 | 0 |
| 4.65317510 | -0.15642571 | -0.20774238 | c | 6.000 | 0 |
| 3.05696204 | -2.27607883 | -0.29399260 | c | 6.000 | 0 |
| -1.93052841 | -4.64831330 | -0.25458307 | h | 1.000 | 0 |
| -5.83555406 | -2.14158953 | 0.09137949 | h | 1.000 | 0 |
| -5.66360967 | 2.52827673 | 0.42252972 | h | 1.000 | 0 |
| -1.58388831 | 4.76643414 | 0.41167398 | h | 1.000 | 0 |
| 3.94268110 | 3.97619597 | 0.12186176 | h | 1.000 | 0 |
| 6.70103288 | -0.22527209 | -0.29930397 | h | 1.000 | 0 |
| 3.64084142 | -4.23129661 | -0.45985441 | h | 1.000 | 0 |

Indenyl Anion Product:

The $H_3C$-CH-C-CH Torsion Angle was constrained to 77.5°.

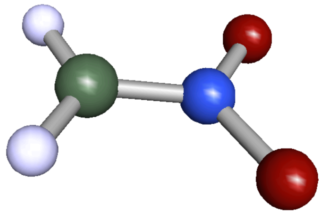


Total Energy = -386.76741517957 hartree
Enthalpy Correction = 0.178457 hartree
Entropy = 0.000137 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.43140885 | -1.27503598 | 1.11834523 | c | 6.000 | 0 |
| -2.66733312 | -0.24178671 | -0.93959519 | c | 6.000 | 0 |
| -2.99033656 | 2.58369770 | -1.06429281 | c | 6.000 | 0 |
| -0.88532550 | 3.78763542 | -0.33167781 | c | 6.000 | 0 |
| 1.09478664 | 1.93317020 | 0.16676105 | c | 6.000 | 0 |
| 0.07937193 | -0.48446470 | -0.24657510 | c | 6.000 | 0 |
| 1.64485205 | -2.57345019 | -0.29866453 | c | 6.000 | 0 |
| 4.19705666 | -2.27193159 | 0.28427488 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 5.17134032 | 0.10630192 | 0.83709504 | c | 6.000 | 0 |
| 3.63321811 | 2.23706457 | 0.75990490 | c | 6.000 | 0 |
| -4.01111165 | -0.37440280 | 2.92724383 | h | 1.000 | 0 |
| -6.40326137 | -0.89802802 | 0.64083707 | h | 1.000 | 0 |
| -4.19880487 | -3.31489969 | 1.33340832 | h | 1.000 | 0 |
| -3.08734950 | -1.16394696 | -2.74391112 | h | 1.000 | 0 |
| -4.77596488 | 3.46440260 | -1.53933206 | h | 1.000 | 0 |
| -0.64608646 | 5.81289271 | -0.15606998 | h | 1.000 | 0 |
| 0.90476459 | -4.43351985 | -0.74579582 | h | 1.000 | 0 |
| 5.43828852 | -3.90206089 | 0.28440293 | h | 1.000 | 0 |
| 7.16121401 | 0.30578456 | 1.28467551 | h | 1.000 | 0 |
| 4.41932664 | 4.10017505 | 1.09680336 | h | 1.000 | 0 |

Nitromethanide Anion (MCA* = 478.5 kJ/mol, N = 20.71, $s_N$ = 0.60):

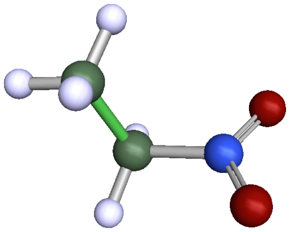


Total Energy = -244.38149919168 hartree
Enthalpy Correction = 0.041682 hartree
Entropy = 0.000099 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -1.33844572 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.14481375 | n | 7.000 | 0 |
| -2.06941365 | 0.00000000 | 2.39275371 | o | 8.000 | 0 |
| 2.06941365 | 0.00000000 | 2.39275371 | o | 8.000 | 0 |
| -1.79753319 | 0.00000000 | -2.29620958 | h | 1.000 | 0 |
| 1.79753319 | 0.00000000 | -2.29620958 | h | 1.000 | 0 |

Nitromethanide Anion Product:

The C-C-N-O Torsion Angle was constrained to 90°.

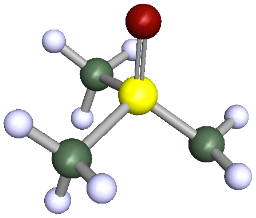


Total Energy = -284.15168673478 hartree
Enthalpy Correction = 0.085716 hartree
Entropy = 0.000117 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.09985009 | 0.48229247 | 0.25197293 | c | 6.000 | 0 |
| 0.25420830 | -0.52837403 | -1.02352231 | c | 6.000 | 0 |
| 2.47816464 | -0.09365215 | 0.64971131 | n | 7.000 | 0 |
| 3.62751759 | 1.87520639 | 0.41625522 | o | 8.000 | 0 |
| 2.97914506 | -1.70090794 | 2.20458965 | o | 8.000 | 0 |
| -1.94578920 | 2.50915001 | 0.59289879 | h | 1.000 | 0 |
| -3.70478843 | 0.15116795 | -0.99735655 | h | 1.000 | 0 |
| -2.45080871 | -0.48867732 | 2.03611399 | h | 1.000 | 0 |
| 0.66454601 | 0.45439359 | -2.78116214 | h | 1.000 | 0 |
| 0.15798308 | -2.55909556 | -1.32422609 | h | 1.000 | 0 |

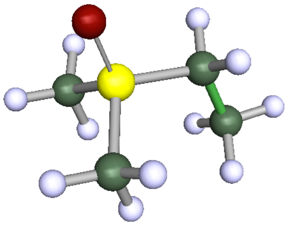
Dimethyl Sulfoxonium Methylide (MCA* = 475.5 kJ/mol, N = 21.29, $s_{\mathrm{N}}$ = 0.47):



Total Energy = -592.20784086128 hartree
Enthalpy Correction = 0.11448 hartree
Entropy = 0.000124 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.75471186 | -0.28316603 | 3.55476817 | o | 8.000 | 0 |
| 0.11301365 | 0.30789856 | 0.90855709 | s | 16.000 | 0 |
| 2.71420330 | -0.67162228 | -0.94225285 | c | 6.000 | 0 |
| -0.67042383 | 3.10788452 | -0.10025765 | c | 6.000 | 0 |
| -2.38372206 | -1.74036415 | 0.05820016 | c | 6.000 | 0 |
| 4.19741446 | 0.72987881 | -0.65568231 | h | 1.000 | 0 |
| 3.33105174 | -2.50476236 | -0.23944873 | h | 1.000 | 0 |
| 2.17459181 | -0.75937843 | -2.92266982 | h | 1.000 | 0 |
| 0.88609048 | 4.44493782 | -0.05833100 | h | 1.000 | 0 |
| -2.48414094 | 3.74601236 | 0.61699195 | h | 1.000 | 0 |
| -1.94313442 | -3.61085705 | 0.79553255 | h | 1.000 | 0 |
| -4.07971620 | -1.00433694 | 0.96808454 | h | 1.000 | 0 |
| -2.60993969 | -1.76212484 | -1.98349222 | h | 1.000 | 0 |

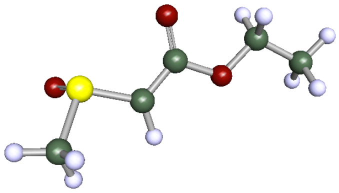
Dimethyl Sulfoxonium Methylide Product:



Total Energy = -631.97926121261 hartree
Enthalpy Correction = 0.158791 hartree
Entropy = 0.000135 hartree/K

```
             atomic coordinates              atom    charge  isotop
   -1.00829216   -2.40407956   -2.59096045    o      8.000     0
   -1.01128733   -0.75307613   -0.41829150    s     16.000     0
   -3.01002330   -1.83003971    1.97946044    c      6.000     0
    2.03962572   -0.46559114    0.90075500    c      6.000     0
    2.23149156    1.26057169    3.17451959    c      6.000     0
   -2.04665102    2.29368271   -1.15809130    c      6.000     0
   -2.31096040   -3.67748789    2.56303090    h      1.000     0
   -4.89219239   -1.97972545    1.15560274    h      1.000     0
   -2.99726215   -0.49121356    3.54291873    h      1.000     0
    3.18655069    0.17384323   -0.69467298    h      1.000     0
    2.55730937   -2.42014643    1.32685239    h      1.000     0
    4.19752846    1.25177795    3.79102224    h      1.000     0
    1.72622994    3.20376416    2.71615184    h      1.000     0
    1.07778012    0.60135378    4.74804625    h      1.000     0
   -0.73668734    3.05389837   -2.55428147    h      1.000     0
   -2.08365440    3.44457378    0.54774306    h      1.000     0
   -3.93727819    2.09616307   -1.95268801    h      1.000     0
```

Alpha Sulfinyl Enolate (MCA* = 475.0 kJ/mol, N = 20.61, $s_N$ = 0.64):

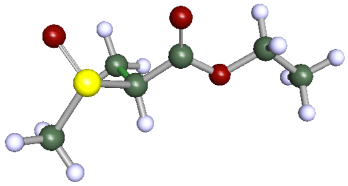


Total Energy = -819.51699449315 hartree
Enthalpy Correction = 0.150593 hartree
Entropy = 0.000161 hartree/K

```
             atomic coordinates              atom    charge  isotop
    5.57159352    4.10632206   -3.95927557    c      6.000     0
    3.26440746    4.71204225   -1.55088032    s     16.000     0
    1.77034596    1.87505675   -1.59534588    c      6.000     0
   -0.76969795    1.77256955   -0.85517473    c      6.000     0
   -1.70194783   -0.65036571   -0.89724748    o      8.000     0
   -4.27624381   -0.95146745   -0.17400693    c      6.000     0
   -4.91281396   -3.72074151   -0.36020181    c      6.000     0
   -2.16986256    3.53585258   -0.22533573    o      8.000     0
    4.86179221    5.08719474    0.81448708    o      8.000     0
    6.85966367    5.71330792   -4.00731247    h      1.000     0
    4.62644861    3.89679548   -5.77706496    h      1.000     0
    6.60652627    2.38681962   -3.47790307    h      1.000     0
    2.83724196    0.16382549   -1.95216570    h      1.000     0
   -5.48484093    0.17559631   -1.41497040    h      1.000     0
   -4.54278617   -0.25315055    1.75332954    h      1.000     0
   -3.71155171   -4.84163277    0.88960154    h      1.000     0
   -4.66901013   -4.40690946   -2.29194803    h      1.000     0
   -6.87900089   -4.02436751    0.18957505    h      1.000     0
```

Alpha Sulfinyl Enolate Product:

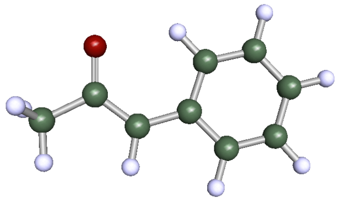
The $H_3C$-CH-C=O Torsion Angle was constrained to 90°.



Total Energy = -859.28640128463 hartree
Enthalpy Correction = 0.193708 hartree
Entropy = 0.000174 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -6.50994771 | 2.73212490 | -0.13974113 | c | 6.000 | 0 |
| -4.10614817 | 1.91936750 | -2.36808447 | s | 16.000 | 0 |
| -1.78455097 | 0.78684819 | -0.05943658 | c | 6.000 | 0 |
| -1.81066006 | 2.14708545 | 1.49114258 | h | 1.000 | 0 |
| 0.77569013 | 0.84134312 | -1.31207570 | c | 6.000 | 0 |
| 2.58938329 | 1.28571281 | 0.34875669 | o | 8.000 | 0 |
| 5.14792855 | 1.25862851 | -0.59865348 | c | 6.000 | 0 |
| 6.87736890 | 1.84859066 | 1.57438582 | c | 6.000 | 0 |
| 1.12586211 | 0.46873890 | -3.53656326 | o | 8.000 | 0 |
| -5.06582472 | -0.31639312 | -3.80571473 | o | 8.000 | 0 |
| -7.00119171 | 1.10385664 | 1.02238838 | h | 1.000 | 0 |
| -5.83977911 | 4.30072610 | 1.01720396 | h | 1.000 | 0 |
| -8.13776725 | 3.33310167 | -1.24932749 | h | 1.000 | 0 |
| -2.39357826 | -1.86203450 | 0.86922225 | c | 6.000 | 0 |
| 5.29458605 | 2.65852393 | -2.10624913 | h | 1.000 | 0 |
| 5.51952472 | -0.60499371 | -1.40173671 | h | 1.000 | 0 |
| 6.47007084 | 3.71258088 | 2.35903821 | h | 1.000 | 0 |
| 8.82985039 | 1.83841452 | 0.90841107 | h | 1.000 | 0 |
| 6.69474721 | 0.44072451 | 3.07116556 | h | 1.000 | 0 |
| -0.91426299 | -2.49517026 | 2.15898746 | h | 1.000 | 0 |
| -2.50920734 | -3.17310897 | -0.71573179 | h | 1.000 | 0 |
| -4.18394138 | -1.89227716 | 1.88669235 | h | 1.000 | 0 |

2-Oxo-1-phenylpropan-1-ide Anion (MCA* = 472.1 kJ/mol, N = 24.99, $s_N$ = 0.60):



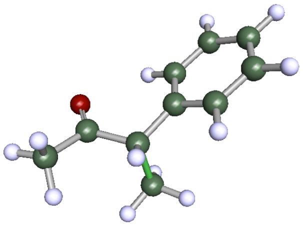
Total Energy = -423.39762231653 hartree
Enthalpy Correction = 0.163561 hartree
Entropy = 0.000145 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -4.98160643 | -4.12140466 | 1.64516041 | c | 6.000 | 0 |
| -2.32536347 | -3.15572379 | 1.16239700 | c | 6.000 | 0 |
| -5.13878546 | -4.75349965 | 3.60892778 | h | 1.000 | 0 |
| -6.44126921 | -2.71000053 | 1.28290457 | h | 1.000 | 0 |
| -5.34155263 | -5.77353054 | 0.45308562 | h | 1.000 | 0 |
| -0.54517431 | -4.72084078 | 1.54812668 | o | 8.000 | 0 |
| -2.08110670 | -0.67149893 | 0.34944949 | c | 6.000 | 0 |
| -3.81597182 | 0.39951085 | 0.11606985 | h | 1.000 | 0 |
| 0.21369425 | 0.66359569 | -0.22763566 | c | 6.000 | 0 |
| 0.09172503 | 3.20275770 | -1.04378048 | c | 6.000 | 0 |
| 2.23540430 | 4.58018275 | -1.62449051 | c | 6.000 | 0 |
| 4.62490442 | 3.49487420 | -1.41971050 | c | 6.000 | 0 |
| 4.79732620 | 0.99738603 | -0.61976367 | c | 6.000 | 0 |
| 2.65640217 | -0.39597747 | -0.03560135 | c | 6.000 | 0 |
| -1.75202003 | 4.09021403 | -1.21668323 | h | 1.000 | 0 |
| 2.04544980 | 6.52677930 | -2.24461653 | h | 1.000 | 0 |
| 6.30757216 | 4.57198542 | -1.87306095 | h | 1.000 | 0 |
| 6.64164466 | 0.11327453 | -0.44593788 | h | 1.000 | 0 |
| 2.80873090 | -2.33808528 | 0.58515823 | h | 1.000 | 0 |

2-Oxo-1-phenylpropan-1-ide Anion Product:

The $H_3$C-C-C-O Torsion Angle was constrained to 270° and the $H_3$C-C-C=C Torsion Angle was constrained to 270°.

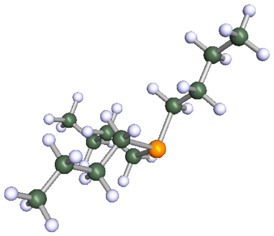


Total Energy = -463.16465848659 hartree
Enthalpy Correction = 0.206599 hartree
Entropy = 0.000162 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.26286099 | -4.11427229 | 1.88091040 | c | 6.000 | 0 |
| -1.83422889 | -2.67136626 | 2.06783831 | c | 6.000 | 0 |
| -4.37994508 | -5.54472505 | 3.35496886 | h | 1.000 | 0 |
| -5.88965364 | -2.84704056 | 1.97127440 | h | 1.000 | 0 |
| -4.32422567 | -5.03003711 | 0.02607052 | h | 1.000 | 0 |
| -1.73188481 | -0.26020446 | 0.52059711 | c | 6.000 | 0 |
| -0.11079600 | -3.39148838 | 3.39528870 | o | 8.000 | 0 |
| -2.75133653 | 1.90775756 | 2.16707423 | c | 6.000 | 0 |
| -3.08570741 | -0.51015111 | -1.02352610 | h | 1.000 | 0 |
| -2.91658736 | 3.61734453 | 1.02754786 | h | 1.000 | 0 |
| -4.61264360 | 1.45604440 | 2.93598075 | h | 1.000 | 0 |
| -1.46501709 | 2.28705394 | 3.73569567 | h | 1.000 | 0 |
| 0.76623202 | 0.44173582 | -0.65725448 | c | 6.000 | 0 |
| 0.71945509 | 1.62213639 | -3.01358017 | c | 6.000 | 0 |
| 2.92406912 | 2.45634524 | -4.15944650 | c | 6.000 | 0 |
| 5.23211375 | 2.13379970 | -2.95383590 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 5.30094904 | 0.98717739 | -0.59639962 | c | 6.000 | 0 |
| 3.08927598 | 0.16354916 | 0.55343305 | c | 6.000 | 0 |
| -1.07731838 | 1.87713092 | -3.97103053 | h | 1.000 | 0 |
| 2.83758715 | 3.35765288 | -5.99768880 | h | 1.000 | 0 |
| 6.96222130 | 2.77744107 | -3.84275624 | h | 1.000 | 0 |
| 7.09175886 | 0.73786614 | 0.36877948 | h | 1.000 | 0 |
| 3.16731805 | -0.71121199 | 2.39767446 | h | 1.000 | 0 |

Tributylphosphine (MCA* = 464.2 kJ/mol, N = 15.49, $s_N$ = 0.69):

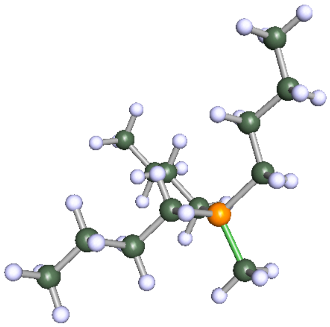


Total Energy = -814.40896920002 hartree
Enthalpy Correction = 0.390026 hartree
Entropy = 0.000222 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 7.62743838 | -5.35714162 | 2.04091210 | c | 6.000 | 0 |
| 5.99604545 | -3.01170861 | 2.31976307 | c | 6.000 | 0 |
| 4.10885813 | -2.70522116 | 0.17326357 | c | 6.000 | 0 |
| 2.45157858 | -0.37546240 | 0.46726863 | c | 6.000 | 0 |
| 0.27061243 | 0.10117725 | -2.20770540 | p | 15.000 | 0 |
| -1.76439037 | 2.63029232 | -0.94496007 | c | 6.000 | 0 |
| -0.48721217 | 5.20777771 | -0.95170513 | c | 6.000 | 0 |
| -2.20647437 | 7.30713695 | -0.00416670 | c | 6.000 | 0 |
| -0.92608915 | 9.87680631 | 0.00264954 | c | 6.000 | 0 |
| -1.83121653 | -2.67399981 | -1.96859814 | c | 6.000 | 0 |
| -2.89815442 | -3.37137700 | 0.60652150 | c | 6.000 | 0 |
| -4.62009437 | -5.67164198 | 0.49924907 | c | 6.000 | 0 |
| -5.66619954 | -6.39651567 | 3.07247741 | c | 6.000 | 0 |
| 6.46493341 | -7.06625539 | 2.00077028 | h | 1.000 | 0 |
| 8.96448706 | -5.54124246 | 3.60382081 | h | 1.000 | 0 |
| 8.71355579 | -5.29849716 | 0.28314423 | h | 1.000 | 0 |
| 7.19815489 | -1.32733056 | 2.40923622 | h | 1.000 | 0 |
| 4.96830270 | -3.08551453 | 4.11658268 | h | 1.000 | 0 |
| 2.92422490 | -4.40219668 | 0.07504733 | h | 1.000 | 0 |
| 5.12767633 | -2.61112428 | -1.62896500 | h | 1.000 | 0 |
| 3.64193732 | 1.31410302 | 0.57018461 | h | 1.000 | 0 |
| 1.38589836 | -0.46435481 | 2.24001761 | h | 1.000 | 0 |
| -2.38932417 | 2.15539191 | 0.96996166 | h | 1.000 | 0 |
| -3.45380045 | 2.68446731 | -2.14129930 | h | 1.000 | 0 |
| 1.21510986 | 5.15270236 | 0.22686165 | h | 1.000 | 0 |
| 0.15353021 | 5.65857289 | -2.86999465 | h | 1.000 | 0 |
| -3.90528055 | 7.37361598 | -1.18681883 | h | 1.000 | 0 |
| -2.85070033 | 6.84269950 | 1.90869483 | h | 1.000 | 0 |
| 0.74596232 | 9.86716157 | 1.21830749 | h | 1.000 | 0 |
| -2.19580157 | 11.35421533 | 0.68728123 | h | 1.000 | 0 |
| -0.31197245 | 10.40351332 | -1.89971521 | h | 1.000 | 0 |
| -3.37218086 | -2.31393764 | -3.30586786 | h | 1.000 | 0 |
| -0.77949639 | -4.27624936 | -2.75202252 | h | 1.000 | 0 |

```
  -1.35332919   -3.75631607    1.92963773     h       1.000      0
  -3.95303460   -1.77610980    1.39692237     h       1.000      0
  -6.17986415   -5.29067633   -0.80922622     h       1.000      0
  -3.56921283   -7.26667007   -0.30254591     h       1.000      0
  -6.76587828   -4.84726946    3.88755260     h       1.000      0
  -4.13913040   -6.84038445    4.39323072     h       1.000      0
  -6.89749891   -8.04989679    2.95258052     h       1.000      0
```

Tributylphosphine Product:

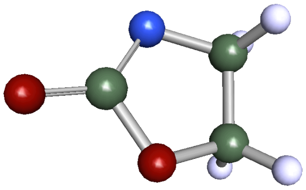


Total Energy = -854.17448751176 hartree
Enthalpy Correction = 0.432161 hartree
Entropy = 0.000231 hartree/K

```
                 atomic coordinates                 atom    charge  isotop
  -0.07505816   -0.27119828    5.73921106     c       6.000      0
  -0.02655760    0.58573869    2.47310860     p      15.000      0
  -1.85076510   -1.64221502    0.67572969     c       6.000      0
  -0.90788827   -4.35595963    0.88294271     c       6.000      0
  -2.41109454   -6.13019032   -0.80535477     c       6.000      0
  -1.49923896   -8.84379179   -0.61843181     c       6.000      0
   3.20974993    0.55628732    1.42190160     c       6.000      0
   3.60356608    0.46728827   -1.43078518     c       6.000      0
   6.39722349    0.41354368   -2.10159140     c       6.000      0
   6.83170369    0.30580213   -4.93593419     c       6.000      0
  -1.42834823    3.66961909    2.22048422     c       6.000      0
  -1.49703913    4.83378041   -0.41141248     c       6.000      0
  -2.97869804    7.29702089   -0.42871966     c       6.000      0
  -3.04782474    8.50704487   -3.02954290     c       6.000      0
  -2.02025485   -0.26252445    6.42104701     h       1.000      0
   0.73832485   -2.14759143    5.98643207     h       1.000      0
   1.03480828    1.09811567    6.80868571     h       1.000      0
  -3.80293938   -1.47651676    1.33760704     h       1.000      0
  -1.82587671   -1.00060223   -1.28988610     h       1.000      0
   1.09318398   -4.45959555    0.36540588     h       1.000      0
  -1.04381479   -4.99760491    2.84388607     h       1.000      0
  -4.41201409   -6.01929515   -0.28852971     h       1.000      0
  -2.27482801   -5.47407264   -2.76391197     h       1.000      0
  -1.66678267   -9.55076312    1.31649258     h       1.000      0
  -2.59896043  -10.08788350   -1.84417760     h       1.000      0
   0.48527864   -8.99811983   -1.17480459     h       1.000      0
   4.08396641   -1.08942346    2.32022824     h       1.000      0
   4.10480312    2.22598623    2.25272310     h       1.000      0
   2.68722258   -1.21197126   -2.21640480     h       1.000      0
   2.71612889    2.09690119   -2.33648207     h       1.000      0
```

| | | | | | |
|---|---|---|---|---|---|
| 7.31519852 | 2.09127692 | -1.31024883 | h | 1.000 | 0 |
| 7.27894207 | -1.22231616 | -1.18967216 | h | 1.000 | 0 |
| 6.00975808 | 1.95373648 | -5.87395627 | h | 1.000 | 0 |
| 5.96418773 | -1.38203505 | -5.75434159 | h | 1.000 | 0 |
| 8.84629617 | 0.26230972 | -5.38205891 | h | 1.000 | 0 |
| -0.39413801 | 4.88266087 | 3.53889846 | h | 1.000 | 0 |
| -3.34331132 | 3.45716268 | 2.97800141 | h | 1.000 | 0 |
| -2.35112602 | 3.51740966 | -1.75919756 | h | 1.000 | 0 |
| 0.42860348 | 5.19963928 | -1.06525003 | h | 1.000 | 0 |
| -2.13173853 | 8.60383355 | 0.93489748 | h | 1.000 | 0 |
| -4.90626496 | 6.92971195 | 0.23023455 | h | 1.000 | 0 |
| -3.93116080 | 7.24681115 | -4.40903157 | h | 1.000 | 0 |
| -1.13977716 | 8.93391693 | -3.69895943 | h | 1.000 | 0 |
| -4.11998417 | 10.27043169 | -3.00558334 | h | 1.000 | 0 |

2-Oxooxazolidin-3-ide Anion (MCA* = 459.0 kJ/mol, N = 22.40, $s_N$ = 0.59):

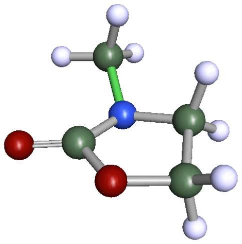


Total Energy = -321.85031011470 hartree
Enthalpy Correction = 0.080309 hartree
Entropy = 0.000113 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.30911975 | -0.48207565 | 1.88725861 | c | 6.000 | 0 |
| 1.43534783 | 0.42606537 | 1.95183860 | c | 6.000 | 0 |
| 2.11564699 | 0.70716755 | -0.69023295 | n | 7.000 | 0 |
| 0.03387548 | 0.68270681 | -2.01507820 | c | 6.000 | 0 |
| -2.14464677 | 0.22510748 | -0.56884347 | o | 8.000 | 0 |
| -2.52207588 | 0.40068739 | 3.30226980 | h | 1.000 | 0 |
| 1.60279317 | 2.23336119 | 2.96584130 | h | 1.000 | 0 |
| -1.44366541 | -2.54055829 | 2.07774084 | h | 1.000 | 0 |
| 2.65579277 | -0.92481337 | 2.93365633 | h | 1.000 | 0 |
| -0.30911769 | 1.00973558 | -4.31601281 | o | 8.000 | 0 |

2-Oxooxazolidin-3-ide Anion Product:

The $H_3C$-N-C=O Torsion Angle was constrained to 45°.

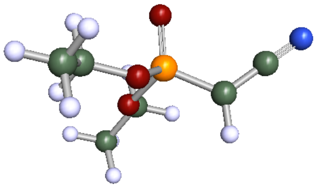


Total Energy = -361.6124737538 hartree

Enthalpy Correction = 0.122558 hartree
Entropy = 0.000127 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.77356077 | -3.17346587 | -0.01479958 | o | 8.000 | 0 |
| 0.29750255 | -1.43108688 | -0.15008162 | c | 6.000 | 0 |
| 0.79904595 | 1.08166006 | 0.22355516 | n | 7.000 | 0 |
| -1.51401260 | 2.51231060 | -0.21864938 | c | 6.000 | 0 |
| -3.52215180 | 0.49648914 | 0.13053935 | c | 6.000 | 0 |
| -2.20520364 | -1.82334523 | -0.37606528 | o | 8.000 | 0 |
| 3.04991285 | 2.13651131 | -0.93943680 | c | 6.000 | 0 |
| -1.70724636 | 4.06420862 | 1.12121197 | h | 1.000 | 0 |
| -1.52389294 | 3.28276770 | -2.14111917 | h | 1.000 | 0 |
| -4.22399390 | 0.41667319 | 2.06820205 | h | 1.000 | 0 |
| -5.09604557 | 0.65888947 | -1.18034341 | h | 1.000 | 0 |
| 2.73923269 | 2.48020781 | -2.95657091 | h | 1.000 | 0 |
| 3.52770289 | 3.91785630 | -0.02219436 | h | 1.000 | 0 |
| 4.62026577 | 0.82822824 | -0.69910157 | h | 1.000 | 0 |

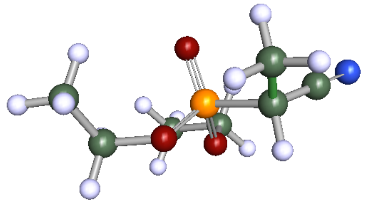
Phosphinate Carbanion (MCA* = 464.2 kJ/mol, N = 15.49, $s_N$ = 0.69):



Total Energy = -856.78155556423 hartree
Enthalpy Correction = 0.186844 hartree
Entropy = 0.000183 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.61789754 | 1.97221946 | 4.64859079 | o | 8.000 | 0 |
| 0.90313679 | 1.68200757 | 2.44399781 | p | 15.000 | 0 |
| -0.96162822 | 4.22226089 | 1.77220471 | c | 6.000 | 0 |
| -0.63752717 | 6.49513695 | 2.99568333 | c | 6.000 | 0 |
| -0.38481499 | 8.43462393 | 4.02742321 | n | 7.000 | 0 |
| -0.82852614 | -0.80892528 | 2.63859031 | o | 8.000 | 0 |
| -2.44371441 | -1.08666097 | 4.78729818 | c | 6.000 | 0 |
| -4.03880163 | -3.41570670 | 4.43244974 | c | 6.000 | 0 |
| 2.36944791 | 0.95840734 | -0.10619844 | o | 8.000 | 0 |
| 3.90995437 | -1.27363533 | -0.18590668 | c | 6.000 | 0 |
| 5.48677668 | -1.19631187 | -2.55193699 | c | 6.000 | 0 |
| -2.40991587 | 4.07522878 | 0.33187535 | h | 1.000 | 0 |
| -1.27939188 | -1.23659540 | 6.48898679 | h | 1.000 | 0 |
| -3.62456159 | 0.60457942 | 4.96210171 | h | 1.000 | 0 |
| -5.27726394 | -3.66879437 | 6.06428546 | h | 1.000 | 0 |
| -5.21294806 | -3.24997139 | 2.74335209 | h | 1.000 | 0 |
| -2.85350894 | -5.09536806 | 4.24907600 | h | 1.000 | 0 |
| 5.10452228 | -1.33082006 | 1.50022722 | h | 1.000 | 0 |
| 2.67842164 | -2.93220229 | -0.16367507 | h | 1.000 | 0 |
| 6.72449329 | 0.45516197 | -2.55571065 | h | 1.000 | 0 |
| 4.28722024 | -1.12576476 | -4.23009144 | h | 1.000 | 0 |
| 6.66007504 | -2.89091251 | -2.66336123 | h | 1.000 | 0 |

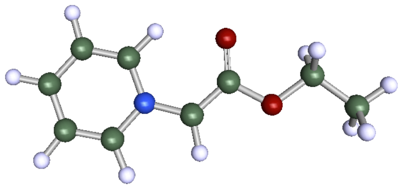
Phosphinate Carbanion Product:



Total Energy = -896.54181616206 hartree
Enthalpy Correction = 0.229956 hartree
Entropy = 0.0002 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.84716579 | 0.34607909 | 1.67558698 | o | 8.000 | 0 |
| 0.13326368 | 0.32910869 | 2.27909272 | p | 15.000 | 0 |
| -1.55893325 | 3.14608187 | 1.23793767 | c | 6.000 | 0 |
| -1.26374110 | 3.58387647 | -1.60790494 | c | 6.000 | 0 |
| -0.65783301 | 5.27963691 | 2.70289063 | c | 6.000 | 0 |
| 0.08854767 | 6.96534090 | 3.85440014 | n | 7.000 | 0 |
| -1.54369272 | -1.75070869 | 0.98393701 | o | 8.000 | 0 |
| -0.74999318 | -4.37361510 | 1.02262088 | c | 6.000 | 0 |
| 0.53155191 | -5.06116268 | -1.41905518 | c | 6.000 | 0 |
| -0.48355038 | 0.06749879 | 5.18665705 | o | 8.000 | 0 |
| 1.41428388 | 0.44232716 | 7.12175921 | c | 6.000 | 0 |
| 2.53008101 | -2.04837020 | 7.91638313 | c | 6.000 | 0 |
| -3.54758430 | 2.85388775 | 1.72823397 | h | 1.000 | 0 |
| 0.71915569 | 3.82871818 | -2.10724992 | h | 1.000 | 0 |
| -2.01689246 | 1.96182199 | -2.62784705 | h | 1.000 | 0 |
| -2.31092556 | 5.26426797 | -2.17445561 | h | 1.000 | 0 |
| 0.48876041 | -4.68988568 | 2.64477071 | h | 1.000 | 0 |
| -2.47693785 | -5.45603198 | 1.31426851 | h | 1.000 | 0 |
| 1.02952847 | -7.06422838 | -1.38674025 | h | 1.000 | 0 |
| 2.25509217 | -3.95965027 | -1.67857873 | h | 1.000 | 0 |
| -0.72501943 | -4.72808502 | -3.02061775 | h | 1.000 | 0 |
| 0.42216986 | 1.36287093 | 8.67385871 | h | 1.000 | 0 |
| 2.86426522 | 1.72281205 | 6.40886129 | h | 1.000 | 0 |
| 3.55122789 | -2.92847406 | 6.35406972 | h | 1.000 | 0 |
| 1.05736458 | -3.33825837 | 8.56720287 | h | 1.000 | 0 |
| 3.85880872 | -1.74035518 | 9.46592319 | h | 1.000 | 0 |

2-Ethoxy-2-oxo-1-(pyridin-1-ium-1-yl)ethan-1-ide (MCA* = 452.0 kJ/mol, N = 26.71, $s_{\mathrm{N}} = 0.37$):

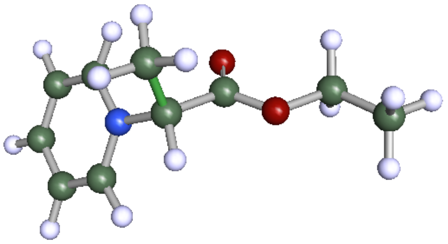


Total Energy = -554.35586833296 hartree
Enthalpy Correction = 0.201256 hartree
Entropy = 0.000165 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -6.97858487 | -5.21287504 | 1.18842961 | c | 6.000 | 0 |
| -4.85584221 | -6.53268240 | 0.52126977 | c | 6.000 | 0 |
| -2.75411055 | -5.36058747 | -0.40969951 | n | 7.000 | 0 |
| -2.81139464 | -2.79810391 | -0.66662997 | c | 6.000 | 0 |
| -4.91807840 | -1.42271699 | -0.01170600 | c | 6.000 | 0 |
| -7.05546851 | -2.59972264 | 0.93295805 | c | 6.000 | 0 |
| -8.57714231 | -6.26315737 | 1.91308219 | h | 1.000 | 0 |
| -4.72530251 | -8.56282502 | 0.69240744 | h | 1.000 | 0 |
| -0.69298648 | -6.83260812 | -1.03717826 | c | 6.000 | 0 |
| -1.10367158 | -1.97032221 | -1.40932404 | h | 1.000 | 0 |
| -4.84507212 | 0.60662935 | -0.26022336 | h | 1.000 | 0 |
| -8.71939098 | -1.53133579 | 1.45200191 | h | 1.000 | 0 |
| 1.58146711 | -5.89896270 | -2.02089018 | c | 6.000 | 0 |
| -0.93318725 | -8.82948859 | -0.72272595 | h | 1.000 | 0 |
| 2.17495536 | -3.69120337 | -2.50041912 | o | 8.000 | 0 |
| 3.24163221 | -7.82637598 | -2.44460892 | o | 8.000 | 0 |
| 5.64153323 | -7.12890476 | -3.45564654 | c | 6.000 | 0 |
| 7.15883701 | -9.51154227 | -3.80000594 | c | 6.000 | 0 |
| 5.37192690 | -6.14504082 | -5.25246597 | h | 1.000 | 0 |
| 6.58032698 | -5.82156103 | -2.15954230 | h | 1.000 | 0 |
| 6.21966247 | -10.80359043 | -5.10723912 | h | 1.000 | 0 |
| 7.43166334 | -10.48143466 | -1.99869814 | h | 1.000 | 0 |
| 9.01504998 | -9.04533394 | -4.57204855 | h | 1.000 | 0 |

2-Ethoxy-2-oxo-1-(pyridin-1-ium-1-yl)ethan-1-ide Product:

The $H_3C$-C-C-O Torsion Angle was constrained to 270°.

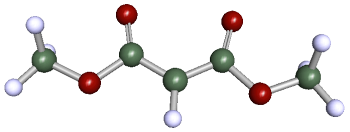


Total Energy = -594.11803290616 hartree
Enthalpy Correction = 0.245574 hartree
Entropy = 0.000177 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -6.63187390 | -4.27227250 | -1.03801537 | c | 6.000 | 0 |
| -4.12915444 | -4.76844949 | -0.56173861 | c | 6.000 | 0 |
| -2.69304633 | -3.09041727 | 0.68891287 | n | 7.000 | 0 |
| -3.65343115 | -0.88430412 | 1.49559222 | c | 6.000 | 0 |
| -6.14650975 | -0.29796340 | 1.06270011 | c | 6.000 | 0 |
| -7.66239860 | -2.00661517 | -0.21883790 | c | 6.000 | 0 |
| -7.74637968 | -5.66103099 | -2.03915853 | h | 1.000 | 0 |
| -3.21030452 | -6.49608311 | -1.14738582 | h | 1.000 | 0 |
| -0.00632219 | -3.68363156 | 1.11047117 | c | 6.000 | 0 |
| -2.38743193 | 0.37104820 | 2.48248486 | h | 1.000 | 0 |
| -6.87534595 | 1.48743281 | 1.73662828 | h | 1.000 | 0 |
| -9.63200034 | -1.57927599 | -0.57170185 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 1.61309190 | -1.97972204 | -0.55057794 | c | 6.000 | 0 |
| 0.25678360 | -5.63480680 | 0.52015977 | h | 1.000 | 0 |
| 0.74600943 | -3.39246550 | 3.86647082 | c | 6.000 | 0 |
| -0.47761976 | -4.55269278 | 5.04951170 | h | 1.000 | 0 |
| 0.64841776 | -1.43241583 | 4.49218472 | h | 1.000 | 0 |
| 2.68762714 | -4.04222605 | 4.09046187 | h | 1.000 | 0 |
| 3.71123505 | -3.14661090 | -1.18871672 | o | 8.000 | 0 |
| 1.06766369 | 0.16397689 | -1.08684574 | o | 8.000 | 0 |
| 5.54423183 | -1.68415143 | -2.59931521 | c | 6.000 | 0 |
| 6.01648029 | -0.01122379 | -1.48984356 | h | 1.000 | 0 |
| 4.65627419 | -1.07829938 | -4.35888829 | h | 1.000 | 0 |
| 7.80122664 | -3.34264914 | -3.05346252 | c | 6.000 | 0 |
| 7.28416057 | -5.01555169 | -4.14365057 | h | 1.000 | 0 |
| 9.21050554 | -2.28178031 | -4.12317208 | h | 1.000 | 0 |
| 8.65285420 | -3.93997792 | -1.27237352 | h | 1.000 | 0 |

1,3-Dimethoxy-1,3-dioxopropan-2-ide Anion (MCA* = 446.7 kJ/mol, N = 18.24, $s_N = 0.64$):

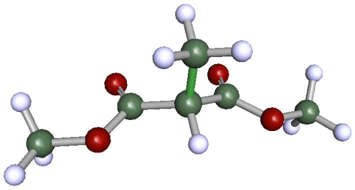


Total Energy = -495.45727076687 hartree
Enthalpy Correction = 0.131581 hartree
Entropy = 0.00015 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -0.83067123 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -2.87348433 | h | 1.000 | 0 |
| 1.36648924 | -1.90637314 | 0.42622907 | c | 6.000 | 0 |
| -1.36648924 | 1.90637314 | 0.42622907 | c | 6.000 | 0 |
| 2.51626943 | -3.51480682 | -1.26793502 | o | 8.000 | 0 |
| 1.63521384 | -2.27897017 | 2.70556993 | o | 8.000 | 0 |
| -1.63521384 | 2.27897017 | 2.70556993 | o | 8.000 | 0 |
| -2.51626943 | 3.51480682 | -1.26793502 | o | 8.000 | 0 |
| 3.95245753 | -5.50041268 | -0.18965175 | c | 6.000 | 0 |
| -3.95245753 | 5.50041268 | -0.18965175 | c | 6.000 | 0 |
| 4.71693993 | -6.57250981 | -1.77195860 | h | 1.000 | 0 |
| 2.77924942 | -6.73090504 | 0.98074971 | h | 1.000 | 0 |
| 5.49981092 | -4.77071495 | 0.96578542 | h | 1.000 | 0 |
| -2.77924942 | 6.73090504 | 0.98074971 | h | 1.000 | 0 |
| -5.49981092 | 4.77071495 | 0.96578542 | h | 1.000 | 0 |
| -4.71693993 | 6.57250981 | -1.77195860 | h | 1.000 | 0 |

1,3-Dimethoxy-1,3-dioxopropan-2-ide Anion Product:

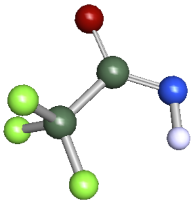
The $H_3C$-C-C-O Torsion Angle was constrained to 270° and the other $H_3C$-C-C-O Torsion Angle was constrained to 90°.



Total Energy = -535.21478698276 hartree
Enthalpy Correction = 0.175046 hartree
Entropy = 0.000168 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.61811917 | -3.44555945 | 0.91405835 | c | 6.000 | 0 |
| -1.97843505 | -0.69728388 | 1.61095122 | c | 6.000 | 0 |
| -5.45064741 | -3.73443894 | 0.72534552 | c | 6.000 | 0 |
| -1.38198508 | -5.20550294 | 2.78947265 | c | 6.000 | 0 |
| -1.81717603 | -3.83621168 | -0.94367544 | h | 1.000 | 0 |
| -2.77392032 | 0.58307873 | 0.20635217 | h | 1.000 | 0 |
| 0.06554644 | -0.44273464 | 1.64801711 | h | 1.000 | 0 |
| -2.74596277 | -0.21713416 | 3.46375291 | h | 1.000 | 0 |
| 0.94451850 | -5.76604900 | 2.01606340 | o | 8.000 | 0 |
| -2.27676719 | -5.96706970 | 4.73753435 | o | 8.000 | 0 |
| -6.87671245 | -4.30367438 | 2.40403834 | o | 8.000 | 0 |
| -6.20230235 | -3.18024546 | -1.60958396 | o | 8.000 | 0 |
| -8.87279434 | -3.21764554 | -2.03631623 | c | 6.000 | 0 |
| 2.41184038 | -7.30335337 | 3.68885240 | c | 6.000 | 0 |
| 2.64717361 | -6.35932408 | 5.50468515 | h | 1.000 | 0 |
| 4.22982743 | -7.54848155 | 2.76579770 | h | 1.000 | 0 |
| 1.49643965 | -9.12689384 | 3.97079493 | h | 1.000 | 0 |
| -9.12754613 | -2.69252723 | -4.00518469 | h | 1.000 | 0 |
| -9.62454772 | -5.10433897 | -1.69249827 | h | 1.000 | 0 |
| -9.81285018 | -1.86279367 | -0.80167610 | h | 1.000 | 0 |

Trifluoroacetamide Anion (MCA* = 443.0 kJ/mol, N = 15.81, $s_N$ = 0.64):

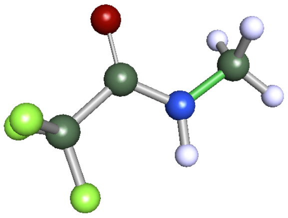


Total Energy = -506.18793316695 hartree
Enthalpy Correction = 0.045955hartree
Entropy = 0.000125 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.55551058 | 3.21911158 | 1.51770886 | o | 8.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 1.03977828 | 1.17731739 | 0.42167747 | c | 6.000 | 0 |
| -1.35156088 | -0.45677350 | -0.01036819 | c | 6.000 | 0 |
| -0.91725640 | -2.67990743 | -1.16192306 | f | 9.000 | 0 |
| -3.05606272 | 0.77010571 | -1.44070070 | f | 9.000 | 0 |
| -2.50321596 | -1.00175922 | 2.18747476 | f | 9.000 | 0 |
| 3.21474498 | 0.34608402 | -0.34423681 | n | 7.000 | 0 |
| 3.01806213 | -1.37417854 | -1.16963231 | h | 1.000 | 0 |

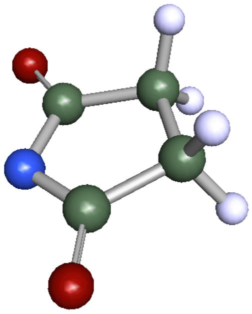
Trifluoroacetamide Anion Product:



Total Energy = -545.94481306624 hartree
Enthalpy Correction = 0.089328 hartree
Entropy = 0.00014 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.56338605 | 0.63962309 | -3.18696503 | o | 8.000 | 0 |
| -0.81377552 | 0.31857066 | -0.91861359 | c | 6.000 | 0 |
| -3.46829461 | 0.67039288 | 0.23010835 | c | 6.000 | 0 |
| -5.08154617 | -0.96308677 | -0.80824830 | f | 9.000 | 0 |
| -3.53007076 | 0.32523509 | 2.73240061 | f | 9.000 | 0 |
| -4.31282787 | 2.99555175 | -0.24515515 | f | 9.000 | 0 |
| 0.98280316 | -0.31860366 | 0.69915613 | n | 7.000 | 0 |
| 3.56298886 | -0.70963167 | -0.11190882 | c | 6.000 | 0 |
| 0.55082083 | -0.52174542 | 2.54099092 | h | 1.000 | 0 |
| 3.65327504 | -2.19570395 | -1.53892635 | h | 1.000 | 0 |
| 4.67940067 | -1.26513075 | 1.52022008 | h | 1.000 | 0 |
| 4.34061241 | 1.02452874 | -0.91305886 | h | 1.000 | 0 |

2,5-dioxopyrrolidin-1-ide Anion (MCA* = 438.1 kJ/mol, N = 16.03, $s_N$ = 0.66):

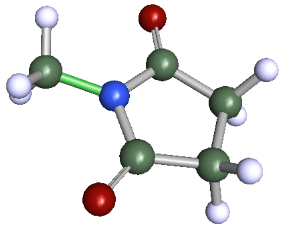


Total Energy = -359.96706375353 hartree
Enthalpy Correction = 0.086207 hartree
Entropy = 0.000118 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 1.42005227 | 0.18366407 | -1.22712345 | c | 6.000 | 0 |
| 2.06665041 | 0.25551356 | 1.57593570 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 3.05446231 | n | 7.000 | 0 |
| -2.06665041 | -0.25551356 | 1.57593570 | c | 6.000 | 0 |
| -1.42005227 | -0.18366407 | -1.22712345 | c | 6.000 | 0 |
| 2.46442482 | -1.35111665 | -2.12915094 | h | 1.000 | 0 |
| -4.24239733 | -0.51993174 | 2.36502891 | o | 8.000 | 0 |
| -2.03345018 | -1.94528179 | -2.11142843 | h | 1.000 | 0 |
| 2.03345018 | 1.94528179 | -2.11142843 | h | 1.000 | 0 |
| 4.24239733 | 0.51993174 | 2.36502891 | o | 8.000 | 0 |
| -2.46442482 | 1.35111665 | -2.12915094 | h | 1.000 | 0 |

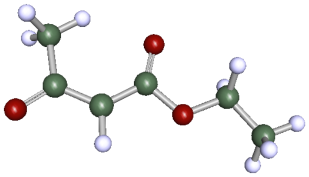
2,5-Dioxopyrrolidin-1-ide Anion Product:



Total Energy = -399.72146724074 hartree
Enthalpy Correction = 0.129264 hartree
Entropy = 0.000134 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.09945728 | -3.25261724 | 1.67476005 | c | 6.000 | 0 |
| -2.61027261 | -2.53694400 | 1.40891803 | n | 7.000 | 0 |
| -1.58105268 | -3.25402250 | -0.87284443 | c | 6.000 | 0 |
| -3.56282609 | -4.65085002 | -2.35596929 | c | 6.000 | 0 |
| -5.89218760 | -4.64794699 | -0.67098627 | c | 6.000 | 0 |
| -6.36730584 | -2.79685537 | 3.52414522 | o | 8.000 | 0 |
| -1.23024331 | -1.16515540 | 3.31789667 | c | 6.000 | 0 |
| -2.85875556 | -6.54243492 | -2.77743060 | h | 1.000 | 0 |
| -7.50624610 | -3.67334157 | -1.50465839 | h | 1.000 | 0 |
| 0.57123066 | -2.79950173 | -1.50249836 | o | 8.000 | 0 |
| -3.84782720 | -3.68129139 | -4.15314206 | h | 1.000 | 0 |
| -6.51838285 | -6.53748772 | -0.13381590 | h | 1.000 | 0 |
| -1.94833413 | -1.70308424 | 5.16841521 | h | 1.000 | 0 |
| 0.76284231 | -1.64763213 | 3.16391210 | h | 1.000 | 0 |
| -1.45956621 | 0.86896642 | 3.06511004 | h | 1.000 | 0 |

1-Ethoxy-1,3-dioxobutan-2-ide Anion (MCA* = 438.0 kJ/mol, N = 18.82, $s_N$ = 0.69):



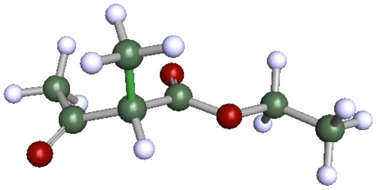
Total Energy = -459.55656995000 hartree
Enthalpy Correction 0.154934 hartree

Entropy 0.000155 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.89394621 | -4.21560835 | 1.37362234 | c | 6.000 | 0 |
| -0.84850031 | -1.78781255 | 0.92427986 | c | 6.000 | 0 |
| -0.90738021 | -5.78561478 | 0.49819003 | h | 1.000 | 0 |
| -4.03518783 | -4.83988682 | 2.80458325 | c | 6.000 | 0 |
| 1.25937801 | -1.96486363 | -0.57419526 | o | 8.000 | 0 |
| -1.54209729 | 0.30980037 | 1.65556675 | o | 8.000 | 0 |
| -4.76777374 | -7.08848463 | 3.05441330 | o | 8.000 | 0 |
| -5.58130517 | -2.83812883 | 4.12736592 | c | 6.000 | 0 |
| -4.85096149 | -0.94090534 | 3.83478502 | h | 1.000 | 0 |
| -5.62425223 | -3.26755950 | 6.14877329 | h | 1.000 | 0 |
| -7.52883044 | -2.95178218 | 3.44452781 | h | 1.000 | 0 |
| 2.50377146 | 0.34630917 | -1.16876759 | c | 6.000 | 0 |
| 1.19517987 | 1.60311654 | -2.15881227 | h | 1.000 | 0 |
| 4.76151048 | -0.27280273 | -2.78900697 | c | 6.000 | 0 |
| 3.07431570 | 1.29471547 | 0.57657490 | h | 1.000 | 0 |
| 4.18385889 | -1.20113200 | -4.53985772 | h | 1.000 | 0 |
| 6.07162969 | -1.51537347 | -1.78842504 | h | 1.000 | 0 |
| 5.76429349 | 1.46356727 | -3.27850516 | h | 1.000 | 0 |

1-Ethoxy-1,3-dioxobutan-2-ide Anion Product:

Both $H_3$C-CH-C(OEt)=O Torsion Angles were constrained to 270°.

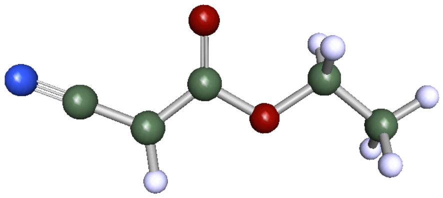


Total Energy = -499.31073218683 hartree
Enthalpy Correction = 0.19779 hartree
Entropy = 0.000171 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.14882890 | -1.01499694 | 1.05579175 | c | 6.000 | 0 |
| 1.67192649 | 1.74584099 | 1.53581152 | c | 6.000 | 0 |
| 1.18168713 | -2.43484044 | 3.59444108 | c | 6.000 | 0 |
| -1.29147915 | -1.66294409 | -0.31178147 | c | 6.000 | 0 |
| 0.11820053 | 3.36183384 | 1.95858368 | o | 8.000 | 0 |
| 4.14431088 | 2.17375041 | 1.50316612 | o | 8.000 | 0 |
| -3.65281482 | -0.20481645 | 0.18841921 | c | 6.000 | 0 |
| -1.27794189 | -3.47880904 | -1.71215642 | o | 8.000 | 0 |
| -5.26475407 | -1.22264305 | -0.58514110 | h | 1.000 | 0 |
| -3.90000996 | 0.14093053 | 2.20591898 | h | 1.000 | 0 |
| -3.50130608 | 1.65240512 | -0.70134032 | h | 1.000 | 0 |
| 4.94988087 | 4.70770888 | 2.09128898 | c | 6.000 | 0 |
| 4.12211481 | 5.99296465 | 0.70591642 | h | 1.000 | 0 |
| 7.78887294 | 4.74985124 | 2.01531439 | c | 6.000 | 0 |
| 4.22042441 | 5.20806121 | 3.95510755 | h | 1.000 | 0 |
| 2.68081953 | -1.76019727 | -0.10576376 | h | 1.000 | 0 |
| 0.93070011 | -4.45264669 | 3.26209241 | h | 1.000 | 0 |
| 2.99174402 | -2.14356077 | 4.53606314 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -0.32264299 | -1.77055078 | 4.83985854 | h | 1.000 | 0 |
| 8.58564926 | 3.44760793 | 3.40288574 | h | 1.000 | 0 |
| 8.45276741 | 6.65276315 | 2.45658956 | h | 1.000 | 0 |
| 8.48768059 | 4.23696713 | 0.14318213 | h | 1.000 | 0 |

1-cyano-2-ethoxy-2-oxoethan-1-ide Anion (MCA* = 434.5 kJ/mol, N = 19.62, $s_N$ = 0.67):

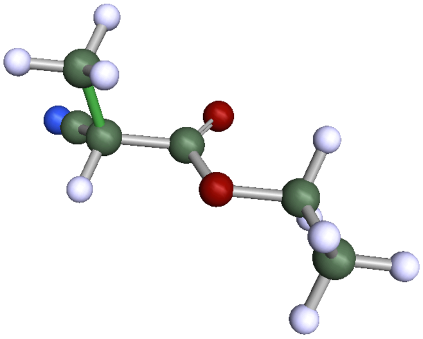


Total Energy = -399.19289217608 hartree
Enthalpy Correction = 0.114276 hartree
Entropy = 0.000142 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.97829927 | -3.54370850 | 0.75359501 | c | 6.000 | 0 |
| -3.48131410 | -1.30987309 | -0.60259740 | c | 6.000 | 0 |
| -6.11316502 | -3.72596638 | 2.25161813 | c | 6.000 | 0 |
| -2.70159575 | -5.13549174 | 0.64824164 | h | 1.000 | 0 |
| -7.90723456 | -3.90447398 | 3.52301532 | n | 7.000 | 0 |
| -4.76514834 | 0.63580191 | -0.65622546 | o | 8.000 | 0 |
| -1.29368407 | -1.46704335 | -1.96603726 | o | 8.000 | 0 |
| -0.62552681 | 0.70684421 | -3.40939558 | c | 6.000 | 0 |
| -2.12001910 | 1.11400566 | -4.77712206 | h | 1.000 | 0 |
| 1.84401670 | 0.15528366 | -4.71444605 | c | 6.000 | 0 |
| -0.46135316 | 2.34324953 | -2.15853824 | h | 1.000 | 0 |
| 2.41426285 | 1.78659499 | -5.84278582 | h | 1.000 | 0 |
| 1.66909326 | -1.47192840 | -5.97242183 | h | 1.000 | 0 |
| 3.33456507 | -0.23441833 | -3.34081848 | h | 1.000 | 0 |

1-Cyano-2-ethoxy-2-oxoethan-1-ide Anion Product:

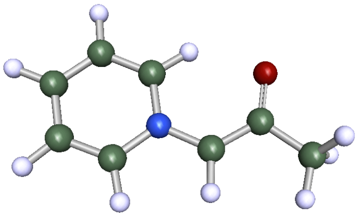
The $H_3C$-C-C-O Torsion Angle was constrained to 270°.



Total Energy = -438.94635329865 hartree
Enthalpy Correction = 0.157457 hartree
Entropy = 0.000157 hartree/K

```
             atomic coordinates            atom    charge  isotop
  1.56309375   -0.27035484   -0.73553922    c      6.000     0
  1.18070739   -2.24284158   -1.21021494    h      1.000     0
  1.85196951    1.28094826   -3.17201625    c      6.000     0
  3.87164751   -0.19369531    0.75460480    c      6.000     0
  5.72200584   -0.13732908    1.88982646    n      7.000     0
 -0.63150564    0.76204417    0.80726849    c      6.000     0
 -0.43294820    2.39562181    2.38053920    o      8.000     0
 -2.77025861   -0.29321495    0.08978040    o      8.000     0
 -5.05132835    0.65215718    1.25940458    c      6.000     0
  0.11484213    1.14300130   -4.26879635    h      1.000     0
  3.40832209    0.53668015   -4.29526754    h      1.000     0
  2.22293719    3.25927801   -2.73259027    h      1.000     0
 -5.16990208    2.67807549    0.89119537    h      1.000     0
 -7.24153859   -0.76785582    0.14380205    c      6.000     0
 -4.89535763    0.36419476    3.29541047    h      1.000     0
 -8.99205332   -0.08649270    0.99654550    h      1.000     0
 -7.08171649   -2.78997896    0.51863051    h      1.000     0
 -7.35550111   -0.47221792   -1.89458231    h      1.000     0
```

2-Oxo-1-(pyridin-1-ium-1-yl)propan-1-ide (MCA* = 434.0 kJ/mol, N = 20.24, $s_N$ = 0.60):

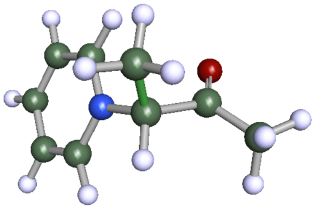


Total Energy = -439.88961917968 hartree
Enthalpy Correction = 0.165466 hartree
Entropy = 0.000145 hartree/K

```
             atomic coordinates            atom    charge  isotop
 -8.04317538   -4.16689427    1.17770117    c      6.000     0
 -5.71581807   -5.35127597    1.46277086    c      6.000     0
 -3.55560829   -4.18286825    0.64753677    c      6.000     0
 -3.60527879   -1.85808937   -0.45314783    n      7.000     0
 -5.87060996   -0.68025453   -0.74237428    c      6.000     0
 -8.07685486   -1.80360272    0.05682049    c      6.000     0
 -9.76775004   -5.06474003    1.81137214    h      1.000     0
 -5.55509835   -7.19915600    2.32370504    h      1.000     0
 -1.70805847   -5.03270879    0.83148239    h      1.000     0
 -1.33073684   -0.78976663   -1.23549641    c      6.000     0
 -5.75825630    1.15531161   -1.62872625    h      1.000     0
 -9.82859786   -0.78422099   -0.21923076    h      1.000     0
 -1.05418823    1.56548915   -2.36926863    c      6.000     0
  0.28910827   -1.97248005   -0.87722338    h      1.000     0
  1.62231195    2.29699026   -3.04086430    c      6.000     0
 -2.79272590    3.11205807   -2.87555562    o      8.000     0
  2.10444091    4.05800315   -2.07317139    h      1.000     0
  3.00894645    0.85690629   -2.54101659    h      1.000     0
  1.73393465    2.66032778   -5.07195465    h      1.000     0
```

2-Oxo-1-(pyridin-1-ium-1-yl)propan-1-ide Product:

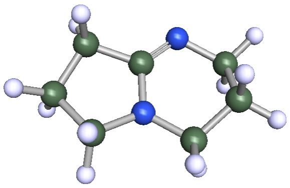
The $H_3C$-C-C-O Torsion Angle was constrained to 270°.



Total Energy = -479.64368057969 hartree
Enthalpy Correction = 0.208826 hartree
Entropy = 0.000158 hartree/K

```
                  atomic coordinates              atom    charge  isotop
     -5.81672601   -5.15502296    0.25254566     c       6.000      0
     -3.36210857   -5.93963372   -0.22766809     c       6.000      0
     -1.43665508   -4.20412308   -0.12116740     c       6.000      0
     -1.90899746   -1.77560833    0.45185495     n       7.000      0
     -4.27185674   -0.97762913    0.91886867     c       6.000      0
     -6.26614779   -2.64231193    0.83235466     c       6.000      0
     -7.36262741   -6.49350807    0.18245901     h       1.000      0
     -2.92328495   -7.88288688   -0.68014374     h       1.000      0
      0.51494293   -4.69227223   -0.47465855     h       1.000      0
      0.20032585    0.03312264    0.43428343     c       6.000      0
     -4.51212307    0.99354132    1.37350334     h       1.000      0
     -8.14832916   -1.95261056    1.22602699     h       1.000      0
      0.25705672    1.65330524    2.80717109     c       6.000      0
      0.00881729    1.73244792   -1.90697762     c       6.000      0
      1.92081235   -1.09044325    0.32482301     h       1.000      0
      0.29050736    0.44687128    4.47690265     h       1.000      0
     -1.35749697    2.92814022    2.91105353     h       1.000      0
      1.97083047    2.79621481    2.80156429     h       1.000      0
      2.46508319    2.60773981   -2.95933510     c       6.000      0
     -2.02768920    2.32977173   -2.73848320     o       8.000      0
      3.74223759    3.20405140   -1.45132770     h       1.000      0
      3.36756576    1.00236325   -3.90275002     h       1.000      0
      2.17320059    4.13104837   -4.30842253     h       1.000      0
```

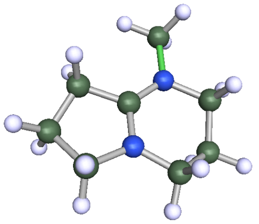
DBN (MCA* = 432.1 kJ/mol, N = 15.50, $s_N$ = 0.76):



Total Energy = -383.18668000139 hartree
Enthalpy Correction = 0.197366 hartree
Entropy = 0.000136 hartree/K

```
              atomic coordinates            atom    charge  isotop
 -0.43798036    1.62088011   -0.22236909     c      6.000     0
  1.37714638    3.15316001   -0.70916867     n      7.000     0
  3.80711013    1.94687464   -1.17546260     c      6.000     0
  4.18632635   -0.43548929    0.38931966     c      6.000     0
  2.05515181   -2.28824502   -0.11472248     c      6.000     0
 -0.31922525   -0.94019272   -0.13762497     n      7.000     0
 -2.67764653   -2.11113370    0.60078104     c      6.000     0
 -4.61437229   -0.04281215    0.06118569     c      6.000     0
 -3.10413451    2.39524634    0.39175017     c      6.000     0
  5.30800567    3.30692531   -0.76796430     h      1.000     0
  3.97643436    1.47679478   -3.19273166     h      1.000     0
  6.00070610   -1.31962730   -0.03938396     h      1.000     0
  4.19469565    0.07509182    2.39366153     h      1.000     0
  1.98172364   -3.73912444    1.35839589     h      1.000     0
  2.33729189   -3.26341055   -1.92078119     h      1.000     0
 -2.63770191   -2.63302045    2.61028491     h      1.000     0
 -3.01686305   -3.83102848   -0.49195786     h      1.000     0
 -6.25279366   -0.16097763    1.30198403     h      1.000     0
 -5.27098018   -0.20546867   -1.88901772     h      1.000     0
 -3.74132544    3.94793859   -0.80117503     h      1.000     0
 -3.15156879    3.04761880    2.35499662     h      1.000     0
```

DBN Product:

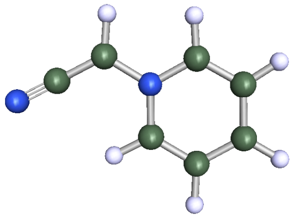


Total Energy = -422.94141912647 hartree
Enthalpy Correction = 0.241838 hartree
Entropy = 0.000148 hartree/K

```
              atomic coordinates            atom    charge  isotop
 -2.46559428    4.26389754    0.06575003     c      6.000     0
 -1.84381576    1.60178406   -0.03967387     n      7.000     0
  0.48616592    0.75690649   -0.01681223     c      6.000     0
  2.82429782    2.32691664    0.13206207     c      6.000     0
  4.89130941    0.36269989    0.61559681     c      6.000     0
  3.77658704   -2.10327324   -0.37300189     c      6.000     0
  1.06439976   -1.65840659   -0.20893835     n      7.000     0
 -0.80269150   -3.62851625   -0.53643874     c      6.000     0
 -3.26672134   -2.75376106    0.62827782     c      6.000     0
 -3.96008142   -0.14723358   -0.32196450     c      6.000     0
 -3.60642640    4.75964184   -1.58067730     h      1.000     0
 -0.76382772    5.41046537    0.05824357     h      1.000     0
 -3.55017602    4.66251627    1.77499797     h      1.000     0
  3.06805233    3.29555567   -1.67929492     h      1.000     0
  2.70413742    3.76301125    1.60146565     h      1.000     0
  6.66234661    0.84499775   -0.31066046     h      1.000     0
  5.23832444    0.20638606    2.64090551     h      1.000     0
```

| | | | | | |
|---|---|---|---|---|---|
| 4.29490643 | -2.48223334 | -2.33911053 | h | 1.000 | 0 |
| 4.28425221 | -3.74421124 | 0.76529782 | h | 1.000 | 0 |
| -0.10554247 | -5.33196931 | 0.39102996 | h | 1.000 | 0 |
| -1.02241652 | -4.04345008 | -2.55102217 | h | 1.000 | 0 |
| -4.77307632 | -4.07640430 | 0.15686912 | h | 1.000 | 0 |
| -3.07803331 | -2.71316237 | 2.68401022 | h | 1.000 | 0 |
| -4.51667873 | -0.19341131 | -2.31294534 | h | 1.000 | 0 |
| -5.53969760 | 0.62125385 | 0.75603377 | h | 1.000 | 0 |

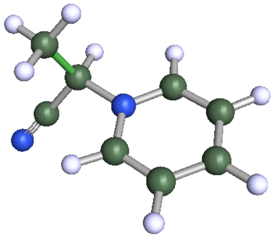
Cyano(pyridin-1-ium-1-yl)methanide (MCA* = 431.9 kJ/mol, N = 25.94, $s_N$ = 0.42):



Total Energy = -379.51229500339 hartree
Enthalpy Correction = 0.124436 hartree
Entropy = 0.000134 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.16593129 | -2.59706353 | 0.00000000 | c | 6.000 | 0 |
| -0.75388535 | -3.63052890 | 0.00000000 | c | 6.000 | 0 |
| 1.33553779 | -2.09903128 | 0.00000000 | c | 6.000 | 0 |
| 1.12731334 | 0.46744480 | 0.00000000 | n | 7.000 | 0 |
| -1.22964570 | 1.49972670 | 0.00000000 | c | 6.000 | 0 |
| -3.35805875 | 0.01669708 | 0.00000000 | c | 6.000 | 0 |
| -4.82950083 | -3.78439716 | 0.00000000 | h | 1.000 | 0 |
| -0.46032439 | -5.65477976 | 0.00000000 | h | 1.000 | 0 |
| 3.24243575 | -2.82848224 | 0.00000000 | h | 1.000 | 0 |
| 3.28865011 | 1.92637663 | 0.00000000 | c | 6.000 | 0 |
| -1.31262256 | 3.53992630 | 0.00000000 | h | 1.000 | 0 |
| -5.17727126 | 0.95192708 | 0.00000000 | h | 1.000 | 0 |
| 5.07253316 | 0.94583906 | 0.00000000 | h | 1.000 | 0 |
| 3.15744288 | 4.52076403 | 0.00000000 | c | 6.000 | 0 |
| 3.06332709 | 6.72558119 | 0.00000000 | n | 7.000 | 0 |

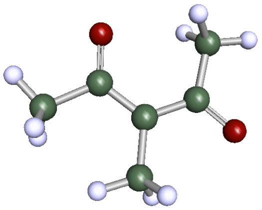
Cyano(pyridin-1-ium-1-yl)methanide Product:



Total Energy = -419.26689392647 hartree
Enthalpy Correction = 0.168547 hartree
Entropy = 0.000145 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -6.80285431 | -5.41554578 | -0.72825582 | c | 6.000 | 0 |
| -4.40813780 | -6.40431057 | -1.10994102 | c | 6.000 | 0 |
| -2.35797091 | -4.80998940 | -1.07700788 | c | 6.000 | 0 |
| -2.67998398 | -2.32804521 | -0.67356834 | n | 7.000 | 0 |
| -4.98164157 | -1.32698065 | -0.29067160 | c | 6.000 | 0 |
| -7.08614867 | -2.84096382 | -0.31592956 | c | 6.000 | 0 |
| -8.44116723 | -6.64049714 | -0.75460249 | h | 1.000 | 0 |
| -4.10833096 | -8.39779537 | -1.44028591 | h | 1.000 | 0 |
| -0.44122074 | -5.45173361 | -1.37118141 | h | 1.000 | 0 |
| -0.42278296 | -0.68435735 | -0.52915326 | c | 6.000 | 0 |
| -5.07380014 | 0.69095505 | 0.02203524 | h | 1.000 | 0 |
| -8.92158825 | -1.99647985 | -0.01494042 | h | 1.000 | 0 |
| -0.75767927 | 1.48391284 | -2.20695388 | c | 6.000 | 0 |
| 1.15622242 | -1.78945408 | -1.26099115 | h | 1.000 | 0 |
| 0.10313528 | 0.12848920 | 2.17536976 | c | 6.000 | 0 |
| 0.38721378 | -1.54931944 | 3.33493022 | h | 1.000 | 0 |
| 1.81676841 | 1.26859597 | 2.21219913 | h | 1.000 | 0 |
| -1.45748209 | 1.23785640 | 2.93450237 | h | 1.000 | 0 |
| -0.99210676 | 3.22028468 | -3.48540137 | n | 7.000 | 0 |

3-Methyl-2,4-dioxopentan-3-ide Anion (MCA* = 429.0 kJ/mol, N = 18.38, $s_N$ = 0.72):

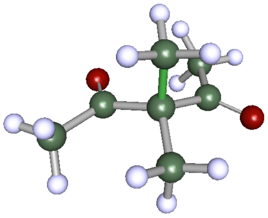


Total Energy = -384.35933169195 hartree
Enthalpy Correction = 0.148101 hartree
Entropy = 0.000146 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.90977684 | -4.57655854 | -0.00818449 | c | 6.000 | 0 |
| -4.42469986 | -7.12076167 | -1.18315473 | c | 6.000 | 0 |
| -3.35335976 | -2.59456795 | -0.91984090 | c | 6.000 | 0 |
| -1.71585153 | -2.99349164 | -2.59201702 | o | 8.000 | 0 |
| -3.58013620 | 0.07635458 | 0.05765808 | c | 6.000 | 0 |
| -2.18702976 | 1.24521436 | -0.91572530 | h | 1.000 | 0 |
| -3.27800821 | 0.15826719 | 2.09642484 | h | 1.000 | 0 |
| -5.47668271 | 0.82718047 | -0.25224934 | h | 1.000 | 0 |
| -6.80023328 | -4.22599692 | 1.85335099 | c | 6.000 | 0 |
| -7.31156821 | -2.17517695 | 2.92903071 | o | 8.000 | 0 |
| -8.37249773 | -6.49910351 | 2.64917349 | c | 6.000 | 0 |
| -9.75495463 | -5.87972642 | 4.04450894 | h | 1.000 | 0 |
| -7.20057251 | -7.98171370 | 3.48512442 | h | 1.000 | 0 |
| -9.36798344 | -7.34512756 | 1.04878527 | h | 1.000 | 0 |
| -4.77670181 | -7.10498390 | -3.22539681 | h | 1.000 | 0 |
| -2.44545380 | -7.68802558 | -0.96027298 | h | 1.000 | 0 |
| -5.59268341 | -8.60445734 | -0.36557930 | h | 1.000 | 0 |

3-Methyl-2,4-dioxopentan-3-ide Anion Product:

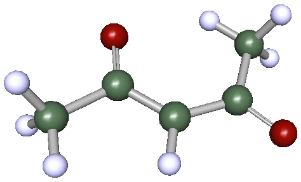
Both $H_3C$-C-C-O Torsion Angles were constrained to 90°.



Total Energy = -424.11224080484 hartree
Enthalpy Correction = 0.189556 hartree
Entropy = 0.00015 hartree/K

```
                 atomic coordinates                atom    charge  isotop
    -2.90808222   -4.36271405    0.54028041     c       6.000     0
    -1.17894402   -2.27448423   -0.55135918     c       6.000     0
    -5.08317488   -3.11035874    1.96547345     c       6.000     0
    -6.40348815   -4.51056250    2.71039605     h       1.000     0
    -6.11705265   -1.81840149    0.74073622     h       1.000     0
    -4.33273155   -2.03185767    3.54778436     h       1.000     0
     0.45053336   -3.06750222   -1.53554595     h       1.000     0
    -0.51483906   -1.07261456    0.98682661     h       1.000     0
    -2.23828017   -1.10415864   -1.87926576     h       1.000     0
    -3.84945265   -5.88410026   -1.73207693     c       6.000     0
    -2.72823354   -7.70851433   -2.54057671     o       8.000     0
    -6.20180928   -4.96553386   -3.01980956     c       6.000     0
    -6.44707863   -5.98547572   -4.78909449     h       1.000     0
    -6.12658182   -2.93536382   -3.37837911     h       1.000     0
    -7.83602764   -5.30077014   -1.80147659     h       1.000     0
    -1.23448442   -5.81352448    2.42427648     c       6.000     0
    -1.18633705   -5.10622940    4.60462822     o       8.000     0
     0.47192644   -7.90658144    1.58978079     c       6.000     0
     1.80509406   -8.31075587    3.10490586     h       1.000     0
     1.46171423   -7.43384032   -0.15325449     h       1.000     0
    -0.65272696   -9.58639607    1.17613650     h       1.000     0
```

2,4-Dioxopentan-3-ide Anion (MCA* = 429.2 kJ/mol, N = 17.64, $s_N$ = 0.73):



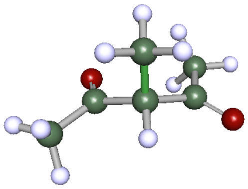
Total Energy = -345.08413304655 hartree
Enthalpy Correction = 0.118913 hartree
Entropy = 0.000137 hartree/K

```
                 atomic coordinates                atom    charge  isotop
    -4.42450720   -3.05183327    0.62863512     c       6.000     0
```

```
-2.52193456   -1.18962553    0.42128237     c       6.000      0
-5.76326110   -3.88013796    2.78546221     c       6.000      0
-4.90995378   -3.96562595   -1.14397374     h       1.000      0
-1.50903862   -0.67081004   -1.65612544     o       8.000      0
-5.53368122   -3.11330813    5.01336126     o       8.000      0
-7.70687569   -5.94165442    2.34688931     c       6.000      0
-7.23498195   -7.57291521    3.52519130     h       1.000      0
-9.55853661   -5.26363746    2.96609731     h       1.000      0
-7.83421701   -6.54617858    0.38138021     h       1.000      0
-1.61942820    0.26316472    2.70324410     c       6.000      0
-2.60428026   -0.29376626    4.41820543     h       1.000      0
 0.41302288   -0.04605544    2.92186949     h       1.000      0
-1.88998866    2.28226111    2.35193754     h       1.000      0
```

2,4-Dioxopentan-3-ide Anion Product:

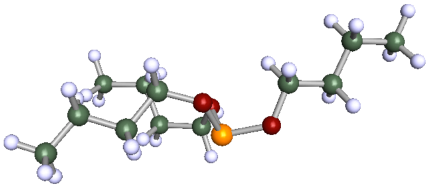
Both $H_3C$-C-C-O Torsion Angles were constrained to 90°.



Total Energy = -384.83473898915 hartree
Enthalpy Correction = 0.161253 hartree
Entropy = 0.000152 hartree/K

```
            atomic coordinates              atom    charge  isotop
-3.33715234   -3.89777846    0.55623070     c       6.000      0
-1.23054197   -1.96351647    0.32904599     c       6.000      0
-2.94038928   -5.33398065   -0.87396993     h       1.000      0
-6.03760621   -3.01248549    0.20280595     c       6.000      0
-3.12042583   -5.18522463    3.15778647     c       6.000      0
-1.56856853    0.65936107    1.30891504     c       6.000      0
 0.76904354   -2.65798400   -0.55758077     o       8.000      0
-6.76917384   -0.94040127    0.84507634     o       8.000      0
-7.76243401   -4.90866976   -0.99294697     c       6.000      0
-3.44010228   -3.83270689    4.68189502     h       1.000      0
-4.51237401   -6.69677555    3.32774050     h       1.000      0
-1.24248854   -6.00567886    3.37211739     h       1.000      0
-2.43277184    0.64428357    3.18092716     h       1.000      0
 0.25171348    1.61784802    1.34984699     h       1.000      0
-2.87793534    1.67891441    0.08046044     h       1.000      0
-9.72613894   -4.32880110   -0.79680790     h       1.000      0
-7.27919703   -5.04166016   -3.00052283     h       1.000      0
-7.47826660   -6.78737054   -0.18679690     h       1.000      0
```

Tributoxyphosphine (MCA* = 427.1 kJ/mol, N = 10.36, $s_N$ = 0.70):

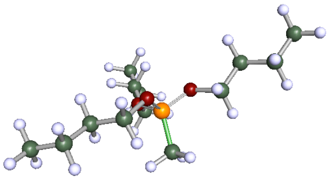


Total Energy = -1039.99750099577 hartree
Enthalpy Correction = 0.408397 hartree
Entropy = 0.000252 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 9.95802792 | -7.10113347 | -2.65590191 | c | 6.000 | 0 |
| 8.21319729 | -4.83743004 | -2.92483132 | c | 6.000 | 0 |
| 7.01603429 | -4.06481673 | -0.42930198 | c | 6.000 | 0 |
| 5.26968032 | -1.83349800 | -0.73578452 | c | 6.000 | 0 |
| 4.24972097 | -1.16334404 | 1.69246391 | o | 8.000 | 0 |
| 1.52008134 | 0.13674202 | 2.02817084 | p | 15.000 | 0 |
| -0.35269917 | -1.66103297 | 0.36999741 | o | 8.000 | 0 |
| -2.24306057 | -3.09685998 | 1.67194474 | c | 6.000 | 0 |
| -4.82556158 | -1.93246891 | 1.32117531 | c | 6.000 | 0 |
| -5.70676498 | -1.86500497 | -1.41157318 | c | 6.000 | 0 |
| -8.23690556 | -0.54670792 | -1.72001859 | c | 6.000 | 0 |
| 1.88332898 | 2.38386575 | -0.05276228 | o | 8.000 | 0 |
| -0.26142621 | 3.75442632 | -0.94989800 | c | 6.000 | 0 |
| -1.59018293 | 5.26256734 | 1.08460778 | c | 6.000 | 0 |
| -3.81494044 | 6.73441103 | 0.02012319 | c | 6.000 | 0 |
| -5.21035849 | 8.23636350 | 2.02858468 | c | 6.000 | 0 |
| 8.93218677 | -8.74489095 | -1.93632151 | h | 1.000 | 0 |
| 11.49718268 | -6.69669851 | -1.33735462 | h | 1.000 | 0 |
| 10.79796036 | -7.62398856 | -4.46797987 | h | 1.000 | 0 |
| 6.72127546 | -5.26965954 | -4.29389589 | h | 1.000 | 0 |
| 9.26820571 | -3.23444655 | -3.70301748 | h | 1.000 | 0 |
| 8.49261324 | -3.58961366 | 0.94121412 | h | 1.000 | 0 |
| 5.94811704 | -5.65350357 | 0.35914825 | h | 1.000 | 0 |
| 3.72569616 | -2.29044068 | -2.02931415 | h | 1.000 | 0 |
| 6.28148666 | -0.19770016 | -1.48963730 | h | 1.000 | 0 |
| -2.17909314 | -5.00720919 | 0.88953687 | h | 1.000 | 0 |
| -1.77114895 | -3.21830936 | 3.68352668 | h | 1.000 | 0 |
| -4.80127158 | -0.01290496 | 2.10317635 | h | 1.000 | 0 |
| -6.17223804 | -3.01248267 | 2.46554183 | h | 1.000 | 0 |
| -5.83287929 | -3.80417578 | -2.12720717 | h | 1.000 | 0 |
| -4.28039169 | -0.91370344 | -2.56784671 | h | 1.000 | 0 |
| -9.70688297 | -1.48776545 | -0.61246562 | h | 1.000 | 0 |
| -8.84491339 | -0.52684303 | -3.69279666 | h | 1.000 | 0 |
| -8.13174814 | 1.41448630 | -1.07390121 | h | 1.000 | 0 |
| -1.57857903 | 2.43364883 | -1.84390730 | h | 1.000 | 0 |
| 0.46029042 | 5.01373822 | -2.41725659 | h | 1.000 | 0 |
| -2.25809389 | 3.98992333 | 2.57710507 | h | 1.000 | 0 |
| -0.23813496 | 6.55548737 | 1.97057316 | h | 1.000 | 0 |
| -3.14234596 | 8.00965854 | -1.46617310 | h | 1.000 | 0 |
| -5.12528068 | 5.41922190 | -0.89921236 | h | 1.000 | 0 |
| -5.95226727 | 6.98979167 | 3.50074767 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -3.95366608 | 9.60154532 | 2.93876467 | h | 1.000 | 0 |
| -6.79905400 | 9.27777667 | 1.22086541 | h | 1.000 | 0 |

Tributoxyphosphine Product:

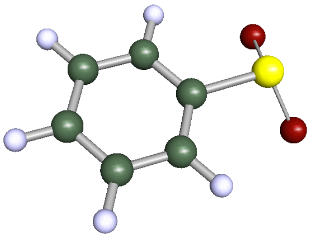


Total Energy = -1079.74723110683 hartree
Enthalpy Correction = 0.450645 hartree
Entropy = 0.000267hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.56613063 | 0.97884325 | 4.50807637 | c | 6.000 | 0 |
| -1.18257317 | 0.30736967 | 1.26945104 | p | 15.000 | 0 |
| -3.61729195 | 0.84495141 | -0.24996641 | o | 8.000 | 0 |
| -6.18733686 | 0.41101778 | 0.65160404 | c | 6.000 | 0 |
| -6.79432228 | -2.36078388 | 0.86546609 | c | 6.000 | 0 |
| -9.54104440 | -2.75343598 | 1.61949839 | c | 6.000 | 0 |
| -10.20873120 | -5.53361089 | 1.87134867 | c | 6.000 | 0 |
| 0.96034867 | 1.89717624 | 0.07215212 | o | 8.000 | 0 |
| 1.06369985 | 4.64534132 | 0.26071181 | c | 6.000 | 0 |
| 3.05393189 | 5.57814571 | -1.53842144 | c | 6.000 | 0 |
| 3.31656006 | 8.43734950 | -1.39943673 | c | 6.000 | 0 |
| 5.30705917 | 9.43162720 | -3.21214891 | c | 6.000 | 0 |
| -0.46139835 | -2.48843416 | 0.81525794 | o | 8.000 | 0 |
| 1.80971737 | -3.62107302 | 1.90570344 | c | 6.000 | 0 |
| 3.03351439 | -5.27560067 | -0.05234824 | c | 6.000 | 0 |
| 5.36884006 | -6.57646530 | 1.00564800 | c | 6.000 | 0 |
| 6.65405600 | -8.24924612 | -0.94019047 | c | 6.000 | 0 |
| -2.12244383 | 2.94798619 | 4.76106184 | h | 1.000 | 0 |
| -3.00879006 | -0.25623119 | 5.31067654 | h | 1.000 | 0 |
| 0.22309996 | 0.64444895 | 5.47837936 | h | 1.000 | 0 |
| -7.36227556 | 1.34139676 | -0.75711682 | h | 1.000 | 0 |
| -6.41137612 | 1.40065302 | 2.44804608 | h | 1.000 | 0 |
| -5.56166335 | -3.25461274 | 2.26849754 | h | 1.000 | 0 |
| -6.41546148 | -3.28004540 | -0.94770733 | h | 1.000 | 0 |
| -10.76788144 | -1.86393568 | 0.21008412 | h | 1.000 | 0 |
| -9.90589457 | -1.78307739 | 3.41115731 | h | 1.000 | 0 |
| -12.18737100 | -5.77935080 | 2.40393672 | h | 1.000 | 0 |
| -9.04493839 | -6.44717337 | 3.31398444 | h | 1.000 | 0 |
| -9.90219534 | -6.53265996 | 0.08884673 | h | 1.000 | 0 |
| 1.52559659 | 5.12379333 | 2.21341688 | h | 1.000 | 0 |
| -0.79813791 | 5.39834254 | -0.21284775 | h | 1.000 | 0 |
| 2.55199507 | 5.00379205 | -3.46040793 | h | 1.000 | 0 |
| 4.85717273 | 4.67813578 | -1.07335507 | h | 1.000 | 0 |
| 3.79814595 | 8.98722618 | 0.53692538 | h | 1.000 | 0 |
| 1.48976656 | 9.31505039 | -1.82064456 | h | 1.000 | 0 |
| 7.15951220 | 8.61503984 | -2.79759040 | h | 1.000 | 0 |
| 5.47598246 | 11.48443484 | -3.08310286 | h | 1.000 | 0 |
| 4.83179188 | 8.95508061 | -5.16578857 | h | 1.000 | 0 |
| 3.08904916 | -2.12027229 | 2.51535965 | h | 1.000 | 0 |
| 1.19177734 | -4.69578146 | 3.55177362 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 1.66503232 | -6.68699052 | -0.69483183 | h | 1.000 | 0 |
| 3.54609475 | -4.12008152 | -1.68954070 | h | 1.000 | 0 |
| 6.70236976 | -5.14540627 | 1.68319985 | h | 1.000 | 0 |
| 4.83470509 | -7.70736496 | 2.65500688 | h | 1.000 | 0 |
| 7.26239467 | -7.14560096 | -2.57785768 | h | 1.000 | 0 |
| 8.31884693 | -9.17454951 | -0.14538637 | h | 1.000 | 0 |
| 5.37052134 | -9.72174465 | -1.61500446 | h | 1.000 | 0 |

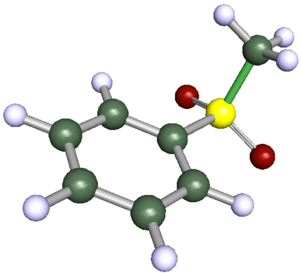
Phenylsulfinate Anion (MCA* = 422.6 kJ/mol, N = 20.11, $s_N$ = 0.59):



Total Energy = -780.02840037143 hartree
Enthalpy Correction = 0.107467 hartree
Entropy = 0.000138 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.79500819 | -0.48010205 | 2.13855649 | o | 8.000 | 0 |
| 4.90124441 | 0.98025008 | -0.13018292 | s | 16.000 | 0 |
| 1.51312769 | 0.50299807 | -0.00269165 | c | 6.000 | 0 |
| 0.53992807 | -1.73076129 | 0.97166547 | c | 6.000 | 0 |
| -2.04872105 | -2.16113628 | 0.92840679 | c | 6.000 | 0 |
| -3.66179434 | -0.36757668 | -0.10859928 | c | 6.000 | 0 |
| -2.68398898 | 1.86373742 | -1.09057531 | c | 6.000 | 0 |
| -0.09659006 | 2.29587293 | -1.04522690 | c | 6.000 | 0 |
| 5.12717960 | 3.78417138 | 0.28022779 | o | 8.000 | 0 |
| 1.81988505 | -3.10356608 | 1.79379471 | h | 1.000 | 0 |
| -2.81063267 | -3.89739723 | 1.70678940 | h | 1.000 | 0 |
| -5.68208070 | -0.70662273 | -0.14899250 | h | 1.000 | 0 |
| -3.94271101 | 3.27041928 | -1.88907718 | h | 1.000 | 0 |
| 0.68531800 | 4.03969412 | -1.78530313 | h | 1.000 | 0 |

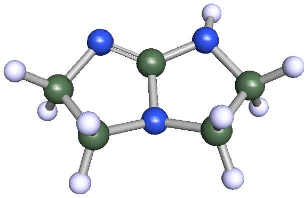
Phenylsulfinate Anion Product:



Total Energy = -819.77789232617 hartree
Enthalpy Correction = 0.14972 hartree
Entropy = 0.000148 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.98114414 | -4.29496443 | -1.03121809 | o | 8.000 | 0 |
| -3.02049682 | -1.97796546 | 0.41547577 | s | 16.000 | 0 |
| -4.91356922 | 0.22600521 | -1.19777694 | c | 6.000 | 0 |
| 0.03420269 | -0.65305790 | 0.36155159 | c | 6.000 | 0 |
| 1.65466855 | -1.24944269 | -1.61465570 | c | 6.000 | 0 |
| 4.04603801 | -0.18068628 | -1.65764782 | c | 6.000 | 0 |
| 4.78584801 | 1.46177401 | 0.25184054 | c | 6.000 | 0 |
| 3.14608929 | 2.04242812 | 2.21833081 | c | 6.000 | 0 |
| 0.75114926 | 0.98387673 | 2.28402995 | c | 6.000 | 0 |
| -3.86114633 | -2.09529888 | 3.01198060 | o | 8.000 | 0 |
| -4.84999564 | 2.02054091 | -0.19250159 | h | 1.000 | 0 |
| -4.20816317 | 0.42654919 | -3.12084826 | h | 1.000 | 0 |
| -6.82742258 | -0.54102716 | -1.20003488 | h | 1.000 | 0 |
| 1.05653563 | -2.54464369 | -3.08179701 | h | 1.000 | 0 |
| 5.33508406 | -0.63615259 | -3.18136978 | h | 1.000 | 0 |
| 6.65793629 | 2.29127238 | 0.21107041 | h | 1.000 | 0 |
| 3.73469120 | 3.31648090 | 3.70873997 | h | 1.000 | 0 |
| -0.54030509 | 1.40431164 | 3.81483044 | h | 1.000 | 0 |

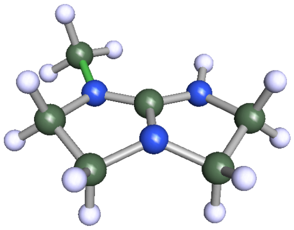
TBO (MCA* = 422.4 kJ/mol, N = 14.44, $s_N$ = 0.79):



Total Energy = -359.93606119346 hartree
Enthalpy Correction = 0.155942 hartree
Entropy = 0.000125 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.43232433 | 0.81468551 | -0.37557574 | n | 7.000 | 0 |
| -1.71741340 | 2.27792815 | 0.48097603 | c | 6.000 | 0 |
| -3.88989237 | 0.64674845 | -0.51623460 | c | 6.000 | 0 |
| -2.81868464 | -1.88914246 | -0.31158272 | n | 7.000 | 0 |
| -0.25729108 | -1.70151048 | -0.38547869 | c | 6.000 | 0 |
| 1.51940705 | -3.35294437 | -0.28904667 | n | 7.000 | 0 |
| 3.84427945 | -1.82027898 | -0.17059072 | c | 6.000 | 0 |
| 2.97883463 | 0.84063981 | 0.63903445 | c | 6.000 | 0 |
| -1.76638509 | 2.39683729 | 2.55489662 | h | 1.000 | 0 |
| -1.73831576 | 4.18281717 | -0.30024453 | h | 1.000 | 0 |
| -4.32652473 | 1.13222074 | -2.48063613 | h | 1.000 | 0 |
| -5.60006921 | 0.83431780 | 0.61480067 | h | 1.000 | 0 |
| -3.68737934 | -3.37087787 | -1.13030025 | h | 1.000 | 0 |
| 5.20418531 | -2.63315361 | 1.15008300 | h | 1.000 | 0 |
| 4.75155718 | -1.74550361 | -2.03445316 | h | 1.000 | 0 |
| 2.94244033 | 1.03280247 | 2.70873746 | h | 1.000 | 0 |
| 4.12892736 | 2.35441397 | -0.15438500 | h | 1.000 | 0 |

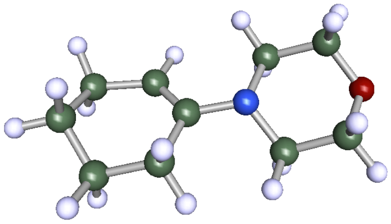
TBO Product:



Total Energy = -399.68611640549 hartree
Enthalpy Correction = 0.200014 hartree
Entropy = 0.000139 hartree/K

```
                 atomic coordinates                atom     charge  isotop
   3.83215794    2.86894342    0.99945679     c       6.000      0
   2.26843736    0.77790387    0.23511595     n       7.000      0
  -0.21638393    0.69240153    0.26119274     c       6.000      0
  -1.15726877   -1.29210457   -1.00705494     n       7.000      0
   0.88617261   -3.08643083   -1.42264201     c       6.000      0
   3.18298928   -1.31864774   -1.33322086     c       6.000      0
  -3.73112473   -1.72534903   -0.13789911     c       6.000      0
  -4.45851786    0.93986765    0.74995291     c       6.000      0
  -1.99095044    2.01699986    1.41726257     n       7.000      0
   2.80088551    4.05619292    2.32719959     h       1.000      0
   4.39624022    4.00526012   -0.63091041     h       1.000      0
   5.51771237    2.14791241    1.93842416     h       1.000      0
   0.94158727   -4.48401611    0.10446963     h       1.000      0
   0.70191693   -4.05189590   -3.22796261     h       1.000      0
   4.83242132   -2.19310501   -0.46825200     h       1.000      0
   3.68884717   -0.61907556   -3.21141550     h       1.000      0
  -3.74739090   -3.08101928    1.42749856     h       1.000      0
  -4.94461953   -2.40959084   -1.64961440     h       1.000      0
  -5.71164293    0.91734747    2.37900611     h       1.000      0
  -5.32603255    2.03205194   -0.77152664     h       1.000      0
  -1.76543633    3.80635368    2.02091944     h       1.000      0
```

4-(Cyclohex-1-en-1-yl)morpholine (MCA* = 419.9 kJ/mol, N = 11.40, $s_{\mathrm{N}}$ = 0.83):

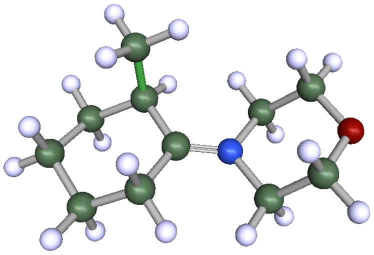


Total Energy = -520.85810937721 hartree
Enthalpy Correction = 0.27469 hartree
Entropy = 0.000161 hartree/K

```
                 atomic coordinates                atom     charge  isotop
  -3.01646431   -5.60117681    1.00819788     c       6.000      0
  -1.92538956   -3.07139066    0.29968588     c       6.000      0
```

| | | | | | |
|---|---|---|---|---|---|
| -3.41181352 | -1.16824082 | -0.47973044 | c | 6.000 | 0 |
| -6.24185551 | -1.28756527 | -0.54705873 | c | 6.000 | 0 |
| -7.26862630 | -3.51301396 | 0.94846118 | c | 6.000 | 0 |
| -5.78821793 | -5.87755378 | 0.29123382 | c | 6.000 | 0 |
| -2.76528739 | -5.86760387 | 3.04953679 | h | 1.000 | 0 |
| -6.90149306 | -1.41119228 | -2.51275688 | h | 1.000 | 0 |
| -7.07779635 | -3.13019575 | 2.97609429 | h | 1.000 | 0 |
| -5.93954290 | -6.22062628 | -1.74620803 | h | 1.000 | 0 |
| -1.95140284 | -7.12354092 | 0.10890426 | h | 1.000 | 0 |
| -2.57101591 | 0.61343690 | -1.03879196 | h | 1.000 | 0 |
| -7.01950989 | 0.48657597 | 0.18488982 | h | 1.000 | 0 |
| -9.28261256 | -3.77224820 | 0.56569073 | h | 1.000 | 0 |
| -6.57524489 | -7.53800291 | 1.23561119 | h | 1.000 | 0 |
| 4.40570630 | -0.17066395 | 1.32083134 | c | 6.000 | 0 |
| 1.74454630 | -0.30925245 | 0.28836368 | c | 6.000 | 0 |
| 0.68328735 | -2.79542761 | 0.70268367 | n | 7.000 | 0 |
| 2.34307396 | -4.74066283 | -0.31614205 | c | 6.000 | 0 |
| 4.98210346 | -4.45942276 | 0.73704488 | c | 6.000 | 0 |
| 5.99169438 | -2.03453608 | 0.24884630 | o | 8.000 | 0 |
| 4.36177330 | -0.40405164 | 3.38500898 | h | 1.000 | 0 |
| 1.75939335 | 0.18772039 | -1.73630595 | h | 1.000 | 0 |
| 2.41682029 | -4.62823767 | -2.39589390 | h | 1.000 | 0 |
| 4.95169521 | -4.79875257 | 2.78682337 | h | 1.000 | 0 |
| 5.23869692 | 1.66322758 | 0.87983486 | h | 1.000 | 0 |
| 0.59293897 | 1.09389361 | 1.26954032 | h | 1.000 | 0 |
| 1.65545632 | -6.61092437 | 0.19208186 | h | 1.000 | 0 |
| 6.24315709 | -5.83137262 | -0.14535671 | h | 1.000 | 0 |

4-(Cyclohex-1-en-1-yl)morpholine Product:

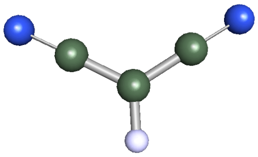


Total Energy = -560.60828044527 hartree
Enthalpy Correction = 0.318963 hartree
Entropy = 0.000172 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.91001230 | -5.10429310 | 1.28669400 | c | 6.000 | 0 |
| -1.69496750 | -2.83885733 | 0.14396603 | c | 6.000 | 0 |
| -3.28943947 | -0.50018293 | 0.01091464 | c | 6.000 | 0 |
| -5.95918567 | -1.10417402 | -0.94825692 | c | 6.000 | 0 |
| -7.21065690 | -3.27477404 | 0.43933180 | c | 6.000 | 0 |
| -5.56145242 | -5.60755170 | 0.25407217 | c | 6.000 | 0 |
| -3.05748995 | -4.67681729 | 3.31243539 | h | 1.000 | 0 |
| -5.83970529 | -1.57026466 | -2.96028442 | h | 1.000 | 0 |
| -7.52151794 | -2.78903843 | 2.42646146 | h | 1.000 | 0 |
| -5.41410325 | -6.21039613 | -1.71911071 | h | 1.000 | 0 |
| -1.75795488 | -6.79282647 | 1.13561647 | h | 1.000 | 0 |
| -7.07315627 | 0.62770593 | -0.79997325 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -9.06880071 | -3.64649738 | -0.38072299 | h | 1.000 | 0 |
| -6.36400723 | -7.18533090 | 1.31258132 | h | 1.000 | 0 |
| 4.26629074 | -0.13936850 | 0.29385795 | c | 6.000 | 0 |
| 2.03892259 | -0.60537596 | -1.45585431 | c | 6.000 | 0 |
| 0.64244715 | -2.83547980 | -0.57595334 | n | 7.000 | 0 |
| 2.36725580 | -5.00557664 | -0.47973183 | c | 6.000 | 0 |
| 4.57558483 | -4.39556604 | 1.24319955 | c | 6.000 | 0 |
| 5.89182873 | -2.24081093 | 0.40139216 | o | 8.000 | 0 |
| 3.57593176 | 0.33124311 | 2.19473377 | h | 1.000 | 0 |
| 2.69931765 | -1.01326958 | -3.36639407 | h | 1.000 | 0 |
| 3.03672337 | -5.31176157 | -2.40672001 | h | 1.000 | 0 |
| 3.89616326 | -4.11193774 | 3.18409984 | h | 1.000 | 0 |
| 5.35166300 | 1.45568540 | -0.42624014 | h | 1.000 | 0 |
| 0.84851904 | 1.05902268 | -1.50266351 | h | 1.000 | 0 |
| 1.41600257 | -6.69852495 | 0.16357563 | h | 1.000 | 0 |
| 5.89304552 | -5.97792627 | 1.22719134 | h | 1.000 | 0 |
| -2.47313711 | 0.82397188 | -1.33289615 | h | 1.000 | 0 |
| -3.29906697 | 0.77101709 | 2.61557748 | c | 6.000 | 0 |
| -4.13527718 | -0.43540108 | 4.06210811 | h | 1.000 | 0 |
| -4.40775131 | 2.50519005 | 2.50004031 | h | 1.000 | 0 |
| -1.38883183 | 1.26597284 | 3.21888940 | h | 1.000 | 0 |

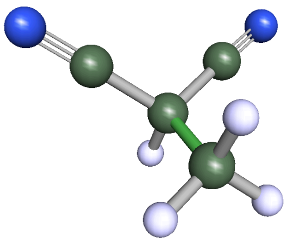
Dicyanomethanide Anion (MCA* = 417.1 kJ/mol, N = 19.36, $s_N$ = 0.67):



Total Energy = -224.35056165709 hartree
Enthalpy Correction = 0.037628 hartree
Entropy = 0.000108 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -0.86577379 | c | 6.000 | 0 |
| -2.27791730 | 0.00000000 | 0.41791198 | c | 6.000 | 0 |
| 2.27791730 | 0.00000000 | 0.41791198 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -2.91079986 | h | 1.000 | 0 |
| 4.21667490 | 0.00000000 | 1.47062119 | n | 7.000 | 0 |
| -4.21667490 | 0.00000000 | 1.47062119 | n | 7.000 | 0 |

Dicyanomethanide Anion Product:

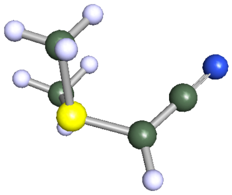


Total Energy = -264.09726084091 hartree
Enthalpy Correction = 0.080675 hartree

Entropy = 0.000123 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.85548072 | 0.21912799 | 0.00000000 | c | 6.000 | 0 |
| 2.12999486 | 1.85152432 | 0.00000000 | h | 1.000 | 0 |
| 1.43383963 | -1.26203962 | 2.26055295 | c | 6.000 | 0 |
| -1.89935628 | 1.13384756 | 0.00000000 | c | 6.000 | 0 |
| -2.22445788 | 2.28233054 | -1.67621885 | h | 1.000 | 0 |
| -3.19440013 | -0.46550726 | 0.00000000 | h | 1.000 | 0 |
| -2.22445788 | 2.28233054 | 1.67621885 | h | 1.000 | 0 |
| 1.84350432 | -2.39250155 | 4.06629440 | n | 7.000 | 0 |
| 1.43383963 | -1.26203962 | -2.26055295 | c | 6.000 | 0 |
| 1.84350432 | -2.39250155 | -4.06629440 | n | 7.000 | 0 |

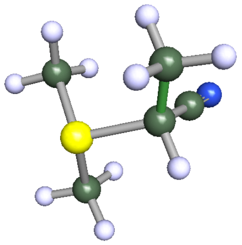
Cyanomethyl Sulfonium Ylide (MCA* = 417.2 kJ/mol, N = 16.23, $s_N$ = 0.60):



Total Energy = -609.23533451877 hartree
Enthalpy Correction = 0.110444 hartree
Entropy = 0.000135 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.40830246 | -1.60466434 | 1.01495583 | c | 6.000 | 0 |
| -0.09344935 | -1.11836333 | -1.40953968 | s | 16.000 | 0 |
| -0.71741323 | 2.14560696 | -2.06675308 | c | 6.000 | 0 |
| 2.79060709 | -1.33669391 | -0.09159718 | c | 6.000 | 0 |
| 3.44536115 | 0.09083608 | 1.99173688 | c | 6.000 | 0 |
| 3.95843145 | 1.31491663 | 3.75157717 | n | 7.000 | 0 |
| -4.27035510 | -1.24790099 | 0.21004834 | h | 1.000 | 0 |
| -2.03866306 | -0.32835829 | 2.58926889 | h | 1.000 | 0 |
| -2.24958121 | -3.56667641 | 1.61173877 | h | 1.000 | 0 |
| -2.66738725 | 2.31280403 | -2.70866962 | h | 1.000 | 0 |
| -0.41352632 | 3.26407534 | -0.36356651 | h | 1.000 | 0 |
| 0.57929223 | 2.71677211 | -3.55785003 | h | 1.000 | 0 |
| 4.08498608 | -2.64235387 | -0.97134976 | h | 1.000 | 0 |

Cyanomethyl Sulfonium Ylide Product:

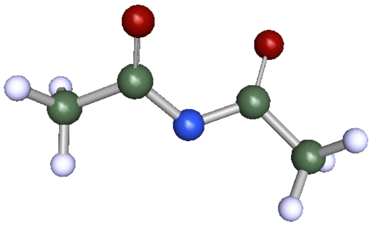


Total Energy = -648.98377600859 hartree
Enthalpy Correction = 0.153702 hartree

Entropy = 0.000145 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.97368505 | 1.04942371 | -1.64139135 | c | 6.000 | 0 |
| 1.96563239 | 0.05005242 | 0.15734688 | c | 6.000 | 0 |
| 2.69451016 | -2.28097311 | 1.40307832 | c | 6.000 | 0 |
| 3.25510326 | -4.15349445 | 2.34805017 | n | 7.000 | 0 |
| -1.01027512 | -0.38284486 | -1.52743247 | s | 16.000 | 0 |
| -0.44197463 | -3.08166883 | -3.44288092 | c | 6.000 | 0 |
| -3.04917002 | -1.58695959 | 0.85233664 | c | 6.000 | 0 |
| 3.29295752 | 2.76967358 | -2.54565231 | h | 1.000 | 0 |
| 5.66160479 | 1.49824862 | -0.55036898 | h | 1.000 | 0 |
| 4.46861811 | -0.34159077 | -3.07520603 | h | 1.000 | 0 |
| 1.50076317 | 1.46159389 | 1.59347895 | h | 1.000 | 0 |
| 0.21361010 | -4.65822693 | -2.29318806 | h | 1.000 | 0 |
| -2.24237603 | -3.52235763 | -4.34007472 | h | 1.000 | 0 |
| 0.93090248 | -2.55449219 | -4.88100580 | h | 1.000 | 0 |
| -3.31621802 | -0.08889273 | 2.23773931 | h | 1.000 | 0 |
| -4.83567341 | -2.00520205 | -0.08195585 | h | 1.000 | 0 |
| -2.24615300 | -3.28181902 | 1.70047526 | h | 1.000 | 0 |

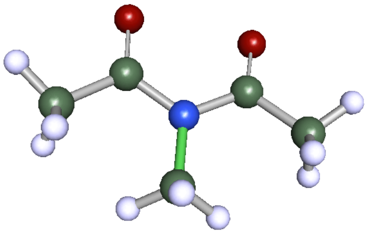
Diacetylamide Anion (MCA* = 413.5 kJ/mol, N = 16.05, $s_N$ = 0.70):



Total Energy = -361.14512948667 hartree
Enthalpy Correction = 0.107253 hartree
Entropy = 0.000139 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.49890230 | -3.03892677 | -0.18454671 | c | 6.000 | 0 |
| -2.84973185 | -2.32492562 | 0.61494939 | c | 6.000 | 0 |
| -6.55181769 | -1.29892228 | -0.56865208 | h | 1.000 | 0 |
| -6.46854740 | -4.04246105 | 1.33242327 | h | 1.000 | 0 |
| -5.49908131 | -4.16746736 | -1.90660028 | h | 1.000 | 0 |
| -1.15912381 | -2.24519277 | -1.28385599 | n | 7.000 | 0 |
| -2.41681550 | -1.96824255 | 2.88803237 | o | 8.000 | 0 |
| 0.92906518 | -0.80753002 | -1.18217836 | c | 6.000 | 0 |
| 1.25313382 | 1.11622077 | 0.11971003 | o | 8.000 | 0 |
| 2.99990872 | -1.56353746 | -3.00400971 | c | 6.000 | 0 |
| 2.58207005 | -3.33248979 | -3.96959467 | h | 1.000 | 0 |
| 3.25891744 | -0.06944982 | -4.40808719 | h | 1.000 | 0 |
| 4.77827394 | -1.73947214 | -1.96913909 | h | 1.000 | 0 |

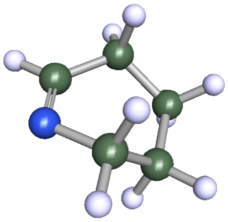
Diacetylamide Anion Product:



Total Energy = -400.89368192196 hartree
Enthalpy Correction = 0.150846 hartree
Entropy = 0.000145 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.59569117 | -3.08707952 | -0.22101296 | c | 6.000 | 0 |
| -3.04969584 | -2.07317181 | 0.52231675 | c | 6.000 | 0 |
| -6.65028608 | -1.68910584 | -1.31481690 | h | 1.000 | 0 |
| -6.62741907 | -3.49889080 | 1.50735817 | h | 1.000 | 0 |
| -5.44403342 | -4.79515120 | -1.36561616 | h | 1.000 | 0 |
| -1.31266289 | -1.72981838 | -1.43642501 | n | 7.000 | 0 |
| -2.55788498 | -1.62535498 | 2.71429318 | o | 8.000 | 0 |
| 1.18988396 | -1.01128876 | -0.97326332 | c | 6.000 | 0 |
| -2.05971669 | -2.36340907 | -4.01730735 | c | 6.000 | 0 |
| 1.87460788 | -0.12225718 | 1.02177413 | o | 8.000 | 0 |
| 3.02790920 | -1.40913281 | -3.10092260 | c | 6.000 | 0 |
| -4.01730961 | -1.83223044 | -4.32334078 | h | 1.000 | 0 |
| -0.93075885 | -1.28755192 | -5.34807920 | h | 1.000 | 0 |
| -1.83374869 | -4.37679046 | -4.40837955 | h | 1.000 | 0 |
| 2.80193197 | -3.24870843 | -4.00188257 | h | 1.000 | 0 |
| 2.77870661 | 0.04115829 | -4.55047222 | h | 1.000 | 0 |
| 4.92202216 | -1.23367043 | -2.32281323 | h | 1.000 | 0 |

Cyclic Imine (MCA* = 410.7 kJ/mol, N = 13.12, $s_N$ = 0.69):

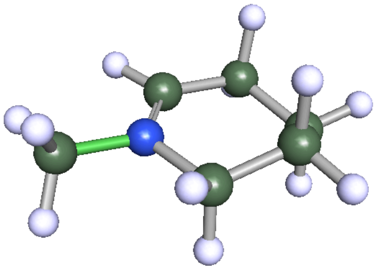


Total Energy = -250.48694412179 hartree
Enthalpy Correction = 0.141654 hartree
Entropy = 0.000120 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.28689508 | 2.12899984 | -0.83751129 | c | 6.000 | 0 |
| 2.24070044 | 0.75884967 | -0.53682700 | c | 6.000 | 0 |
| 2.01669042 | -1.43189576 | 1.31685669 | c | 6.000 | 0 |
| 0.14465268 | -3.25734898 | 0.45378902 | n | 7.000 | 0 |
| -1.95036121 | -2.29904397 | -0.21621917 | c | 6.000 | 0 |
| -2.53592060 | 0.45530820 | -0.05458576 | c | 6.000 | 0 |
| -0.31235507 | 3.84383820 | 0.30955855 | h | 1.000 | 0 |
| -0.52936541 | 2.72306532 | -2.79823990 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 2.84895334 | -0.02337276 | -2.35130573 | h | 1.000 | 0 |
| 3.71791166 | 2.06024686 | 0.08338601 | h | 1.000 | 0 |
| 1.46677762 | -0.71877260 | 3.18844774 | h | 1.000 | 0 |
| 3.82725358 | -2.39359206 | 1.54449066 | h | 1.000 | 0 |
| -3.41580521 | -3.58066817 | -0.89822455 | h | 1.000 | 0 |
| -2.99935548 | 0.83354827 | 1.93226752 | h | 1.000 | 0 |
| -4.23288168 | 0.90083794 | -1.13588280 | h | 1.000 | 0 |

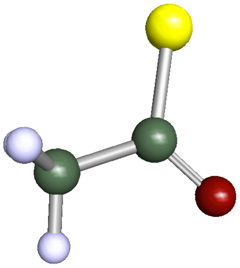
Cyclic Imine Product:



Total Energy = -290.23448105307 hartree
Enthalpy Correction = 0.185580 hartree
Entropy = 0.000127 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.55541746 | -0.34043407 | 0.03553774 | c | 6.000 | 0 |
| 1.83157298 | 0.01910999 | -0.02001043 | n | 7.000 | 0 |
| 0.83626764 | 2.09359017 | -0.74803387 | c | 6.000 | 0 |
| -1.89636983 | 2.59634184 | -0.79184839 | c | 6.000 | 0 |
| -3.46593930 | 0.58408797 | 0.51744276 | c | 6.000 | 0 |
| -2.37634544 | -2.00500516 | -0.05766133 | c | 6.000 | 0 |
| 0.33264481 | -2.16018241 | 0.82652435 | c | 6.000 | 0 |
| 5.49645188 | 1.40226255 | -0.50844892 | h | 1.000 | 0 |
| 5.10612144 | -0.87770061 | 1.94670868 | h | 1.000 | 0 |
| 5.05108696 | -1.85883554 | -1.26476763 | h | 1.000 | 0 |
| 2.12957467 | 3.55859061 | -1.37265144 | h | 1.000 | 0 |
| -2.17901329 | 4.48220168 | 0.00916460 | h | 1.000 | 0 |
| -2.40033971 | 2.79310256 | -2.79662774 | h | 1.000 | 0 |
| -3.44581567 | 0.91006691 | 2.55792159 | h | 1.000 | 0 |
| -5.42527137 | 0.71610835 | -0.10514903 | h | 1.000 | 0 |
| -3.44615541 | -3.49543228 | 0.88183369 | h | 1.000 | 0 |
| -2.45733522 | -2.37294395 | -2.09072543 | h | 1.000 | 0 |
| 0.47220697 | -2.20876879 | 2.88725224 | h | 1.000 | 0 |
| 1.28124044 | -3.83615982 | 0.09353856 | h | 1.000 | 0 |

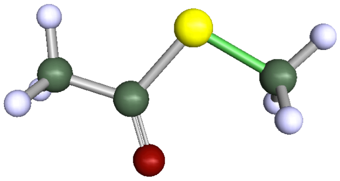
Thioacetate Anion (MCA* = 410.7 kJ/mol, N = 13.12, $s_N$ = 0.69):



Total Energy = -551.35629296177 hartree
Enthalpy Correction = 0.052455 hartree
Entropy = 0.000111 hartree/K

```
                 atomic coordinates                atom    charge  isotop
        2.55251695   -2.21435721   -0.73739515     o       8.000      0
        1.55638691   -0.21953056   -0.07133668     c       6.000      0
       -1.29794859   -0.04329557   -0.04356544     c       6.000      0
        3.20584559    2.43610648    0.88421161     s      16.000      0
       -1.93261950    1.64619030   -1.04035671     h       1.000      0
       -2.13042586   -1.72532094   -0.89990311     h       1.000      0
       -1.95375550    0.12020749    1.90834549     h       1.000      0
```

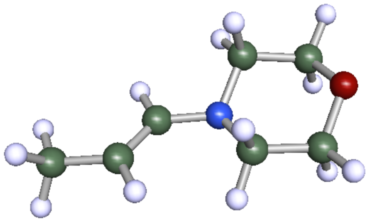
Thioacetate Anion Product:



Total Energy = -591.09817101924 hartree
Enthalpy Correction = 0.093374 hartree
Entropy = 0.000126 hartree/K

```
                 atomic coordinates                atom    charge  isotop
        0.63267121   -3.86739453   -0.95161533     o       8.000      0
        1.03567073   -1.62226061   -0.77694653     c       6.000      0
        2.97901561   -0.51439639    0.95678120     c       6.000      0
       -0.62101278    0.64771643   -2.55101076     s      16.000      0
       -2.70459830   -1.33634966   -4.33789804     c       6.000      0
        2.53280324   -1.07860989    2.89161819     h       1.000      0
        3.06099846    1.53974093    0.84084981     h       1.000      0
        4.82220840   -1.30653462    0.47065933     h       1.000      0
       -3.95481721   -2.37429739   -3.07585844     h       1.000      0
       -1.61733267   -2.64535496   -5.49412179     h       1.000      0
       -3.80909150   -0.08679964   -5.54493704     h       1.000      0
```

(E)-1-(N-morpholino)propene (MCA* = 409.5 kJ/mol, N = 12.06, $s_N$ = 0.80):

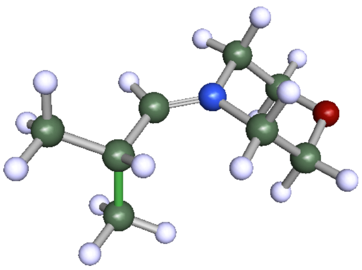


Total Energy = -404.20991168493 hartree
Enthalpy Correction = 0.206702 hartree
Entropy = 0.000145 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 6.78848558 | 0.18868431 | -0.26508340 | c | 6.000 | 0 |
| 4.05569156 | 0.73735917 | 0.18085201 | c | 6.000 | 0 |
| 2.19523442 | -0.63257004 | -0.84536425 | c | 6.000 | 0 |
| -0.38183612 | -0.20150519 | -0.71231766 | n | 7.000 | 0 |
| -1.25891943 | 1.76892927 | 0.96293936 | c | 6.000 | 0 |
| -4.03573683 | 2.27938415 | 0.51082606 | c | 6.000 | 0 |
| -5.50881093 | 0.05966016 | 0.73599659 | o | 8.000 | 0 |
| -4.68402531 | -1.77460537 | -1.02753673 | c | 6.000 | 0 |
| -1.94572005 | -2.45543814 | -0.59652424 | c | 6.000 | 0 |
| 7.03167096 | -1.49368846 | -1.43779097 | h | 1.000 | 0 |
| 7.80095517 | -0.12255165 | 1.51294236 | h | 1.000 | 0 |
| 7.74195391 | 1.76207843 | -1.21542796 | h | 1.000 | 0 |
| 3.61331928 | 2.35345934 | 1.36526734 | h | 1.000 | 0 |
| 2.66854745 | -2.27467111 | -1.99104425 | h | 1.000 | 0 |
| -0.94404085 | 1.24978263 | 2.95681046 | h | 1.000 | 0 |
| -0.20244660 | 3.50341165 | 0.59329010 | h | 1.000 | 0 |
| -4.74584171 | 3.62214617 | 1.90433393 | h | 1.000 | 0 |
| -4.29122627 | 3.08841087 | -1.38569430 | h | 1.000 | 0 |
| -4.93277568 | -1.04482217 | -2.95668575 | h | 1.000 | 0 |
| -5.88208603 | -3.43400882 | -0.78233319 | h | 1.000 | 0 |
| -1.32356552 | -3.78401989 | -2.04940712 | h | 1.000 | 0 |
| -1.75882699 | -3.39542532 | 1.25281914 | h | 1.000 | 0 |

(E)-1-(N-morpholino)propene Product:

The $H_3C$-C-C-N Torsion Angles were constrained to 270°.

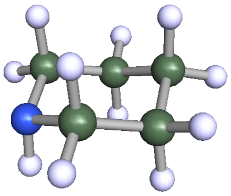


Total Energy = -443.95574673478 hartree
Enthalpy Correction = 0.250871 hartree

Entropy = 0.000157 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.75610637 | -0.86259722 | -2.48954163 | c | 6.000 | 0 |
| -3.41984453 | -0.58746933 | 0.37855386 | c | 6.000 | 0 |
| -5.77232523 | 0.50734924 | 1.62727049 | c | 6.000 | 0 |
| -1.24527472 | 1.11013959 | 0.82477152 | c | 6.000 | 0 |
| 1.06862342 | 0.45962180 | 1.06210525 | n | 7.000 | 0 |
| 2.02782611 | -2.12686712 | 0.91832390 | c | 6.000 | 0 |
| 4.00780324 | -2.26070150 | -1.15858636 | c | 6.000 | 0 |
| 5.96500103 | -0.50633404 | -0.74411607 | o | 8.000 | 0 |
| 5.01367408 | 1.98220554 | -0.71521682 | c | 6.000 | 0 |
| 3.08817389 | 2.32258894 | 1.38235438 | c | 6.000 | 0 |
| -5.40557628 | -2.04572948 | -2.85027082 | h | 1.000 | 0 |
| -2.11215217 | -1.74338644 | -3.36968641 | h | 1.000 | 0 |
| -4.06645677 | 0.97580688 | -3.37539601 | h | 1.000 | 0 |
| -3.03085687 | -2.44833047 | 1.18209605 | h | 1.000 | 0 |
| -6.23187230 | 2.35735861 | 0.83257729 | h | 1.000 | 0 |
| -5.51701764 | 0.71241206 | 3.66337551 | h | 1.000 | 0 |
| -7.36991059 | -0.75249430 | 1.29721962 | h | 1.000 | 0 |
| -1.60054364 | 3.13292296 | 0.90035578 | h | 1.000 | 0 |
| 0.49769715 | -3.44205709 | 0.54587800 | h | 1.000 | 0 |
| 2.87762087 | -2.56453423 | 2.74622801 | h | 1.000 | 0 |
| 4.84177538 | -4.14272926 | -1.16187663 | h | 1.000 | 0 |
| 3.11796488 | -1.92069523 | -3.00269284 | h | 1.000 | 0 |
| 6.59859962 | 3.25478207 | -0.38861952 | h | 1.000 | 0 |
| 4.14906928 | 2.44163898 | -2.54439228 | h | 1.000 | 0 |
| 2.27335732 | 4.21058459 | 1.34930885 | h | 1.000 | 0 |
| 3.95931976 | 1.97361735 | 3.21960074 | h | 1.000 | 0 |

Piperidine (equatorial l.p.) (MCA* = 402.3 kJ/mol, N = 17.35, $s_N$ = 0.68):

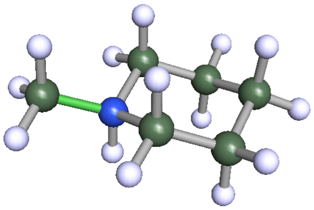


Total Energy = -251.70878388335 hartree
Enthalpy Correction = 0.166189 hartree
Entropy = 0.000118 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.64537859 | -0.41304260 | -2.28013917 | c | 6.000 | 0 |
| 2.97778153 | 0.37629013 | 0.00000000 | n | 7.000 | 0 |
| 1.64537859 | -0.41304260 | 2.28013917 | c | 6.000 | 0 |
| -1.10792711 | 0.42417019 | 2.36512759 | c | 6.000 | 0 |
| -2.50292545 | -0.43768623 | 0.00000000 | c | 6.000 | 0 |
| -1.10792711 | 0.42417019 | -2.36512759 | c | 6.000 | 0 |
| 1.72999375 | -2.48336623 | -2.37044247 | h | 1.000 | 0 |
| 3.10147067 | 2.29112283 | 0.00000000 | h | 1.000 | 0 |
| 1.72999375 | -2.48336623 | 2.37044247 | h | 1.000 | 0 |
| -1.17732236 | 2.49245340 | 2.49424961 | h | 1.000 | 0 |
| -2.62269507 | -2.50795015 | 0.00000000 | h | 1.000 | 0 |
| -1.17732236 | 2.49245340 | -2.49424961 | h | 1.000 | 0 |

```
   2.67458110    0.30310390   -3.92265008     h      1.000     0
   2.67458110    0.30310390    3.92265008     h      1.000     0
  -2.01866802   -0.31893352    4.06761806     h      1.000     0
  -4.44469422    0.27076551    0.00000000     h      1.000     0
  -2.01866802   -0.31893352   -4.06761806     h      1.000     0
```

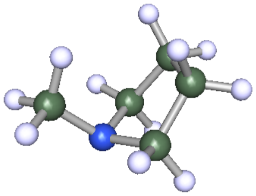
Piperidine (equatorial l.p.) Product:



Total Energy = -291.45357013429 hartree
Enthalpy Correction = 0.211472 hartree
Entropy = 0.000128 hartree/K

```
                 atomic coordinates              atom    charge  isotop
   2.25080488   -0.54598680   -2.35488161     c      6.000     0
   3.66085091    0.30232777    0.00000000     c      6.000     0
   2.25080488   -0.54598680    2.35488161     c      6.000     0
  -0.45601808    0.36621422    2.33179641     c      6.000     0
  -1.79111436   -0.49902905    0.00000000     n      7.000     0
  -0.45601808    0.36621422   -2.33179641     c      6.000     0
   2.27599617   -2.61135729   -2.49394489     h      1.000     0
   3.82898612    2.36555463    0.00000000     h      1.000     0
   2.27599617   -2.61135729    2.49394489     h      1.000     0
  -0.56738728    2.42621617    2.32296625     h      1.000     0
  -1.75834125   -2.42778071    0.00000000     h      1.000     0
  -0.56738728    2.42621617   -2.32296625     h      1.000     0
   3.14502141    0.18108251   -4.06610857     h      1.000     0
   5.57473721   -0.46667683    0.00000000     h      1.000     0
   3.14502141    0.18108251    4.06610857     h      1.000     0
  -1.53049033   -0.34894961    3.93564390     h      1.000     0
  -4.46607966    0.30338528    0.00000000     c      6.000     0
  -1.53049033   -0.34894961   -3.93564390     h      1.000     0
  -5.37845360   -0.43531740    1.68680259     h      1.000     0
  -4.52688716    2.35916206    0.00000000     h      1.000     0
  -5.37845360   -0.43531740   -1.68680259     h      1.000     0
```

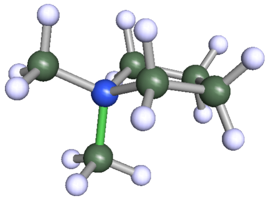
1-Methylpyrrolidine (MCA* = 401.0 kJ/mol, N = 20.6, $s_N = 0.52$):



Total Energy = -251.69039579229 hartree
Enthalpy Correction = 0.165108 hartree
Entropy = 0.000122 hartree/K

```
                atomic coordinates                atom    charge  isotop
   -4.27028584   -5.54838345   -0.78722797     n       7.000      0
   -0.51779666   -3.98778437    1.26783783     c       6.000      0
   -2.63672104   -2.01541190    1.57510463     c       6.000      0
   -1.51631762   -5.77231249   -0.80505402     c       6.000      0
   -4.65033376   -2.84522654   -0.35679190     c       6.000      0
    1.27948932   -3.13789835    0.72113717     h       1.000      0
   -0.19898377   -5.00863934    3.03204584     h       1.000      0
   -3.39676295   -2.04295342    3.49243080     h       1.000      0
   -1.98821959   -0.09375707    1.20247810     h       1.000      0
   -0.94621198   -7.73749546   -0.54748600     h       1.000      0
   -0.82783022   -5.14858306   -2.65322448     h       1.000      0
   -6.58441715   -2.47099647    0.25363322     h       1.000      0
   -4.34824967   -1.85552387   -2.14815681     h       1.000      0
   -5.39108221   -7.05581231    1.22107133     c       6.000      0
   -4.68317772   -6.58892426    3.12093760     h       1.000      0
   -7.43729429   -6.78607996    1.22276254     h       1.000      0
   -5.00924517   -9.05431105    0.87535515     h       1.000      0
```

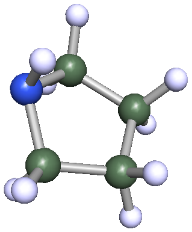
1-Methylpyrrolidine Product:



Total Energy = -291.43553898613 hartree
Enthalpy Correction = 0.21034 hartree
Entropy = 0.000129 hartree/K

```
                atomic coordinates                atom    charge  isotop
   -1.11396723   -0.12783380    0.00000000     n       7.000      0
    0.35893399    0.84803437    2.21641394     c       6.000      0
    3.11646370    0.56561254    1.45721086     c       6.000      0
    3.11646370    0.56561254   -1.45721086     c       6.000      0
    0.35893399    0.84803437   -2.21641394     c       6.000      0
   -3.74425874    0.81435242    0.00000000     c       6.000      0
   -0.17349145    2.82240927    2.45225283     h       1.000      0
    3.90958653   -1.18626537    2.19329891     h       1.000      0
    3.90958653   -1.18626537   -2.19329891     h       1.000      0
   -0.17349145    2.82240927   -2.45225283     h       1.000      0
   -1.12244704   -2.93395724    0.00000000     c       6.000      0
   -0.19634619   -0.19853199    3.89727365     h       1.000      0
    4.21831759    2.11683787    2.24000954     h       1.000      0
    4.21831759    2.11683787   -2.24000954     h       1.000      0
   -0.19634619   -0.19853199   -3.89727365     h       1.000      0
   -4.69670520    0.11885200   -1.68475399     h       1.000      0
   -3.71015100    2.86995462    0.00000000     h       1.000      0
   -4.69670520    0.11885200    1.68475399     h       1.000      0
   -2.09963065   -3.58548276   -1.68708316     h       1.000      0
    0.81254691   -3.62340541    0.00000000     h       1.000      0
   -2.09963065   -3.58548276    1.68708316     h       1.000      0
```

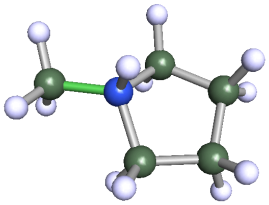
Pyrrolidine (MCA* = 399.3 kJ/mol, N = 18.64, $s_N$ = 0.60):



Total Energy = -212.42043590722 hartree
Enthalpy Correction = 0.136334 hartree
Entropy = 0.000114 hartree/K

```
             atomic coordinates              atom    charge  isotop
 -5.48489963   -5.14596512   -0.87004933     n       7.000     0
 -1.96193492   -3.41792238    1.40897967     c       6.000     0
 -4.12077981   -1.46238852    1.45413061     c       6.000     0
 -2.73072430   -5.27101375   -0.68703514     c       6.000     0
 -6.04051819   -2.46367886   -0.49230656     c       6.000     0
 -0.12080071   -2.55984942    1.04751541     h       1.000     0
 -1.84023733   -4.40582086    3.21754117     h       1.000     0
 -4.97223051   -1.35408317    3.33023996     h       1.000     0
 -3.46909410    0.43250122    0.96302703     h       1.000     0
 -2.10974639   -7.20669909   -0.34083905     h       1.000     0
 -1.93217031   -4.66430454   -2.49812886     h       1.000     0
 -8.00233566   -2.20591811    0.08745282     h       1.000     0
 -5.78649894   -1.48826128   -2.29950535     h       1.000     0
 -6.21998775   -6.11943478    0.61168984     h       1.000     0
```

Pyrrolidine Product:

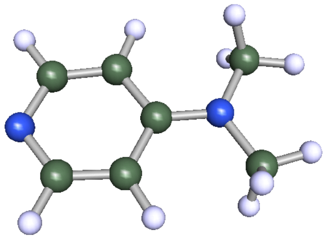


Total Energy = -252.16425167492 hartree
Enthalpy Correction = 0.181475 hartree
Entropy = 0.000123 hartree/K

```
             atomic coordinates              atom    charge  isotop
 -5.29186218   -4.05834492    2.30767018     c       6.000     0
 -2.57798170   -3.31087036    2.18412086     n       7.000     0
 -1.74152065   -4.13983375   -0.38473725     c       6.000     0
 -4.04363793   -3.75259414   -2.08354970     c       6.000     0
 -6.28739973   -3.32718898   -0.27449364     c       6.000     0
 -6.18764649   -3.11119525    3.89701418     h       1.000     0
 -2.50240419   -1.38605480    2.23678820     h       1.000     0
 -1.23090848   -6.12607863   -0.20848679     h       1.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -4.32209258 | -5.41574894 | -3.26315195 | h | 1.000 | 0 |
| -6.85234861 | -1.34453594 | -0.27423601 | h | 1.000 | 0 |
| -5.32137728 | -6.09689299 | 2.61109751 | h | 1.000 | 0 |
| -1.00839307 | -4.29203287 | 4.26628424 | c | 6.000 | 0 |
| -0.07636251 | -3.05982720 | -0.91795804 | h | 1.000 | 0 |
| -3.78477457 | -2.13482170 | -3.32881716 | h | 1.000 | 0 |
| -7.93646798 | -4.45152534 | -0.77369312 | h | 1.000 | 0 |
| 0.93000548 | -3.66750171 | 3.98791293 | h | 1.000 | 0 |
| -1.10620355 | -6.34596651 | 4.23857927 | h | 1.000 | 0 |
| -1.73652257 | -3.56635591 | 6.04576767 | h | 1.000 | 0 |

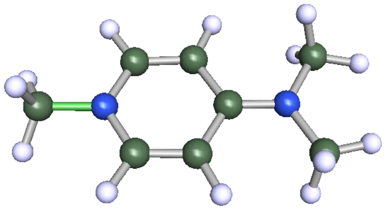
DMAP (MCA* = 397.4 kJ/mol, N = 14.80, $s_N$ = 0.67):



Total Energy = -381.9689329 hartree
Enthalpy Correction = 0.172471 hartree
Entropy = 0.000142 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.34406109 | -1.92719648 | -1.62688858 | c | 6.000 | 0 |
| -2.08913203 | -0.10817604 | -0.02420119 | n | 7.000 | 0 |
| -3.55414143 | 1.38898442 | 1.72660315 | c | 6.000 | 0 |
| 0.45725899 | 0.06298637 | -0.03345294 | c | 6.000 | 0 |
| 1.97261716 | -1.42743187 | -1.64041461 | c | 6.000 | 0 |
| 4.56289265 | -1.15817415 | -1.57404312 | c | 6.000 | 0 |
| 5.81383739 | 0.43848022 | -0.06925050 | n | 7.000 | 0 |
| 4.37249474 | 1.84195265 | 1.45770916 | c | 6.000 | 0 |
| 1.77148947 | 1.74298175 | 1.56350840 | c | 6.000 | 0 |
| -2.81171405 | -3.86980333 | -1.14824040 | h | 1.000 | 0 |
| -2.89921764 | -1.60874217 | -3.62107125 | h | 1.000 | 0 |
| -5.37608685 | -1.73812786 | -1.38813275 | h | 1.000 | 0 |
| -3.11185481 | 0.92206158 | 3.69463394 | h | 1.000 | 0 |
| -3.22063430 | 3.41133579 | 1.45219816 | h | 1.000 | 0 |
| -5.55128931 | 1.02308977 | 1.41048276 | h | 1.000 | 0 |
| 1.14730207 | -2.78286327 | -2.92732148 | h | 1.000 | 0 |
| 5.71136923 | -2.31593215 | -2.82335051 | h | 1.000 | 0 |
| 5.36533741 | 3.14596156 | 2.69619193 | h | 1.000 | 0 |
| 0.78353240 | 2.95861324 | 2.87503983 | h | 1.000 | 0 |

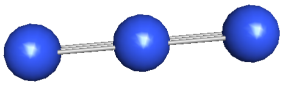
DMAP Product:



Total Energy = -421.7101611 hartree
Enthalpy Correction = 0.216336 hartree
Entropy = 0.000153 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.93104234 | -2.34811083 | -0.80928642 | c | 6.000 | 0 |
| 3.61696669 | -0.03782699 | -0.14184529 | n | 7.000 | 0 |
| 5.06351282 | 2.23379827 | 0.36513148 | c | 6.000 | 0 |
| 1.10576414 | -0.00550272 | 0.01676170 | c | 6.000 | 0 |
| -0.24565602 | 2.21402935 | 0.66889780 | c | 6.000 | 0 |
| -2.81179345 | 2.17093436 | 0.81964816 | c | 6.000 | 0 |
| -4.15791710 | 0.05956321 | 0.35632277 | n | 7.000 | 0 |
| -6.89885653 | 0.05681409 | 0.64549643 | c | 6.000 | 0 |
| -2.93424956 | -2.08368960 | -0.27528228 | c | 6.000 | 0 |
| -0.37314661 | -2.18837826 | -0.46302026 | c | 6.000 | 0 |
| 6.94988187 | -1.97869248 | -0.83174323 | h | 1.000 | 0 |
| 4.36697181 | -3.01064965 | -2.68254147 | h | 1.000 | 0 |
| 4.55489297 | -3.84137420 | 0.56741806 | h | 1.000 | 0 |
| 4.56420345 | 3.74323007 | -0.95346216 | h | 1.000 | 0 |
| 7.05976073 | 1.81117779 | 0.14332867 | h | 1.000 | 0 |
| 4.74746014 | 2.90171464 | 2.29421656 | h | 1.000 | 0 |
| 0.70879945 | 3.97509279 | 1.05358636 | h | 1.000 | 0 |
| -3.88782931 | 3.83549254 | 1.31713607 | h | 1.000 | 0 |
| -7.60719901 | 1.95923096 | 0.32856382 | h | 1.000 | 0 |
| -7.40312348 | -0.56346244 | 2.54426978 | h | 1.000 | 0 |
| -7.72178583 | -1.21764141 | -0.74141426 | h | 1.000 | 0 |
| -4.10683352 | -3.71995172 | -0.62808424 | h | 1.000 | 0 |
| 0.47913400 | -3.96579777 | -0.98672325 | h | 1.000 | 0 |

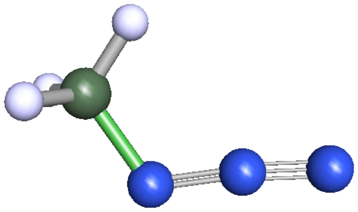
Azide Anion (MCA* = 394.2 kJ/mol, N = 20.50, $s_N$ = 0.59):



Total Energy = -164.22162021667 hartree
Enthalpy Correction = 0.013693 hartree
Entropy = 0.000061 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.21069394 | 0.08162507 | 0.00000000 | n | 7.000 | 0 |
| 0.00001128 | 0.00004787 | 0.00000000 | n | 7.000 | 0 |
| -2.21070522 | -0.08167294 | 0.00000000 | n | 7.000 | 0 |

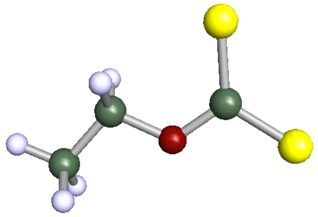
Azide Anion Product:



Total Energy = -203.94960169644 hartree
Enthalpy Correction = 0.056298 hartree
Entropy = 0.000108 hartree/K

```
               atomic coordinates                   atom     charge  isotop
    4.65695085    0.66605825   -0.03792942     n      7.000     0
    2.73376236   -0.25285960    0.03311832     n      7.000     0
    0.77732473   -1.44175166    0.12651321     n      7.000     0
   -1.58550524    0.00592887   -0.00696575     c      6.000     0
   -1.23843092    2.03003761   -0.17989461     h      1.000     0
   -2.67865355   -0.36003335    1.70114094     h      1.000     0
   -2.66544823   -0.64738011   -1.63598270     h      1.000     0
```

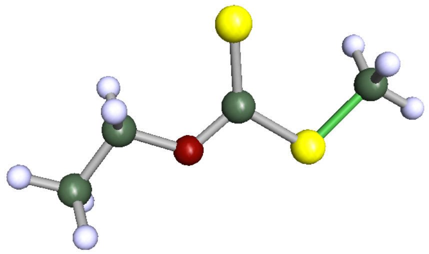
Xanthate Anion (MCA* = 391.1 kJ/mol, N = 19.30, $s_N = 0.69$):



Total Energy = -988.69742284954 hartree
Enthalpy Correction = 0.086483 hartree
Entropy = 0.000133 hartree/K

```
               atomic coordinates                   atom     charge  isotop
    2.88312796    3.12645161    4.72037243     s     16.000     0
    3.49325355    0.68046905    2.77676515     c      6.000     0
    1.68210506   -0.28388182    1.29437460     o      8.000     0
   -0.82546175    0.73887767    1.33086824     c      6.000     0
   -2.38367106   -0.78001002   -0.50198599     c      6.000     0
    6.31660083   -0.79360702    2.46303378     s     16.000     0
   -1.56645109    0.62515379    3.25447838     h      1.000     0
   -0.74140576    2.73389386    0.80648269     h      1.000     0
   -2.44869156   -2.76728891    0.04997954     h      1.000     0
   -1.61803111   -0.64937899   -2.41386001     h      1.000     0
   -4.31418815   -0.05150840   -0.52651942     h      1.000     0
```

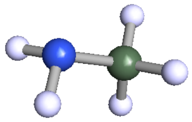
Xanthate Anion Product:



Total Energy = -1028.43209633714 hartree
Enthalpy Correction = 0.127392 hartree
Entropy = 0.000148 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.15947768 | 3.24538155 | -2.92764250 | s | 16.000 | 0 |
| 0.58552908 | 1.48180161 | -0.48723520 | c | 6.000 | 0 |
| 2.93115923 | 2.11977888 | 1.73085464 | s | 16.000 | 0 |
| 4.21258749 | 5.05382149 | 0.65959333 | c | 6.000 | 0 |
| -0.48102384 | -0.67711255 | 0.15253942 | o | 8.000 | 0 |
| -2.50543930 | -1.67919504 | -1.37279166 | c | 6.000 | 0 |
| -3.32321462 | -4.12603895 | -0.18734345 | c | 6.000 | 0 |
| 2.77037126 | 6.52083655 | 0.67495658 | h | 1.000 | 0 |
| 5.70225590 | 5.51247691 | 2.00840783 | h | 1.000 | 0 |
| 5.00713584 | 4.84914913 | -1.22695953 | h | 1.000 | 0 |
| -4.02430765 | -0.28385966 | -1.42129486 | h | 1.000 | 0 |
| -1.79597173 | -1.93551040 | -3.29294368 | h | 1.000 | 0 |
| -1.77125145 | -5.48407704 | -0.14156621 | h | 1.000 | 0 |
| -4.00896355 | -3.82714041 | 1.73477539 | h | 1.000 | 0 |
| -4.85778096 | -4.93165733 | -1.30622518 | h | 1.000 | 0 |

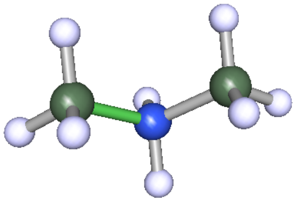
Methanamine (MCA* = 389.2 kJ/mol, N = 15.19, $s_{\mathrm{N}}$ = 0.68):



Total Energy = -95.78704451254 hartree
Enthalpy Correction = 0.068833 hartree
Entropy = 0.000091 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.07537958 | 0.03053886 | 0.00000000 | c | 6.000 | 0 |
| 1.61956496 | 0.61375034 | 0.00000000 | n | 7.000 | 0 |
| -1.96372443 | 0.87005968 | -1.66358884 | h | 1.000 | 0 |
| -1.51662883 | -1.99682200 | 0.00000000 | h | 1.000 | 0 |
| -1.96372443 | 0.87005968 | 1.66358884 | h | 1.000 | 0 |
| 2.45002723 | -0.19395619 | 1.52556173 | h | 1.000 | 0 |
| 2.45002723 | -0.19395619 | -1.52556173 | h | 1.000 | 0 |

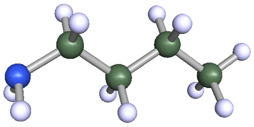
Methanamine Product:



Total Energy = -135.52824241474 hartree
Enthalpy Correction = 0.115209 hartree
Entropy = 0.0001 hartree/K

```
                 atomic coordinates              atom    charge  isotop
   0.00000000   -2.33642745   -0.43270688     c      6.000     0
   0.00000000    0.00000000    1.10110823     n      7.000     0
   0.00000000    2.33642745   -0.43270688     c      6.000     0
   0.00000000   -3.95823508    0.82739164     h      1.000     0
  -1.68688140   -2.33615153   -1.60696732     h      1.000     0
   1.68688140   -2.33615153   -1.60696732     h      1.000     0
   1.53352452    0.00000000    2.26671839     h      1.000     0
  -1.53352452    0.00000000    2.26671839     h      1.000     0
   0.00000000    3.95823508    0.82739164     h      1.000     0
  -1.68688140    2.33615153   -1.60696732     h      1.000     0
   1.68688140    2.33615153   -1.60696732     h      1.000     0
```

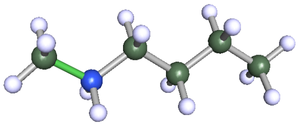
Butan-1-amine (MCA* = 389.0 kJ/mol, N = 15.27, $s_N$ = 0.63):



Total Energy = -213.63253619997 hartree
Enthalpy Correction = 0.158341 hartree
Entropy = 0.000126 hartree/K

```
                 atomic coordinates              atom    charge  isotop
  -5.15639887    0.58328025    0.00000000     n      7.000     0
  -2.56893147    1.53558579    0.00000000     c      6.000     0
  -5.41683813   -0.54737764    1.52708195     h      1.000     0
  -5.41683813   -0.54737764   -1.52708195     h      1.000     0
  -0.51005890   -0.46986793    0.00000000     c      6.000     0
  -2.33353636    2.75527359   -1.65615951     h      1.000     0
  -2.33353636    2.75527359    1.65615951     h      1.000     0
  -0.75450793   -1.68669443    1.66114205     h      1.000     0
  -0.75450793   -1.68669443   -1.66114205     h      1.000     0
   2.14061477    0.63680142    0.00000000     c      6.000     0
   2.36589885    1.86041085    1.65613960     h      1.000     0
   2.36589885    1.86041085   -1.65613960     h      1.000     0
   4.19488002   -1.36900844    0.00000000     c      6.000     0
   6.07983846   -0.52534584    0.00000000     h      1.000     0
   4.04533113   -2.58102624    1.66788741     h      1.000     0
   4.04533113   -2.58102624   -1.66788741     h      1.000     0
```

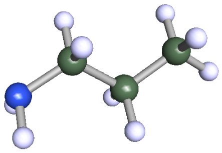
Butan-1-amine Product:



Total Energy = -253.37296769400 hartree
Enthalpy Correction = 0.204341 hartree
Entropy = 0.000136 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.17898696 | -3.18458440 | 0.17960933 | n | 7.000 | 0 |
| -0.76753537 | -1.78812286 | -0.17175639 | c | 6.000 | 0 |
| -4.86187311 | -3.11377530 | -2.04924458 | c | 6.000 | 0 |
| -2.79013587 | -5.01877573 | 0.62762946 | h | 1.000 | 0 |
| -4.11040211 | -2.46633574 | 1.70679003 | h | 1.000 | 0 |
| -6.56642413 | -4.17811549 | -1.62350174 | h | 1.000 | 0 |
| -5.32548156 | -1.15307666 | -2.45254811 | h | 1.000 | 0 |
| -3.87129009 | -3.95741233 | -3.63953738 | h | 1.000 | 0 |
| 0.86217343 | -1.94171445 | 2.16561466 | c | 6.000 | 0 |
| 0.16481304 | -2.62344341 | -1.80845465 | h | 1.000 | 0 |
| -1.27283991 | 0.15801743 | -0.62339662 | h | 1.000 | 0 |
| -0.16972657 | -1.15711828 | 3.78005245 | h | 1.000 | 0 |
| 1.25703983 | -3.92685418 | 2.60208031 | h | 1.000 | 0 |
| 3.33500145 | -0.51968009 | 1.81671739 | c | 6.000 | 0 |
| 2.92480630 | 1.45778060 | 1.36335626 | h | 1.000 | 0 |
| 5.00593545 | -0.65445407 | 4.14563565 | c | 6.000 | 0 |
| 4.34350811 | -1.29893202 | 0.18594457 | h | 1.000 | 0 |
| 6.76940901 | 0.37871881 | 3.85908018 | h | 1.000 | 0 |
| 4.05358604 | 0.15976780 | 5.78879513 | h | 1.000 | 0 |
| 5.48407454 | -2.61248932 | 4.60098645 | h | 1.000 | 0 |

Propan-1-amine (MCA* = 388.6 kJ/mol, N = 15.11, $s_N$ = 0.63):

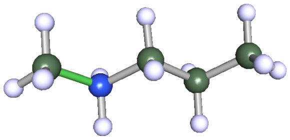


Total Energy = -174.35186612957 hartree
Enthalpy Correction = 0.128452 hartree
Entropy = 0.000114 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.28143728 | -1.17977449 | -2.97457349 | n | 7.000 | 0 |
| -1.50590981 | -1.42058371 | -0.34037519 | c | 6.000 | 0 |
| -2.40533424 | -2.92373911 | -3.76285641 | h | 1.000 | 0 |
| -0.91154518 | -0.26749120 | -3.95916755 | h | 1.000 | 0 |
| 0.99213832 | -2.77488236 | 0.09861804 | c | 6.000 | 0 |
| -3.00803690 | -2.41108017 | 0.68462712 | h | 1.000 | 0 |
| -1.40153849 | 0.47895744 | 0.47697782 | h | 1.000 | 0 |
| 1.67436098 | -2.95525776 | 2.88184259 | c | 6.000 | 0 |
| 0.87801437 | -4.67149673 | -0.72653917 | h | 1.000 | 0 |
| 2.48426698 | -1.77279437 | -0.93181795 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 1.83496577 | -1.07675776 | 3.72989890 | h | 1.000 | 0 |
| 3.47395372 | -3.92766231 | 3.15909001 | h | 1.000 | 0 |
| 0.22908153 | -3.99359179 | 3.93369868 | h | 1.000 | 0 |

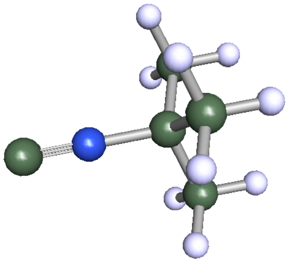
Propan-1-amine Product:



Total Energy = -214.09204543299 hartree
Enthalpy Correction = 0.174647 hartree
Entropy = 0.000125 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.56514726 | -3.52976442 | 1.14208845 | n | 7.000 | 0 |
| -1.46134057 | -1.73831148 | 0.63867158 | c | 6.000 | 0 |
| -3.04813496 | -5.29406159 | 0.56294917 | h | 1.000 | 0 |
| -3.83679104 | -3.66968612 | 3.04543796 | h | 1.000 | 0 |
| -5.97218119 | -2.82079613 | -0.08698596 | c | 6.000 | 0 |
| -5.67082563 | -2.75377330 | -2.11846302 | h | 1.000 | 0 |
| -7.39124500 | -4.23094292 | 0.37903397 | h | 1.000 | 0 |
| -6.54146697 | -0.97521845 | 0.61395508 | h | 1.000 | 0 |
| -1.21842128 | -1.67146099 | -1.40675458 | h | 1.000 | 0 |
| -2.09313008 | 0.11258810 | 1.28767755 | h | 1.000 | 0 |
| 0.93240969 | -2.55813895 | 1.96142690 | c | 6.000 | 0 |
| 0.58337401 | -2.67581345 | 3.99698233 | h | 1.000 | 0 |
| 1.45368906 | -4.45470490 | 1.32157445 | h | 1.000 | 0 |
| 3.07565872 | -0.72194151 | 1.43770798 | c | 6.000 | 0 |
| 2.60392126 | 1.17796028 | 2.09626893 | h | 1.000 | 0 |
| 4.79643279 | -1.32070453 | 2.40247449 | h | 1.000 | 0 |
| 3.48333600 | -0.61345508 | -0.58396167 | h | 1.000 | 0 |

2-Isocyano-2-methylpropane (MCA* = 388.5 kJ/mol, N = 5.47, $s_N$ = 0.77):

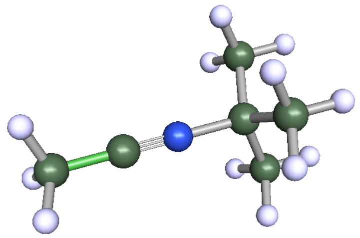


Total Energy = -250.46647213288 hartree
Enthalpy Correction = 0.138435 hartree
Entropy = 0.000124 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | 0.34123000 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 3.05977103 | n | 7.000 | 0 |
| 1.37134581 | -2.37524062 | -0.54531518 | c | 6.000 | 0 |
| 1.37134581 | 2.37524062 | -0.54531518 | c | 6.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.74269162 | 0.00000000 | -0.54531518 | c | 6.000 | 0 |
| 3.31829885 | 2.39156849 | 0.13342832 | h | 1.000 | 0 |
| 1.39088997 | 2.40909210 | -2.60695372 | h | 1.000 | 0 |
| 0.41200964 | 4.06951535 | 0.13342832 | h | 1.000 | 0 |
| 0.41200964 | -4.06951535 | 0.13342832 | h | 1.000 | 0 |
| 3.31829885 | -2.39156849 | 0.13342832 | h | 1.000 | 0 |
| 1.39088997 | -2.40909210 | -2.60695372 | h | 1.000 | 0 |
| -3.73030849 | -1.67794686 | 0.13342832 | h | 1.000 | 0 |
| -2.78177994 | 0.00000000 | -2.60695372 | h | 1.000 | 0 |
| -3.73030849 | 1.67794686 | 0.13342832 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 5.25390063 | c | 6.000 | 0 |

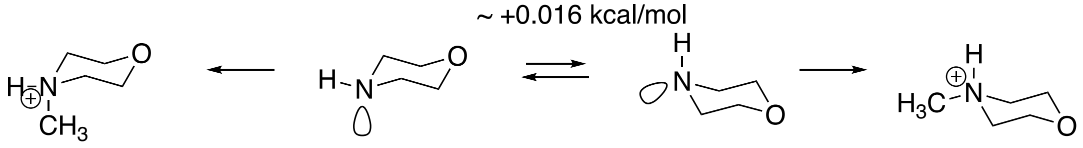
2-Isocyano-2-methylpropane Product:

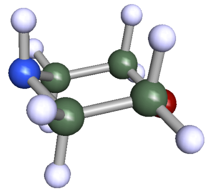


Total Energy = -290.20106428905 hartree
Enthalpy Correction = 0.180574 hartree
Entropy = 0.00014 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -1.46418444 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.27464529 | n | 7.000 | 0 |
| 0.14902122 | -2.74887834 | -2.30453214 | c | 6.000 | 0 |
| 2.30608786 | 1.50349533 | -2.30453214 | c | 6.000 | 0 |
| -2.45510908 | 1.24538300 | -2.30453214 | c | 6.000 | 0 |
| -1.47517678 | -3.81956640 | -1.62275191 | h | 1.000 | 0 |
| 0.14965029 | -2.78970187 | -4.36472855 | h | 1.000 | 0 |
| 1.88191318 | -3.63240246 | -1.62463195 | h | 1.000 | 0 |
| -2.49077783 | 1.26524998 | -4.36472855 | h | 1.000 | 0 |
| -2.57025314 | 3.18732377 | -1.62275191 | h | 1.000 | 0 |
| -4.08670940 | 0.18641660 | -1.62463195 | h | 1.000 | 0 |
| 2.20479621 | 3.44598585 | -1.62463195 | h | 1.000 | 0 |
| 4.04542992 | 0.63224263 | -1.62275191 | h | 1.000 | 0 |
| 2.34112754 | 1.52445189 | -4.36472855 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 3.42709227 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 6.12654799 | c | 6.000 | 0 |
| -0.42262698 | 1.90539805 | 6.79478073 | h | 1.000 | 0 |
| -1.43880963 | -1.31870473 | 6.79478073 | h | 1.000 | 0 |
| 1.86143661 | -0.58669332 | 6.79478073 | h | 1.000 | 0 |

Morpholine (equatorial l.p.) (MCA* = 388.4 kJ/mol, N = 15.65, $s_N$ = 0.74):

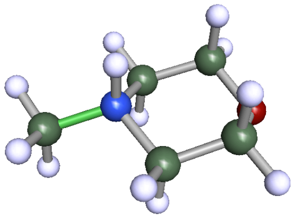




Total Energy = -287.59229345716 hartree
Enthalpy Correction = 0.142183 hartree
Entropy = 0.000116 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.79534518 | 0.59458407 | 0.00000000 | o | 8.000 | 0 |
| 1.55603943 | -0.28000129 | 2.20930874 | c | 6.000 | 0 |
| -1.17936400 | 0.56930454 | 2.26278831 | c | 6.000 | 0 |
| -2.56389350 | -0.17571139 | 0.00000000 | n | 7.000 | 0 |
| -1.17936400 | 0.56930454 | -2.26278831 | c | 6.000 | 0 |
| 1.55603943 | -0.28000129 | -2.20930874 | c | 6.000 | 0 |
| 1.64843091 | -2.35748407 | 2.27726450 | h | 1.000 | 0 |
| 2.60589144 | 0.47405686 | 3.81848554 | h | 1.000 | 0 |
| -1.24193284 | 2.63441961 | 2.40955725 | h | 1.000 | 0 |
| -2.12213111 | -0.20675193 | 3.92873058 | h | 1.000 | 0 |
| -2.76359796 | -2.08419390 | 0.00000000 | h | 1.000 | 0 |
| -1.24193284 | 2.63441961 | -2.40955725 | h | 1.000 | 0 |
| -2.12213111 | -0.20675193 | -3.92873058 | h | 1.000 | 0 |
| 2.60589144 | 0.47405686 | -3.81848554 | h | 1.000 | 0 |
| 1.64843091 | -2.35748407 | -2.27726450 | h | 1.000 | 0 |

Morpholine (equatorial l.p.) Product:

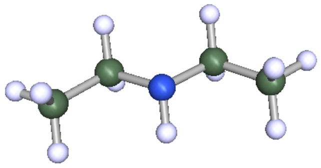


Total Energy = -327.33169346444 hartree
Enthalpy Correction = 0.187377 hartree
Entropy = 0.000126 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.23298299 | -5.71603939 | 0.64391953 | c | 6.000 | 0 |
| -0.31292785 | -3.31875509 | -0.07236573 | o | 8.000 | 0 |
| -1.81964903 | -1.38959259 | 0.98383442 | c | 6.000 | 0 |
| -4.52164357 | -1.56912711 | 0.08336526 | c | 6.000 | 0 |
| -5.58015866 | -4.09646130 | 0.73545374 | n | 7.000 | 0 |
| -3.90413949 | -6.12240398 | -0.27529512 | c | 6.000 | 0 |
| -1.14774920 | -5.92454709 | 2.70831531 | h | 1.000 | 0 |
| -1.74856089 | -1.48452963 | 3.05696873 | h | 1.000 | 0 |
| -4.64215285 | -1.38899175 | -1.96573831 | h | 1.000 | 0 |
| -5.58848802 | -4.24930831 | 2.65924047 | h | 1.000 | 0 |
| -4.01535139 | -6.01106235 | -2.32975532 | h | 1.000 | 0 |
| -0.00917050 | -7.13767932 | -0.20444950 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -1.03401248 | 0.41767363 | 0.38805564 | h | 1.000 | 0 |
| -5.70292887 | -0.13711619 | 0.97208286 | h | 1.000 | 0 |
| -8.21387984 | -4.38325321 | -0.15137419 | c | 6.000 | 0 |
| -4.64487283 | -7.93456986 | 0.35904466 | h | 1.000 | 0 |
| -8.90125085 | -6.23298229 | 0.42228044 | h | 1.000 | 0 |
| -9.35601625 | -2.89882870 | 0.69448120 | h | 1.000 | 0 |
| -8.22934597 | -4.21794769 | -2.20089643 | h | 1.000 | 0 |

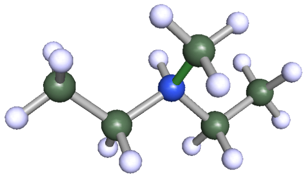
Diethylamine (MCA* = 388.1 kJ/mol, N = 15.10, $s_\mathrm{N}$ = 0.73):



Total Energy = -213.62380749306 hartree
Enthalpy Correction = 0.157531 hartree
Entropy = 0.000126 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.98893130 | -4.12721058 | 0.45718760 | n | 7.000 | 0 |
| -1.04833143 | -2.19554332 | 0.27145590 | c | 6.000 | 0 |
| -2.43414112 | -5.42828678 | 1.75423581 | h | 1.000 | 0 |
| -3.45110075 | -5.40959766 | -1.92458822 | c | 6.000 | 0 |
| -0.51926731 | -1.00722926 | 2.81923064 | c | 6.000 | 0 |
| 0.72197586 | -2.95443215 | -0.52824775 | h | 1.000 | 0 |
| -1.71344416 | -0.75109379 | -1.05451352 | h | 1.000 | 0 |
| 0.92209207 | 0.46105014 | 2.65710760 | h | 1.000 | 0 |
| 0.16688275 | -2.42095479 | 4.16288311 | h | 1.000 | 0 |
| -2.23100523 | -0.15847450 | 3.60247180 | h | 1.000 | 0 |
| -5.36669195 | -7.51185590 | -1.61682850 | c | 6.000 | 0 |
| -1.69316196 | -6.17879875 | -2.74183779 | h | 1.000 | 0 |
| -4.15564685 | -4.00751485 | -3.27576930 | h | 1.000 | 0 |
| -7.15447712 | -6.77374846 | -0.89390200 | h | 1.000 | 0 |
| -4.68219800 | -8.94381581 | -0.29187925 | h | 1.000 | 0 |
| -5.72764682 | -8.44399347 | -3.42254919 | h | 1.000 | 0 |

Diethylamine Product:

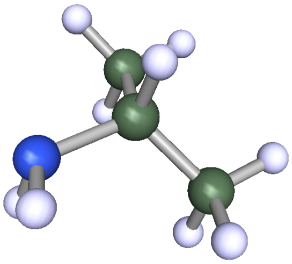


Total Energy = -253.36406072422 hartree
Enthalpy Correction = 0.203403 hartree
Entropy = 0.000135 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.03652119 | 0.32317667 | 0.00000000 | n | 7.000 | 0 |
| 1.37347975 | -0.47150464 | 2.31906228 | c | 6.000 | 0 |
| -2.67186075 | -0.61326925 | 0.00000000 | c | 6.000 | 0 |
| -0.10120429 | 2.25151839 | 0.00000000 | h | 1.000 | 0 |
| 1.37347975 | -0.47150464 | -2.31906228 | c | 6.000 | 0 |

```
-3.63626695    0.08163652    1.67225083     h       1.000      0
-2.62433505   -2.66949553    0.00000000     h       1.000      0
-3.63626695    0.08163652   -1.67225083     h       1.000      0
 1.39236407   -2.53238441    2.29888005     h       1.000      0
 0.25412574    0.57282743    4.72313675     c       6.000      0
 3.30367055    0.20004754    2.06963127     h       1.000      0
 1.53001056    0.11155123    6.27472947     h       1.000      0
 0.08300191    2.62821232    4.63552852     h       1.000      0
-1.58594741   -0.23913085    5.16582610     h       1.000      0
 1.39236407   -2.53238441   -2.29888005     h       1.000      0
 0.25412574    0.57282743   -4.72313675     c       6.000      0
 3.30367055    0.20004754   -2.06963127     h       1.000      0
 0.08300191    2.62821232   -4.63552852     h       1.000      0
-1.58594741   -0.23913085   -5.16582610     h       1.000      0
 1.53001056    0.11155123   -6.27472947     h       1.000      0
```

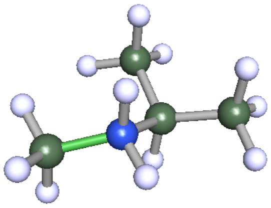
Propan-2-amine (MCA* = 387.8 kJ/mol, N = 13.77, $s_N$ = 0.70):



Total Energy = -174.35505046185 hartree
Enthalpy Correction = 0.127706 hartree
Entropy = 0.000113 hartree/K

```
                 atomic coordinates              atom    charge  isotop
-3.75910186   -3.10068074    0.32766861     n       7.000      0
-1.64499439   -1.33373267    0.07588199     c       6.000      0
-3.61928094   -4.43482744   -1.04716127     h       1.000      0
-3.59680621   -4.05530860    1.98350040     h       1.000      0
-1.84114993    0.00837669   -2.45112621     c       6.000      0
 0.92702183   -2.58614925    0.39458037     c       6.000      0
-1.86875132    0.07562040    1.57854289     h       1.000      0
 2.45858513   -1.20236659    0.28352101     h       1.000      0
 1.22685155   -3.99550037   -1.09061277     h       1.000      0
 1.05701839   -3.54140464    2.22205942     h       1.000      0
-1.66171560   -1.35116780   -4.00183276     h       1.000      0
-3.66186842    0.96191388   -2.63906915     h       1.000      0
-0.34000901    1.40898166   -2.66339426     h       1.000      0
```

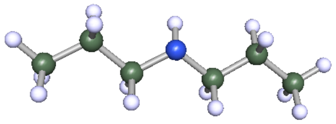
Propan-2-amine Product:



Total Energy = -214.09443817033 hartree
Enthalpy Correction = 0.173421 hartree
Entropy = 0.000124 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.98321614 | -4.05111063 | 0.95431343 | n | 7.000 | 0 |
| -1.32424096 | -1.79672717 | 0.48160202 | c | 6.000 | 0 |
| -5.72264278 | -3.52711326 | 1.12296467 | c | 6.000 | 0 |
| -2.68175835 | -5.32584754 | -0.45933119 | h | 1.000 | 0 |
| -2.39983613 | -4.93027123 | 2.57024655 | h | 1.000 | 0 |
| -6.09364089 | -2.37836830 | 2.78203217 | h | 1.000 | 0 |
| -6.71368959 | -5.31959217 | 1.27904582 | h | 1.000 | 0 |
| -6.30259569 | -2.53955767 | -0.58346586 | h | 1.000 | 0 |
| -1.46985092 | 0.01640889 | 2.68341323 | c | 6.000 | 0 |
| 1.32919938 | -2.73916340 | -0.00711117 | c | 6.000 | 0 |
| -2.09295764 | -0.92411347 | -1.22242877 | h | 1.000 | 0 |
| 2.54009484 | -1.14112642 | -0.48054932 | h | 1.000 | 0 |
| 1.37916908 | -4.07033767 | -1.58367230 | h | 1.000 | 0 |
| 2.10661734 | -3.66015437 | 1.67069106 | h | 1.000 | 0 |
| -3.36227757 | 0.78417221 | 2.94950559 | h | 1.000 | 0 |
| -0.19858456 | 1.59643795 | 2.31839527 | h | 1.000 | 0 |
| -0.86245881 | -0.90096262 | 4.43230704 | h | 1.000 | 0 |

Dipropylamine (MCA* = 386.8 kJ/mol, N = 14.51, $s_N$ = 0.80):

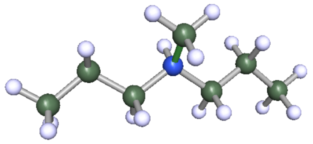


Total Energy = -292.18512025623 hartree
Enthalpy Correction = 0.217288 hartree
Entropy = 0.000149 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.10072554 | -3.64346695 | 0.69467340 | n | 7.000 | 0 |
| -1.87353513 | -2.05007048 | 0.84338167 | c | 6.000 | 0 |
| -4.16174531 | -4.44446873 | -1.04788237 | h | 1.000 | 0 |
| -4.11312835 | -5.64159853 | 2.57322861 | c | 6.000 | 0 |
| -0.11033906 | -3.16382463 | 0.74365118 | h | 1.000 | 0 |
| -1.85184728 | -0.06418136 | -1.22114310 | c | 6.000 | 0 |
| -1.87005734 | -1.12187743 | 2.69642829 | h | 1.000 | 0 |
| 0.45605624 | 1.63637624 | -1.08419690 | c | 6.000 | 0 |
| -1.91401382 | -1.00836796 | -3.06463877 | h | 1.000 | 0 |
| -3.57999240 | 1.06481184 | -1.07904385 | h | 1.000 | 0 |
| 0.43720170 | 3.05042604 | -2.58790539 | h | 1.000 | 0 |
| 2.20003426 | 0.54294553 | -1.26970658 | h | 1.000 | 0 |
| 0.53307280 | 2.63800610 | 0.72220946 | h | 1.000 | 0 |
| -4.13336494 | -4.76045464 | 4.44899308 | h | 1.000 | 0 |
| -6.39952075 | -7.34455459 | 2.29308032 | c | 6.000 | 0 |
| -2.37809202 | -6.80004390 | 2.48987999 | h | 1.000 | 0 |
| -6.45571071 | -9.43861991 | 4.25523018 | c | 6.000 | 0 |
| -8.11154181 | -6.19083092 | 2.43135322 | h | 1.000 | 0 |
| -6.39602011 | -8.16949435 | 0.39224104 | h | 1.000 | 0 |
| -4.78175530 | -10.64167846 | 4.10857140 | h | 1.000 | 0 |

```
-6.50290950   -8.66051480    6.16963588    h       1.000      0
-8.11718378  -10.64077864    4.02277273    h       1.000      0
```

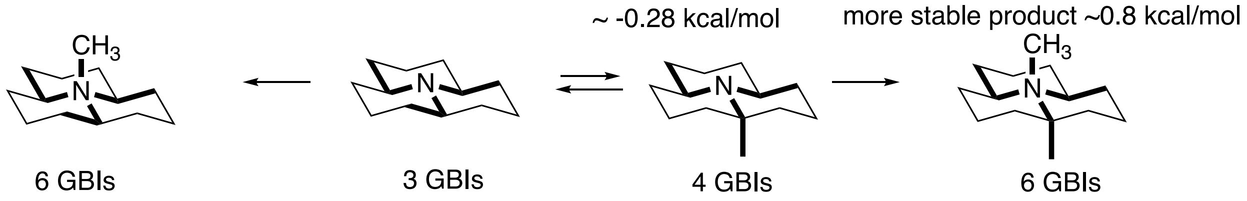
Dipropylamine Product:

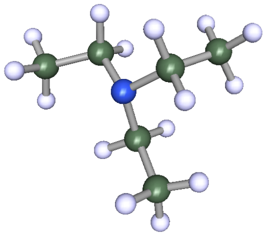


Total Energy = -331.92506382022 hartree
Enthalpy Correction = 0.263028 hartree
Entropy = 0.000157 hartree/K

```
                 atomic coordinates                atom    charge  isotop
-3.57939569   -2.98632277    1.45620927    n       7.000      0
-1.26282060   -1.40274769    1.77533615    c       6.000      0
-4.68204582   -2.12032864    0.12967762    h       1.000      0
-5.06826629   -3.15781591    3.82024281    c       6.000      0
-2.90566843   -5.53499194    0.44183107    c       6.000      0
-6.76301101   -4.26091216    3.47392411    h       1.000      0
-5.59833639   -1.27053011    4.42422158    h       1.000      0
-3.89991624   -4.06725926    5.24813696    h       1.000      0
-0.21661731   -1.56076952    0.00746894    h       1.000      0
-1.83782514    1.33804874    2.34440812    c       6.000      0
-0.15002861   -2.28459919    3.27124303    h       1.000      0
-2.75442886    1.52662894    4.18345317    h       1.000      0
 0.58204226    2.88648710    2.32660572    c       6.000      0
-3.15205021    2.06804063    0.92260272    h       1.000      0
-1.83992550   -6.49455716    1.92376953    h       1.000      0
-1.64446945   -5.19877278   -1.15315684    h       1.000      0
-5.17816486   -7.05248809   -0.39575422    c       6.000      0
-6.38687681   -7.51048170    1.21285533    h       1.000      0
-6.30540169   -5.92069849   -1.71097274    h       1.000      0
-4.33600259   -9.48479460   -1.67076819    c       6.000      0
-3.17575238   -9.09315458   -3.33346861    h       1.000      0
-3.22732840  -10.65340626   -0.37820360    h       1.000      0
-5.97115585  -10.58509650   -2.27618352    h       1.000      0
 0.17596317    4.86383636    2.74585752    h       1.000      0
 1.91359732    2.19700134    3.74714160    h       1.000      0
 1.51021311    2.79878342    0.48421473    h       1.000      0
```

Triethylamine (MCA* = 385.1 kJ/mol, N = 17.30, $s_N$ = 0.52):

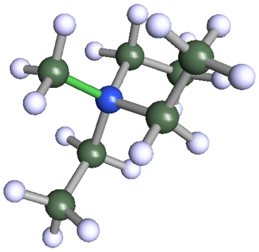




Total Energy = -292.17396505909 hartree
Enthalpy Correction = 0.216385 hartree
Entropy = 0.000146 hartree/K

```
                  atomic coordinates              atom    charge  isotop
   -3.50431513   -3.76986049    0.67976344     n       7.000      0
   -1.46322013   -1.98451409    0.19608679     c       6.000      0
   -3.61573243   -4.53763653    3.31810219     c       6.000      0
   -5.95466123   -2.93184339   -0.24110307     c       6.000      0
   -1.26772684   -1.76635185   -1.84853670     h       1.000      0
    0.28440617   -2.87678814    0.84940151     h       1.000      0
   -1.70390372    0.61978458    1.40635121     c       6.000      0
   -1.83693726    0.49585907    3.46269602     h       1.000      0
   -3.36340425    1.63784514    0.71807932     h       1.000      0
   -0.04115144    1.75582659    0.94887551     h       1.000      0
   -4.54936573   -3.09484409    4.50097566     h       1.000      0
   -4.91387429   -7.06506105    3.70648697     c       6.000      0
   -1.67019513   -4.68108536    4.00166440     h       1.000      0
   -3.99038284   -8.53125222    2.58292936     h       1.000      0
   -4.81644104   -7.61013344    5.69599745     h       1.000      0
   -6.90801441   -7.01110446    3.17942189     h       1.000      0
   -6.01740140   -2.44966105   -3.06384587     c       6.000      0
   -7.32055279   -4.41380489    0.20171178     h       1.000      0
   -6.60847206   -1.22790230    0.77183168     h       1.000      0
   -7.95871642   -2.09480867   -3.66888206     h       1.000      0
   -5.30544537   -4.08969506   -4.09880531     h       1.000      0
   -4.88991673   -0.80810850   -3.60458163     h       1.000      0
```

Triethylamine Product:

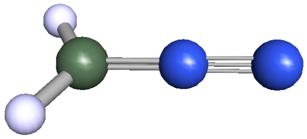


Total Energy = -331.91425904380 hartree
Enthalpy Correction = 0.26194 hartree
Entropy = 0.00015 hartree/K

```
                  atomic coordinates              atom    charge  isotop
   -3.52412199   -3.61210512    0.29997886     n       7.000      0
   -1.34676840   -1.89039578    0.71060623     c       6.000      0
```

```
 -2.62724732   -6.31604598    0.32847789     c       6.000      0
 -5.32247727   -3.22892874    2.47530644     c       6.000      0
 -4.76425868   -3.05759889   -2.19740000     c       6.000      0
 -2.04385257    0.01974129    0.99151028     h       1.000      0
 -0.33444111   -2.50858857    2.39066306     h       1.000      0
 -0.11047835   -1.94673495   -0.92681688     h       1.000      0
 -0.56286341   -6.94561128   -1.53600900     c       6.000      0
 -1.99412230   -6.66688582    2.25776406     h       1.000      0
 -4.28849500   -7.47500819   -0.02673865     h       1.000      0
 -0.14884160   -8.95417948   -1.31855871     h       1.000      0
 -1.13149225   -6.64510061   -3.49264738     h       1.000      0
  1.18066088   -5.91236136   -1.17006170     h       1.000      0
 -7.73514190   -4.74258764    2.35260793     c       6.000      0
 -4.24070347   -3.69440600    4.16595103     h       1.000      0
 -5.72804421   -1.21319428    2.53293705     h       1.000      0
 -8.87225671   -4.28716112    0.69544245     h       1.000      0
 -7.41065732   -6.77516851    2.40616844     h       1.000      0
 -8.84592974   -4.24973514    4.01860222     h       1.000      0
 -3.29209818   -3.26419665   -3.61800997     h       1.000      0
 -6.14687748   -4.55119945   -2.50179451     h       1.000      0
 -5.97409619   -0.48324653   -2.39283734     c       6.000      0
 -4.62648656    1.04736030   -2.10101747     h       1.000      0
 -7.55412154   -0.24404037   -1.09313851     h       1.000      0
 -6.71308331   -0.29874227   -4.30880866     h       1.000      0
```

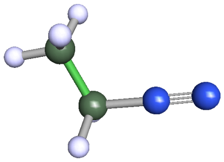
Diazomethane (MCA* = 383.7 kJ/mol, N = 10.48, $s_N$ = 0.78):



Total Energy = -148.63293772196 hartree
Enthalpy Correction = 0.036624 hartree
Entropy = 0.000092 hartree/K

```
                  atomic coordinates             atom     charge  isotop
  0.00000000    0.00000000   -1.02021859     c       6.000      0
  0.00000000    0.00000000    1.40591699     n       7.000      0
 -1.80822793    0.00000000   -1.96381179     h       1.000      0
  1.80822793    0.00000000   -1.96381179     h       1.000      0
  0.00000000    0.00000000    3.54181071     n       7.000      0
```

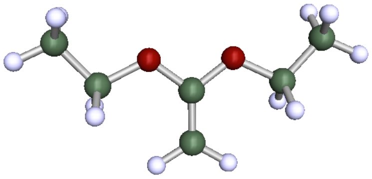
Diazomethane product:



Total Energy = -188.36766329417 hartree
Enthalpy Correction = 0.080704 hartree
Entropy = 0.000108 hartree/K

```
                 atomic coordinates                 atom     charge  isotop
    -0.25071197   -1.15170623    0.00000000     c       6.000      0
     2.46360235   -1.29772147    0.00000000     n       7.000      0
    -1.09254285    1.58143295    0.00000000     c       6.000      0
    -0.79915646   -2.20193812   -1.69053087     h       1.000      0
    -0.79915646   -2.20193812    1.69053087     h       1.000      0
    -0.44014820    2.55731630    1.68886518     h       1.000      0
    -0.44014820    2.55731630   -1.68886518     h       1.000      0
    -3.15171139    1.54183009    0.00000000     h       1.000      0
     4.51595771   -1.38230719    0.00000000     n       7.000      0
```

1,1-Diethoxyethene (MCA* = 382.0 kJ/mol, N = 9.81 $s_N$ = 0.81):

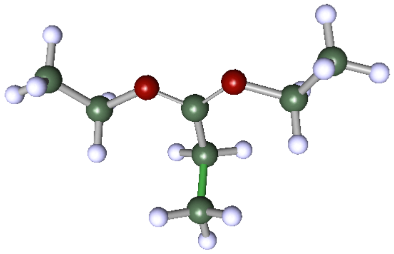


Total Energy = -386.00129785158 hartree
Enthalpy Correction = 0.185933 hartree
Entropy = 0.000148 hartree/K

```
              atomic coordinates                    atom     charge  isotop
     0.00000000    0.00000000   -3.17632292     c       6.000      0
     0.00000000    0.00000000   -0.64454929     c       6.000      0
     0.00000000    1.75024297   -4.22072098     h       1.000      0
     0.00000000   -1.75024297   -4.22072098     h       1.000      0
     0.00000000    2.02935449    0.86773436     o       8.000      0
     0.00000000   -2.02935449    0.86773436     o       8.000      0
     0.00000000   -4.45639784   -0.30038921     c       6.000      0
     0.00000000    4.45639784   -0.30038921     c       6.000      0
    -1.67653215   -4.62911326   -1.50003381     h       1.000      0
     1.67653215   -4.62911326   -1.50003381     h       1.000      0
     0.00000000   -6.41646637    1.75904662     c       6.000      0
    -1.67737298   -6.23702760    2.94686170     h       1.000      0
     0.00000000   -8.29852599    0.91453478     h       1.000      0
     1.67737298   -6.23702760    2.94686170     h       1.000      0
     0.00000000    6.41646637    1.75904662     c       6.000      0
    -1.67653215    4.62911326   -1.50003381     h       1.000      0
     1.67653215    4.62911326   -1.50003381     h       1.000      0
    -1.67737298    6.23702760    2.94686170     h       1.000      0
     1.67737298    6.23702760    2.94686170     h       1.000      0
     0.00000000    8.29852599    0.91453478     h       1.000      0
```

1,1-Diethoxyethene Product:

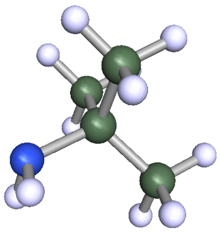
The $H_3C$-C-C-O Torsion Angle was constrained to 90°.



Total Energy = -425.73519952329 hartree
Enthalpy Correction = 0.229828 hartree
Entropy = 0.000164 hartree/K

```
                atomic coordinates               atom    charge  isotop
       -2.78402888   -1.92153295    0.44123311    c       6.000     0
       -0.45129389   -0.43862735    0.06305575    c       6.000     0
        1.02887858    0.21302716    1.84565758    o       8.000     0
        0.27575850    0.39614752   -2.07435455    o       8.000     0
       -1.10168498   -0.16740983   -4.41054948    c       6.000     0
        0.58185612   -0.55367193    4.46961854    c       6.000     0
       -0.96392029   -2.19810190   -4.71937469    h       1.000     0
       -3.06676422    0.37715473   -4.13850420    h       1.000     0
        0.13929990    1.32026256   -6.47491241    c       6.000     0
        2.11811820    0.78371628   -6.68624075    h       1.000     0
       -0.84061207    0.91427917   -8.24366757    h       1.000     0
        0.01313458    3.34445438   -6.10782924    h       1.000     0
        2.51569545    0.77428010    6.05431883    c       6.000     0
        0.78318505   -2.60141580    4.54434946    h       1.000     0
       -1.33722409   -0.00962352    4.97322906    h       1.000     0
        4.42551296    0.24579663    5.48779433    h       1.000     0
        2.30268001    2.82012726    5.92268617    h       1.000     0
        2.23793590    0.21347714    8.01957202    h       1.000     0
       -5.03880598   -0.15312035    0.90754553    c       6.000     0
       -2.52183559   -3.18882522    2.04094662    h       1.000     0
       -3.11577672   -3.07705143   -1.23015877    h       1.000     0
       -5.35693980    1.11106196   -0.68718233    h       1.000     0
       -4.76518727    0.99125826    2.59802596    h       1.000     0
       -6.71963590   -1.31203565    1.16714797    h       1.000     0
```

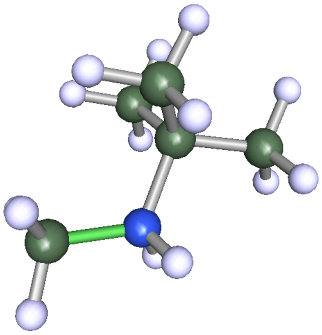
2-Methylpropan-2-amine (MCA* = 381.9 kJ/mol, N = 12.35, $s_N$ = 0.72):



Total Energy = -213.63944394870 hartree
Enthalpy Correction = 0.15657 hartree
Entropy = 0.000122 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.93192503 | -2.99882790 | 0.07299539 | n | 7.000 | 0 |
| -0.95831023 | -1.04584283 | 0.07811910 | c | 6.000 | 0 |
| -2.81040771 | -4.01729355 | 1.69555892 | h | 1.000 | 0 |
| -2.57584561 | -4.24545380 | -1.34230447 | h | 1.000 | 0 |
| 1.67920029 | -2.19209188 | 0.35481579 | c | 6.000 | 0 |
| -1.48467492 | 0.72649733 | 2.28312109 | c | 6.000 | 0 |
| -1.13907060 | 0.38962547 | -2.40919172 | c | 6.000 | 0 |
| -1.41591753 | -0.30085114 | 4.07618784 | h | 1.000 | 0 |
| -0.07938757 | 2.23720175 | 2.36031507 | h | 1.000 | 0 |
| -3.35602374 | 1.57852969 | 2.09541338 | h | 1.000 | 0 |
| -0.82359821 | -0.88185756 | -4.00882581 | h | 1.000 | 0 |
| 0.28011080 | 1.88682128 | -2.49632884 | h | 1.000 | 0 |
| -3.00771123 | 1.24246682 | -2.61747709 | h | 1.000 | 0 |
| 3.14143415 | -0.73080888 | 0.35936245 | h | 1.000 | 0 |
| 1.82459366 | -3.25166137 | 2.12370127 | h | 1.000 | 0 |
| 2.07121434 | -3.48813917 | -1.20701833 | h | 1.000 | 0 |

2-Methylpropan-2-amine Product:

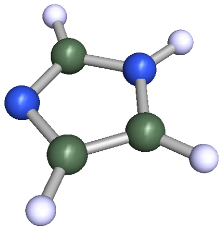


Total Energy = -253.37691578954 hartree
Enthalpy Correction = 0.202302 hartree
Entropy = 0.000132 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.58668910 | -3.75531486 | 0.10400407 | n | 7.000 | 0 |
| -1.54485687 | -1.73771523 | 0.15191220 | c | 6.000 | 0 |
| -5.29711664 | -2.86369083 | 0.09165775 | h | 1.000 | 0 |
| -3.47718174 | -4.66540493 | -1.59329052 | h | 1.000 | 0 |
| -3.58583269 | -5.66426143 | 2.14497082 | c | 6.000 | 0 |
| 1.01174440 | -3.02150145 | -0.02918648 | c | 6.000 | 0 |
| -2.04278273 | -0.10148691 | -2.15404400 | c | 6.000 | 0 |
| -1.81601985 | -0.22055219 | 2.56890175 | c | 6.000 | 0 |
| -1.38443979 | -1.34182503 | 4.24300359 | h | 1.000 | 0 |
| -3.71750609 | 0.56302337 | 2.75147716 | h | 1.000 | 0 |
| -0.48433023 | 1.35099935 | 2.50670138 | h | 1.000 | 0 |
| -3.91095268 | 0.77344470 | -2.05949076 | h | 1.000 | 0 |
| -0.63484385 | 1.40012900 | -2.23680387 | h | 1.000 | 0 |

```
 -1.90953219   -1.20425661   -3.89494964     h       1.000      0
  1.12305761   -4.23844315   -1.69361929     h       1.000      0
  2.46141041   -1.56769449   -0.20718407     h       1.000      0
  1.44316533   -4.13525922    1.65029842     h       1.000      0
 -3.81354290   -4.72473501    3.95483741     h       1.000      0
 -5.16535344   -6.93599160    1.81678930     h       1.000      0
 -1.82423934   -6.71487488    2.09148445     h       1.000      0
```

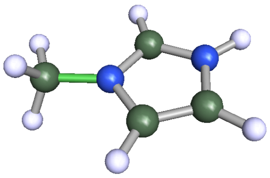
Imidazole (MCA* = 382.4 kJ/mol, N = 11.47, $s_N$ = 0.79):



Total Energy = -226.065589971 hartree
Enthalpy Correction = 0.076994 hartree
Entropy = 0.000103 hartree/K

```
                  atomic coordinates              atom    charge  isotop
  2.06103022   -1.10284264    0.02797651     c       6.000      0
  1.29759304    1.36436919    0.01601897     c       6.000      0
 -1.28210338    1.27639487   -0.01783531     n       7.000      0
 -1.97855877   -1.17399162   -0.02508413     c       6.000      0
 -0.00053418   -2.67783414    0.00214183     n       7.000      0
  3.96839451   -1.82626740    0.05364953     h       1.000      0
  2.32457422    3.12243836    0.02796739     h       1.000      0
 -2.45647470    2.77402782   -0.03470819     h       1.000      0
 -3.93392097   -1.75629444   -0.05012662     h       1.000      0
```

Imidazole Product:

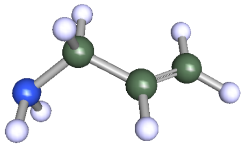


Total Energy = -265.80056515596 hartree
Enthalpy Correction = 0.120639 hartree
Entropy = 0.000115 hartree/K

```
                  atomic coordinates              atom    charge  isotop
 -3.53216164    0.15049628    0.10574399     c       6.000      0
 -0.79345988    0.03654294    0.02350675     n       7.000      0
  0.56979137   -2.05702099   -0.13719874     c       6.000      0
  2.98788256   -1.40501629   -0.16444465     n       7.000      0
  3.19644688    1.16725976   -0.01830396     c       6.000      0
  0.80539604    2.08113677    0.10070796     c       6.000      0
 -4.21760367    1.24073664   -1.49848805     h       1.000      0
 -4.27451712   -1.76236028    0.01190807     h       1.000      0
```

| | | | | | |
|---|---|---|---|---|---|
| -4.12513496 | 1.03970367 | 1.86348070 | h | 1.000 | 0 |
| -0.15936916 | -3.95500481 | -0.23010903 | h | 1.000 | 0 |
| 4.43726388 | -2.63860737 | -0.27757520 | h | 1.000 | 0 |
| 4.99573230 | 2.11433641 | -0.01124874 | h | 1.000 | 0 |
| 0.10973339 | 3.98779727 | 0.23202092 | h | 1.000 | 0 |

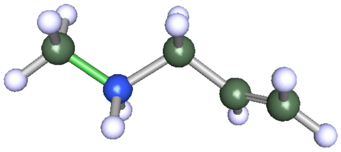
Prop-2-en-1-amine (MCA* = 382.0 kJ/mol, N = 14.37, $s_N$ = 0.66):



Total Energy = -173.11896999738 hartree
Enthalpy Correction = 0.104499 hartree
Entropy = 0.00011 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.55527782 | -3.70037531 | 0.63522837 | n | 7.000 | 0 |
| -2.35030762 | -2.10986485 | 0.13550183 | c | 6.000 | 0 |
| -4.42061556 | -4.45259237 | 2.39384057 | h | 1.000 | 0 |
| -4.54557635 | -5.19089462 | -0.57118164 | h | 1.000 | 0 |
| -2.32779600 | -0.60569579 | 1.55751990 | h | 1.000 | 0 |
| 0.11688172 | -3.49160984 | 0.18101591 | c | 6.000 | 0 |
| -2.59305286 | -1.19405550 | -1.70225733 | h | 1.000 | 0 |
| 0.56824932 | -4.45948717 | 1.94181161 | h | 1.000 | 0 |
| 1.70646824 | -3.63400241 | -1.75448929 | c | 6.000 | 0 |
| 1.29824468 | -2.69435510 | -3.53443863 | h | 1.000 | 0 |
| 3.46445373 | -4.68154003 | -1.63383772 | h | 1.000 | 0 |

Prop-2-en-1-amine Product:

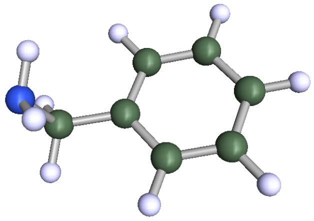


Total Energy = -212.85594323595 hartree
Enthalpy Correction = 0.150304 hartree
Entropy = 0.000122 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.83609934 | -3.15587332 | 0.74404769 | n | 7.000 | 0 |
| -2.55062558 | -1.53457822 | 0.42990947 | c | 6.000 | 0 |
| -4.28898040 | -4.97855887 | 1.05206861 | h | 1.000 | 0 |
| -5.77476707 | -2.61884963 | 2.34001606 | h | 1.000 | 0 |
| -6.57621103 | -3.06705716 | -1.44044110 | c | 6.000 | 0 |
| -5.56461813 | -3.72062690 | -3.10525126 | h | 1.000 | 0 |
| -7.20115619 | -1.12650747 | -1.69590791 | h | 1.000 | 0 |
| -8.17982493 | -4.28976299 | -1.05103062 | h | 1.000 | 0 |
| -3.21502060 | 0.39405150 | 0.15473999 | h | 1.000 | 0 |
| -1.62445284 | -2.18093614 | -1.29581982 | h | 1.000 | 0 |
| -0.85302614 | -1.74590019 | 2.66267357 | c | 6.000 | 0 |
| -0.28135025 | 0.20320836 | 4.12686139 | c | 6.000 | 0 |

```
        -0.04980754   -3.60056265    3.03328923     h       1.000      0
        -1.05838776    2.06893964    3.77398183     h       1.000      0
         0.99799817    0.00077046    5.71338175     h       1.000      0
```

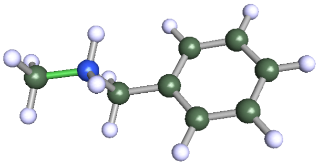
Phenylmethanamine (MCA* = 379.3 kJ/mol, N = 14.29, $s_N$ = 0.67):



Total Energy = -326.66053877550 hartree
Enthalpy Correction = 0.155413 hartree
Entropy = 0.000132 hartree/K

```
                  atomic coordinates              atom    charge  isotop
        -4.11421857   -5.78951109    0.87519368     c       6.000      0
        -1.77278948   -6.89813830    0.45635009     c       6.000      0
         0.29574259   -5.38565357   -0.11475919     c       6.000      0
         0.01953016   -2.78162492   -0.25841462     c       6.000      0
        -2.31726822   -1.64651484    0.16986463     c       6.000      0
        -4.37925080   -3.18322419    0.73011320     c       6.000      0
        -5.74075242   -6.95889473    1.30733642     h       1.000      0
        -1.56224152   -8.93332400    0.56366882     h       1.000      0
         2.12679854   -6.23916940   -0.45948248     h       1.000      0
         1.64058490   -1.60944102   -0.71618809     h       1.000      0
        -2.58147645    1.18699010    0.13025015     c       6.000      0
        -6.21592709   -2.32620101    1.05058436     h       1.000      0
        -2.01367888    2.42695168    2.53605752     n       7.000      0
        -1.32356327    1.97805166   -1.30557488     h       1.000      0
        -4.51088616    1.69062951   -0.40910319     h       1.000      0
        -3.14950676    1.70748140    3.90388008     h       1.000      0
        -0.22408407    1.98914172    3.06778028     h       1.000      0
```

Phenylmethanamine Product:

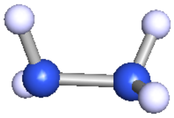


Total Energy = -366.39713615756 hartree
Enthalpy Correction = 0.201245 hartree
Entropy = 0.000142 hartree/K

```
                  atomic coordinates              atom    charge  isotop
        -5.65778900   -5.16185624    0.35167636     c       6.000      0
        -3.60265625   -5.98521086    1.76115896     c       6.000      0
        -1.47665000   -4.46879002    1.98622171     c       6.000      0
        -1.39126077   -2.12173670    0.80130356     c       6.000      0
```

```
-3.45734128   -1.30500326   -0.60652959    c       6.000      0
-5.58481975   -2.82018416   -0.83068124    c       6.000      0
-7.32291319   -6.34267246    0.18319250    h       1.000      0
-3.65928954   -7.80655779    2.69589693    h       1.000      0
 0.12233910   -5.10422424    3.10196783    h       1.000      0
 0.92398124   -0.51346780    0.99551557    c       6.000      0
-3.40497327    0.53114292   -1.51805383    h       1.000      0
-7.19079934   -2.16775782   -1.92132706    h       1.000      0
 2.75427522   -1.13879604   -1.06253687    n       7.000      0
 0.48803373    1.48824673    0.79928783    h       1.000      0
 1.92181369   -0.81093506    2.77079133    h       1.000      0
 3.19959210   -3.01200404   -0.96412704    h       1.000      0
 5.09437777    0.38696762   -0.97957618    c       6.000      0
 1.88913174   -0.90571880   -2.76981703    h       1.000      0
 6.31127561   -0.19544332   -2.52818775    h       1.000      0
 6.02193739    0.05670593    0.82417523    h       1.000      0
 4.58565890    2.36833343   -1.17373621    h       1.000      0
```

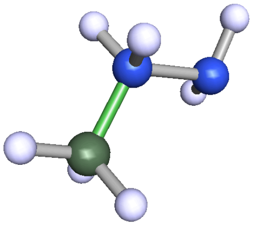
Hydrazine (MCA* = 378.0 kJ/mol, N = 16.45, $s_N$ = 0.56):



Total Energy = -111.79998111841 hartree
Enthalpy Correction = 0.058386 hartree
Entropy = 0.00009 hartree/K

```
                 atomic coordinates              atom    charge  isotop
 1.29946999    0.31982885   -0.49633586    n       7.000      0
-1.32108161   -0.31445711   -0.43946494    n       7.000      0
 2.27356200   -1.28997830   -0.84337209    h       1.000      0
 1.89186584    0.95982064    1.21352905    h       1.000      0
-1.83420683   -0.97408110    1.28852687    h       1.000      0
-2.30960939    1.29886703   -0.72288303    h       1.000      0
```

Hydrazine Product:

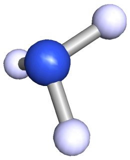


Total Energy = -151.5353465796 hartree
Enthalpy Correction = 0.103787 hartree
Entropy = 0.000101 hartree/K

```
                 atomic coordinates              atom    charge  isotop
-2.43318156    0.44650977   -1.18740234    n       7.000      0
-0.24930660   -0.94864216   -0.44709690    n       7.000      0
 1.84415880    0.74946859    0.26271291    c       6.000      0
```

| | | | | | |
|---|---|---|---|---|---|
| -3.78299624 | -0.83565977 | -1.65375507 | h | 1.000 | 0 |
| -1.96676824 | 1.37862702 | -2.79969858 | h | 1.000 | 0 |
| -0.73913744 | -2.02072896 | 1.07767314 | h | 1.000 | 0 |
| 0.34460712 | -2.18054586 | -1.81250352 | h | 1.000 | 0 |
| 1.19241401 | 1.96375547 | 1.78447489 | h | 1.000 | 0 |
| 3.42636621 | -0.41179185 | 0.87067806 | h | 1.000 | 0 |
| 2.36384395 | 1.85900774 | -1.38715723 | h | 1.000 | 0 |

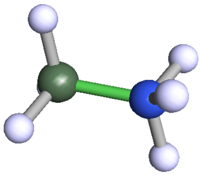
Ammonia (MCA* = 375.6 kJ/mol, N = 11.39, $s_N$ = 0.69):



Total Energy = -56.52300480668 hartree
Enthalpy Correction = 0.038344 hartree
Entropy = 0.000073 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -0.55420265 | n | 7.000 | 0 |
| -0.88452007 | 1.53203371 | 0.18448474 | h | 1.000 | 0 |
| -0.88452007 | -1.53203371 | 0.18448474 | h | 1.000 | 0 |
| 1.76904015 | 0.00000000 | 0.18448474 | h | 1.000 | 0 |

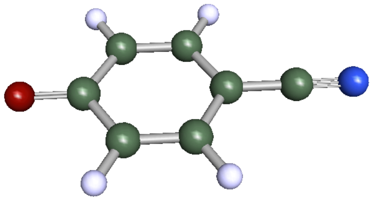
Ammonia Product:



Total Energy = -96.25779423342 hartree
Enthalpy Correction = 0.08527 hartree
Entropy = 0.000088 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -1.37610166 | n | 7.000 | 0 |
| 0.00000000 | 0.00000000 | 1.41774334 | c | 6.000 | 0 |
| -0.89512833 | 1.55040775 | -2.08448543 | h | 1.000 | 0 |
| -0.89512833 | -1.55040775 | -2.08448543 | h | 1.000 | 0 |
| 1.79025667 | 0.00000000 | -2.08448543 | h | 1.000 | 0 |
| -1.94654710 | 0.00000000 | 2.07083608 | h | 1.000 | 0 |
| 0.97327355 | -1.68575924 | 2.07083608 | h | 1.000 | 0 |
| 0.97327355 | 1.68575924 | 2.07083608 | h | 1.000 | 0 |

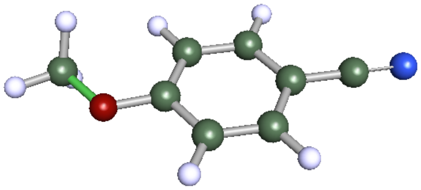
Cyanophenolate Anion (MCA* = 373.8 kJ/mol, N = 19.58, $s_{\mathrm{N}}$ = 0.59):



Total Energy = -398.96250640945 hartree
Enthalpy Correction = 0.099065 hartree
Entropy = 0.000131 hartree/K

```
              atomic coordinates              atom    charge  isotop
 -5.67502290    0.69706109    0.23325453     o       8.000      0
 -3.30298219    0.40570547    0.13550059     c       6.000      0
 -1.58110835    2.49980219    0.17487326     c       6.000      0
  0.98741138    2.18022276    0.06968340     c       6.000      0
  2.05181057   -0.25219161   -0.08363198     c       6.000      0
  4.69179248   -0.57628264   -0.19220232     c       6.000      0
  6.86394313   -0.84257292   -0.28195988     n       7.000      0
  0.42217398   -2.35366533   -0.12704476     c       6.000      0
 -2.14724791   -2.04174269   -0.02243054     c       6.000      0
 -2.37756666    4.38653748    0.29293873     h       1.000      0
  2.22656659    3.81371545    0.10410548     h       1.000      0
  1.22302701   -4.23773032   -0.24524297     h       1.000      0
 -3.38279711   -3.67885893   -0.05784355     h       1.000      0
```

Cyanophenolate Anion Product:

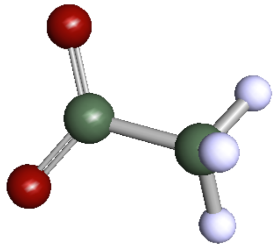


Total Energy = -438.69388543137 hartree
Enthalpy Correction = 0.142391 hartree
Entropy = 0.000143 hartree/K

```
              atomic coordinates              atom    charge  isotop
 -5.48487649    0.91994821    0.83510612     c       6.000      0
 -3.92402119   -0.34897923   -0.94168163     o       8.000      0
 -1.41709638   -0.29251511   -0.59252967     c       6.000      0
  0.03260391   -1.56703959   -2.39930284     c       6.000      0
  2.62280426   -1.61469190   -2.20323616     c       6.000      0
  3.81733436   -0.38338829   -0.18798282     c       6.000      0
  6.49287975   -0.42496860    0.02041201     c       6.000      0
  8.66693178   -0.45929889    0.18663546     n       7.000      0
  2.37090886    0.88522218    1.61183121     c       6.000      0
 -0.23392124    0.93640819    1.41888802     c       6.000      0
 -5.25534875    0.11875853    2.72487652     h       1.000      0
 -7.41602625    0.63203138    0.19528452     h       1.000      0
```

| | | | | | |
|---|---|---|---|---|---|
| -5.06296809 | 2.94100488 | 0.87742923 | h | 1.000 | 0 |
| -0.91883122 | -2.50958490 | -3.94732958 | h | 1.000 | 0 |
| 3.73981338 | -2.60208011 | -3.60510077 | h | 1.000 | 0 |
| 3.29003609 | 1.83813526 | 3.17249956 | h | 1.000 | 0 |
| -1.32022278 | 1.93103799 | 2.83420081 | h | 1.000 | 0 |

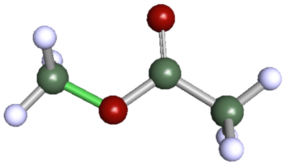
Acetate anion (MCA* = 372.0 kJ/mol, N = 16.90, $s_{\mathrm{N}}$ = 0.75):



Total Energy = -228.47917530035 hartree
Enthalpy Correction = 0.054282 hartree
Entropy = 0.000107 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.30454205 | -3.91677153 | 0.36233227 | c | 6.000 | 0 |
| -2.17577320 | -1.98378346 | 0.17754259 | c | 6.000 | 0 |
| -5.97497300 | -3.14806080 | -0.58458351 | h | 1.000 | 0 |
| -3.80202102 | -5.68691148 | -0.56527492 | h | 1.000 | 0 |
| -4.81395556 | -4.26827255 | 2.32899286 | h | 1.000 | 0 |
| -2.17064823 | -0.23103689 | 1.77482076 | o | 8.000 | 0 |
| -0.61036959 | -2.24586730 | -1.58275706 | o | 8.000 | 0 |

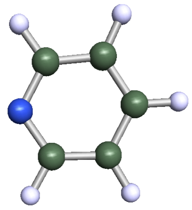
Acetate anion Product:



Total Energy = -268.20909584522 hartree
Enthalpy Correction = 0.097125 hartree
Entropy = 0.00012 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.25380648 | -4.72608012 | 0.47998497 | c | 6.000 | 0 |
| -1.96040684 | -3.31609701 | -0.36342625 | c | 6.000 | 0 |
| -3.72944011 | -6.38631357 | 1.57996375 | h | 1.000 | 0 |
| -5.38028765 | -5.26482945 | -1.15222462 | h | 1.000 | 0 |
| -5.37695363 | -3.49167593 | 1.69740527 | h | 1.000 | 0 |
| -0.23018365 | -3.16109231 | 1.45832609 | o | 8.000 | 0 |
| -1.67682150 | -2.37736078 | -2.42791845 | o | 8.000 | 0 |
| 2.01155214 | -1.77685042 | 0.85804464 | c | 6.000 | 0 |
| 1.54730174 | 0.17614624 | 0.39442333 | h | 1.000 | 0 |
| 2.98895381 | -2.64802620 | -0.73231954 | h | 1.000 | 0 |
| 3.18161595 | -1.85267948 | 2.54453872 | h | 1.000 | 0 |

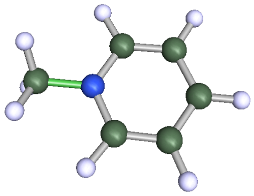
Pyridine (MCA* = 371.6 kJ/mol, N = 12.90, $s_N$ = 0.67):



Total Energy = -248.09291778524 hartree
Enthalpy Correction 0.094839 hartree
Entropy = 0.000107 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.25211260 | 0.00000000 | -0.90516394 | c | 6.000 | 0 |
| -2.15191543 | 0.00000000 | 1.71396712 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 3.02159127 | n | 7.000 | 0 |
| 2.15191543 | 0.00000000 | 1.71396712 | c | 6.000 | 0 |
| 2.25211260 | 0.00000000 | -0.90516394 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -2.24318683 | c | 6.000 | 0 |
| -4.06059986 | 0.00000000 | -1.86438390 | h | 1.000 | 0 |
| -3.88646898 | 0.00000000 | 2.81190435 | h | 1.000 | 0 |
| 3.88646898 | 0.00000000 | 2.81190435 | h | 1.000 | 0 |
| 4.06059986 | 0.00000000 | -1.86438390 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | -4.29154950 | h | 1.000 | 0 |

Pyridine Product:

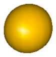


Total Energy = -287.82291499180 hartree
Enthalpy Correction 0.138517 hartree
Entropy = 0.000122 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.45618159 | -5.20546487 | 0.36068716 | c | 6.000 | 0 |
| -3.01643216 | -6.10080409 | 0.33455340 | c | 6.000 | 0 |
| -1.05480500 | -4.49829302 | 0.31758427 | n | 7.000 | 0 |
| -1.41241592 | -1.98904787 | 0.32538518 | c | 6.000 | 0 |
| -3.81169807 | -0.99474313 | 0.35202639 | c | 6.000 | 0 |
| -5.86791142 | -2.61909495 | 0.37004752 | c | 6.000 | 0 |
| -7.00421010 | -6.53870375 | 0.36799813 | h | 1.000 | 0 |
| -2.56309997 | -8.09230624 | 0.32435391 | h | 1.000 | 0 |
| 1.52662512 | -5.49398602 | 0.36687115 | c | 6.000 | 0 |
| 0.27145522 | -0.83264539 | 0.30759340 | h | 1.000 | 0 |
| -4.04746529 | 1.03477375 | 0.35295989 | h | 1.000 | 0 |
| -7.77365552 | -1.87492336 | 0.38626736 | h | 1.000 | 0 |
| 2.19240352 | -5.53263359 | 2.31429286 | h | 1.000 | 0 |
| 2.73211321 | -4.27544257 | -0.76474511 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 1.52182340 | -7.39327707 | -0.41203554 | h | 1.000 | 0 |

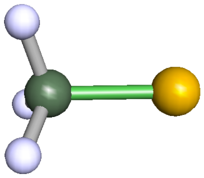
Chloride Anion (MCA* = 364.2 kJ/mol, N = 17.20, $s_N$ = 0.60):



Total Energy = -460.23988439252 hartree

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.51185959 | -3.38131867 | 0.35233660 | cl | 17.000 | 0 |

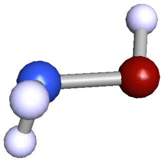
Chloride Anion Product:



Total Energy = -499.9415452311 hartree
Enthalpy Correction = 0.041394 hartree
Entropy = 0.000093 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.29236569 | -0.01353351 | 0.00218921 | c | 6.000 | 0 |
| 3.07788818 | 0.14245110 | -0.02315910 | cl | 17.000 | 0 |
| -0.89465075 | -1.04722430 | -1.66639687 | h | 1.000 | 0 |
| -0.87198097 | -0.98820077 | 1.71375503 | h | 1.000 | 0 |
| -1.01889077 | 1.90650748 | -0.02638827 | h | 1.000 | 0 |

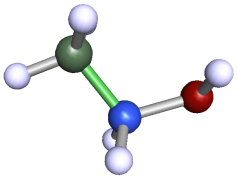
Hydroxylamine (MCA* = 358.2 kJ/mol, N = 12.80, $s_N$ = 0.63):



Total Energy = -131.64273302654 hartree
Enthalpy Correction = 0.045029 hartree
Entropy = 0.000089 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.77376021 | 0.07314351 | -0.58277507 | n | 7.000 | 0 |
| 1.48284766 | -0.12291510 | 0.87722240 | o | 8.000 | 0 |
| -1.69415766 | 1.59311097 | 0.14586813 | h | 1.000 | 0 |
| -1.81963260 | -1.45399128 | -0.07032190 | h | 1.000 | 0 |
| 2.80470281 | -0.08934811 | -0.36999356 | h | 1.000 | 0 |

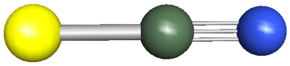
Hydroxylamine Product:



Total Energy = -171.36999328277 hartree
Enthalpy Correction = 0.090171 hartree
Entropy = 0.000101 hartree/K

```
                  atomic coordinates                 atom     charge  isotop
         -2.78650613    0.46958188    0.83631081      o        8.000     0
         -0.74840131   -0.93850718   -0.02848154      n        7.000     0
          1.66251837    0.44450726    0.04265100      c        6.000     0
         -2.96902395    1.85990928   -0.34278724      h        1.000     0
         -1.12344390   -1.60601322   -1.80387073      h        1.000     0
         -0.68511258   -2.47417842    1.13809714      h        1.000     0
          1.53367285    2.03648170   -1.24981066      h        1.000     0
          3.13392244   -0.85849980   -0.56451862      h        1.000     0
          1.98237420    1.06671850    1.97240986      h        1.000     0
```

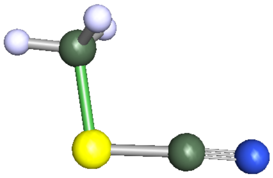
NCS Anion (MCA* = 342.9 kJ/mol, N = 17.94, $s_N$ = 0.60):



Total Energy = -491.0072761493 hartree
Enthalpy Correction = 0.01195 hartree
Entropy = 0.000067 hartree/K

```
                  atomic coordinates                 atom     charge  isotop
          2.80769106    0.05899980    0.00000000      s       16.000     0
         -0.29725173   -0.00619909    0.00000000      c        6.000     0
         -2.51043934   -0.05280072    0.00000000      n        7.000     0
```

NCS Anion product:

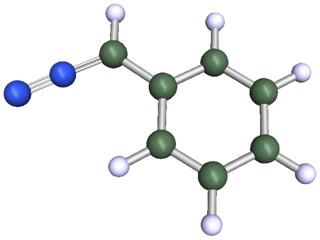


Total Energy = -530.71482718926 hartree
Enthalpy Correction = 0.053047 hartree
Entropy = 0.000112 hartree/K

```
                  atomic coordinates                 atom     charge  isotop
          4.96917849    0.86441213    0.58625694      n        7.000     0
          3.20080255   -0.08257478   -0.28362955      c        6.000     0
```

| | | | | | |
|---|---|---|---|---|---|
| 0.70960277 | -1.51757635 | -1.61283214 | s | 16.000 | 0 |
| -1.83188392 | -0.00511624 | 0.10786125 | c | 6.000 | 0 |
| -1.82711046 | 2.01756213 | -0.25264060 | h | 1.000 | 0 |
| -1.67640612 | -0.42215393 | 2.11361162 | h | 1.000 | 0 |
| -3.54418331 | -0.85455296 | -0.65862752 | h | 1.000 | 0 |

(Diazomethyl)benzene (MCA* = 342.9 kJ/mol, N = 9.35, $s_{\mathrm{N}}$ = 0.83):

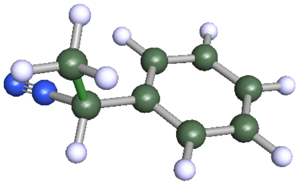


Total Energy = -379.51336561991 hartree
Enthalpy Correction = 0.123804 hartree
Entropy = 0.000134 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.70009650 | 1.40585663 | 0.00000000 | c | 6.000 | 0 |
| 4.01028677 | 3.82571238 | 0.00000000 | n | 7.000 | 0 |
| 5.41808806 | 0.29971053 | 0.00000000 | h | 1.000 | 0 |
| 1.19666933 | 0.30215774 | 0.00000000 | c | 6.000 | 0 |
| -1.01152400 | 1.75890321 | 0.00000000 | c | 6.000 | 0 |
| -3.36106517 | 0.60643203 | 0.00000000 | c | 6.000 | 0 |
| -3.56827218 | -2.01161446 | 0.00000000 | c | 6.000 | 0 |
| -1.38471505 | -3.46998391 | 0.00000000 | c | 6.000 | 0 |
| 0.97279407 | -2.33375393 | 0.00000000 | c | 6.000 | 0 |
| -0.89709617 | 3.80575243 | 0.00000000 | h | 1.000 | 0 |
| -5.04889741 | 1.76827360 | 0.00000000 | h | 1.000 | 0 |
| -5.41126898 | -2.90431973 | 0.00000000 | h | 1.000 | 0 |
| -1.51604429 | -5.51498424 | 0.00000000 | h | 1.000 | 0 |
| 2.66696718 | -3.48719755 | 0.00000000 | h | 1.000 | 0 |
| 4.23398135 | 5.94905526 | 0.00000000 | n | 7.000 | 0 |

(Diazomethyl)benzene Product:

The $H_3C$-C-C-C Torsion Angle was constrained to 270°.

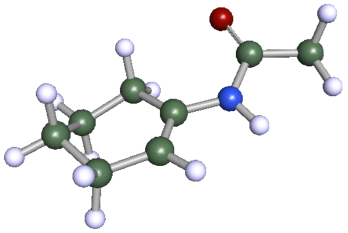


Total Energy = -419.23175303261 hartree
Enthalpy Correction = 0.166489 hartree
Entropy = 0.000148 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.24447654 | 0.16504354 | -0.74686809 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 0.59722389 | 2.77397101 | -0.97703260 | n | 7.000 | 0 |
| 1.22623858 | 4.72191722 | -1.16201025 | n | 7.000 | 0 |
| -2.70111010 | -0.12898703 | -2.20755598 | c | 6.000 | 0 |
| 1.29754196 | -0.84817240 | -1.68225380 | h | 1.000 | 0 |
| -4.20851298 | 0.96114361 | -1.32712892 | h | 1.000 | 0 |
| -2.46509689 | 0.41748562 | -4.17724852 | h | 1.000 | 0 |
| -3.17449362 | -2.13156118 | -2.11628914 | h | 1.000 | 0 |
| -0.36874716 | -0.51758240 | 2.01817028 | c | 6.000 | 0 |
| 0.10703006 | -3.02372589 | 2.64141801 | c | 6.000 | 0 |
| -0.07036920 | -3.78876271 | 5.13978957 | c | 6.000 | 0 |
| -0.68013231 | -2.05186165 | 7.00977706 | c | 6.000 | 0 |
| -1.12292991 | 0.45391168 | 6.37895097 | c | 6.000 | 0 |
| -0.97131938 | 1.22830996 | 3.87917964 | c | 6.000 | 0 |
| 0.61220379 | -4.37159751 | 1.18303949 | h | 1.000 | 0 |
| 0.29113282 | -5.74427742 | 5.62615644 | h | 1.000 | 0 |
| -0.79942645 | -2.65141847 | 8.96394586 | h | 1.000 | 0 |
| -1.58795160 | 1.81899990 | 7.83193260 | h | 1.000 | 0 |
| -1.34032329 | 3.18996014 | 3.41434413 | h | 1.000 | 0 |

*N*-Acetyl Enamine (MCA* = 341.3 kJ/mol, N = 5.64, $s_N$ = 0.79):

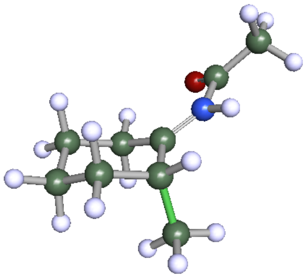


Total Energy = -442.34610461775 hartree
Enthalpy Correction = 0.213268 hartree
Entropy = 0.000155 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.20611268 | 1.57413897 | 2.64696307 | o | 8.000 | 0 |
| 4.58328590 | 0.01389503 | 0.97611554 | c | 6.000 | 0 |
| 7.19040502 | -0.99612949 | 0.46402956 | c | 6.000 | 0 |
| 2.75049454 | -0.92395076 | -0.53797528 | n | 7.000 | 0 |
| 0.15065667 | -0.34595616 | -0.54749823 | c | 6.000 | 0 |
| -1.45682628 | -2.04408126 | -1.49921680 | c | 6.000 | 0 |
| -4.24196396 | -1.62782977 | -1.70626682 | c | 6.000 | 0 |
| -5.11096101 | 0.67376921 | -0.21902481 | c | 6.000 | 0 |
| -3.30139190 | 2.86470576 | -0.62885392 | c | 6.000 | 0 |
| -0.66997689 | 2.21924150 | 0.33766910 | c | 6.000 | 0 |
| 7.23952228 | -2.44753635 | -0.99571551 | h | 1.000 | 0 |
| 7.95620070 | -1.76337291 | 2.21815770 | h | 1.000 | 0 |
| 8.39812646 | 0.57529019 | -0.11136503 | h | 1.000 | 0 |
| 3.27166265 | -2.34711429 | -1.69235303 | h | 1.000 | 0 |
| -0.71322167 | -3.83277852 | -2.18694645 | h | 1.000 | 0 |
| -5.23719219 | -3.32312919 | -1.05852828 | h | 1.000 | 0 |
| -4.75715594 | -1.41399941 | -3.70620164 | h | 1.000 | 0 |
| -5.16507678 | 0.21060500 | 1.79920196 | h | 1.000 | 0 |
| -7.03254266 | 1.19277473 | -0.77099755 | h | 1.000 | 0 |
| -3.20467219 | 3.29754269 | -2.65217598 | h | 1.000 | 0 |
| -3.98214849 | 4.56811435 | 0.32024990 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -0.61990635 | 2.29544851 | 2.40263866 | h | 1.000 | 0 |
| 0.70420602 | 3.62179114 | -0.30255628 | h | 1.000 | 0 |

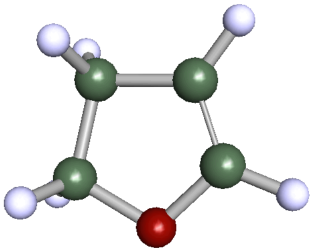
*N*-Acetyl Enamine Product:



Total Energy = -482.06495701084 hartree
Enthalpy Correction = 0.256157 hartree
Entropy = 0.000166 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.64708497 | -1.97308678 | 0.47571896 | o | 8.000 | 0 |
| 5.03540433 | 0.09877516 | -0.17904584 | c | 6.000 | 0 |
| 6.66800833 | 2.03721583 | -1.37528073 | c | 6.000 | 0 |
| 2.48236916 | 1.00917615 | 0.18217162 | n | 7.000 | 0 |
| 0.42696036 | -0.20354857 | 0.77974736 | c | 6.000 | 0 |
| -1.89609768 | 1.33700672 | 1.14047650 | c | 6.000 | 0 |
| -1.54630776 | 3.22909804 | 0.38865523 | h | 1.000 | 0 |
| -4.13749028 | 0.14821028 | -0.26521205 | c | 6.000 | 0 |
| -4.43931564 | -2.64460560 | 0.32022426 | c | 6.000 | 0 |
| -2.01949104 | -4.05700306 | -0.27766333 | c | 6.000 | 0 |
| 0.27343977 | -2.96042806 | 1.12832237 | c | 6.000 | 0 |
| 6.70281835 | 3.73734218 | -0.20104039 | h | 1.000 | 0 |
| 8.56854758 | 1.29496880 | -1.59967152 | h | 1.000 | 0 |
| 5.88234202 | 2.56995808 | -3.21027673 | h | 1.000 | 0 |
| 2.28501855 | 2.89665388 | -0.10610099 | h | 1.000 | 0 |
| -2.38226209 | 1.59038963 | 3.99330086 | c | 6.000 | 0 |
| -5.83169281 | 1.21327939 | 0.23997389 | h | 1.000 | 0 |
| -3.84769231 | 0.39558196 | -2.29738144 | h | 1.000 | 0 |
| -5.99273541 | -3.41716260 | -0.79911524 | h | 1.000 | 0 |
| -4.94578877 | -2.92085645 | 2.30573551 | h | 1.000 | 0 |
| -1.64237700 | -3.97789700 | -2.30898740 | h | 1.000 | 0 |
| -2.16474302 | -6.04833814 | 0.23598669 | h | 1.000 | 0 |
| 0.01222159 | -3.24791176 | 3.16846098 | h | 1.000 | 0 |
| 2.01792101 | -3.89712008 | 0.60556360 | h | 1.000 | 0 |
| -3.99455868 | 2.84870535 | 4.25091107 | h | 1.000 | 0 |
| -2.82239073 | -0.22209358 | 4.86615319 | h | 1.000 | 0 |
| -0.75476313 | 2.40757249 | 4.95977315 | h | 1.000 | 0 |

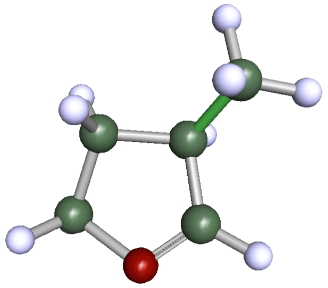
2,3-Dihydrofuran (MCA* = 339.2 kJ/mol, N = 4.37, $s_{\mathrm{N}}$ = 0.90):



Total Energy = -231.05480491438 hartree
Enthalpy Correction = 0.09789 hartree
Entropy = 0.000105 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.65289345 | -0.00307137 | 2.73062551 | o | 8.000 | 0 |
| 2.51083863 | -0.00182334 | 0.95463139 | c | 6.000 | 0 |
| 1.71850576 | 0.00001638 | -1.42297926 | c | 6.000 | 0 |
| -1.12304077 | -0.00054939 | -1.44760205 | c | 6.000 | 0 |
| -1.73774483 | 0.00167424 | 1.39246284 | c | 6.000 | 0 |
| 4.41342264 | -0.00274940 | 1.70387141 | h | 1.000 | 0 |
| 2.91724034 | 0.00086481 | -3.07415827 | h | 1.000 | 0 |
| -2.78387846 | -1.67310156 | 1.98454675 | h | 1.000 | 0 |
| -2.77615952 | 1.68189787 | 1.98297826 | h | 1.000 | 0 |
| -1.89544181 | -1.66372005 | -2.40094477 | h | 1.000 | 0 |
| -1.89663859 | 1.66056339 | -2.40343193 | h | 1.000 | 0 |

2,3-Dihydrofuran Product:

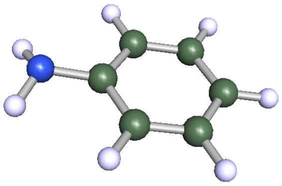


Total Energy = -270.77261262116 hartree
Enthalpy Correction = 0.141716 hartree
Entropy = 0.00012 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.69738792 | 1.85322603 | 1.48950766 | o | 8.000 | 0 |
| 2.71806543 | -0.00145769 | 0.41086037 | c | 6.000 | 0 |
| 1.91935233 | 0.41863102 | -2.19802976 | c | 6.000 | 0 |
| 3.22785727 | 2.93190878 | -2.81733620 | c | 6.000 | 0 |
| 3.75032759 | 4.07424671 | -0.24892061 | c | 6.000 | 0 |
| 2.50719607 | -1.71759637 | 1.52346894 | h | 1.000 | 0 |
| 2.27104206 | 5.31402736 | 0.46154524 | h | 1.000 | 0 |
| 5.59909134 | 4.92494487 | 0.00789739 | h | 1.000 | 0 |
| 2.04510898 | 4.15918341 | -3.96538041 | h | 1.000 | 0 |
| 4.98708189 | 2.56240900 | -3.82631427 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 2.39139326 | -1.77901644 | -3.98797403 | c | 6.000 | 0 |
| -0.14276498 | 0.68906239 | -2.00399668 | h | 1.000 | 0 |
| 1.64646169 | -1.29983890 | -5.84716190 | h | 1.000 | 0 |
| 1.44849491 | -3.48838829 | -3.32879381 | h | 1.000 | 0 |
| 4.41169339 | -2.14844238 | -4.16371032 | h | 1.000 | 0 |

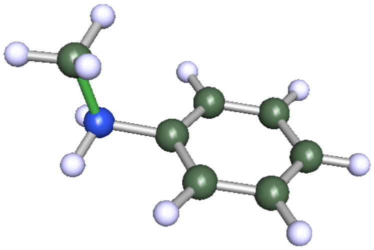
Aniline (MCA* = 334.7 kJ/mol, N = 12.64, $s_{\mathrm{N}}$ = 0.68):



Total Energy = -287.39043085590 hartree
Enthalpy Correction = 0.124848 hartree
Entropy = 0.000119 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.56532457 | 0.07932049 | 0.00000000 | c | 6.000 | 0 |
| -2.22952539 | 0.02851803 | -2.26162668 | c | 6.000 | 0 |
| 0.38689961 | -0.07444455 | -2.27042191 | c | 6.000 | 0 |
| 1.73877925 | -0.14097193 | 0.00000000 | c | 6.000 | 0 |
| 0.38689961 | -0.07444455 | 2.27042191 | c | 6.000 | 0 |
| -2.22952539 | 0.02851803 | 2.26162668 | c | 6.000 | 0 |
| -5.61114758 | 0.16493167 | 0.00000000 | h | 1.000 | 0 |
| -3.23486632 | 0.07825470 | -4.04743802 | h | 1.000 | 0 |
| 1.40911150 | -0.11371871 | -4.04852847 | h | 1.000 | 0 |
| 4.34031845 | -0.38392556 | 0.00000000 | n | 7.000 | 0 |
| 1.40911150 | -0.11371871 | 4.04852847 | h | 1.000 | 0 |
| -3.23486632 | 0.07825470 | 4.04743802 | h | 1.000 | 0 |
| 5.21747450 | 0.22143068 | 1.57966628 | h | 1.000 | 0 |
| 5.21747450 | 0.22143068 | -1.57966628 | h | 1.000 | 0 |

Aniline Product:

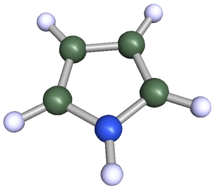


Total Energy = -327.10896743476 hartree
Enthalpy Correction = 0.170232 hartree
Entropy = 0.000131 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.96865468 | -1.61459462 | 0.00600914 | c | 6.000 | 0 |
| 0.42440657 | -2.62888308 | -0.35366091 | c | 6.000 | 0 |
| 2.52612584 | -1.06357584 | -0.38493710 | c | 6.000 | 0 |
| 2.17359199 | 1.50265763 | -0.05510596 | c | 6.000 | 0 |

```
   -0.18745803    2.55567236    0.30588289     c       6.000      0
   -2.27487160    0.97006940    0.33275984     c       6.000      0
   -3.60468803   -2.84520168    0.02466789     h       1.000      0
    0.66309169   -4.64445336   -0.61794281     h       1.000      0
    4.40370482   -1.83217166   -0.67036193     h       1.000      0
    4.38521192    3.15370483   -0.01684463     n       7.000      0
   -0.40146530    4.57840512    0.55243356     h       1.000      0
   -4.14190049    1.76367441    0.60387082     h       1.000      0
    5.58571717    3.36624306    2.51819489     c       6.000      0
    3.88710455    4.91217444   -0.63306022     h       1.000      0
    5.69021729    2.51930490   -1.28796603     h       1.000      0
    7.19677979    4.63150970    2.36473909     h       1.000      0
    4.19168469    4.11657783    3.82691837     h       1.000      0
    6.18688884    1.49193239    3.10406728     h       1.000      0
```

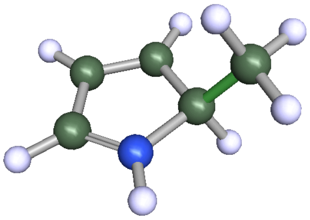
Pyrrole (MCA* = 334.1 kJ/mol, N = 4.63, $s_N$ = 1.00):



Total Energy = -210.01722458643 hartree
Enthalpy Correction = 0.088315 hartree
Entropy = 0.000104 hartree/K

```
                 atomic coordinates              atom    charge  isotop
    0.60072253    2.17466321    0.02733999     c       6.000      0
    2.20890120    0.13317228   -0.01238921     c       6.000      0
    0.76916042   -1.99932875   -0.03358843     n       7.000      0
   -1.72850211   -1.38167640   -0.00861186     c       6.000      0
   -1.90331222    1.21133699    0.02975509     c       6.000      0
    1.16181002    4.13631577    0.05185765     h       1.000      0
    4.24451272    0.03024942   -0.02722785     h       1.000      0
    1.45151774   -3.77315966   -0.06379605     h       1.000      0
   -3.17024062   -2.82253937   -0.01989729     h       1.000      0
   -3.63456966    2.29096652    0.05655796     h       1.000      0
```

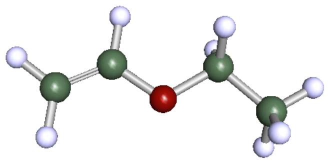
Pyrrole product



Total Energy = -249.73281904305 hartree
Enthalpy Correction = 0.130961 hartree
Entropy = 0.000116 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.25729639 | -0.20280134 | -0.86486851 | c | 6.000 | 0 |
| -0.95609403 | 0.11776074 | 0.83469709 | c | 6.000 | 0 |
| 0.76739424 | -2.00478740 | 0.68450139 | n | 7.000 | 0 |
| 3.02331630 | -1.28092699 | 0.08728357 | c | 6.000 | 0 |
| 3.08886778 | 1.40509165 | -0.24245603 | c | 6.000 | 0 |
| 0.73091728 | 2.25682383 | 0.19656291 | c | 6.000 | 0 |
| -2.68010467 | -0.40753621 | -2.83222050 | h | 1.000 | 0 |
| -4.33031232 | -1.86370207 | -0.28846262 | h | 1.000 | 0 |
| -4.46082806 | 1.45721713 | -0.68231495 | h | 1.000 | 0 |
| -1.57459829 | 0.29366434 | 2.80936783 | h | 1.000 | 0 |
| 0.25862993 | -3.81500122 | 1.01945761 | h | 1.000 | 0 |
| 4.56100553 | -2.61616726 | -0.09802151 | h | 1.000 | 0 |
| 4.75203077 | 2.47014155 | -0.74585043 | h | 1.000 | 0 |
| 0.07707193 | 4.19022326 | 0.12232413 | h | 1.000 | 0 |

Ethoxyethene (MCA* = 328.6 kJ/mol, N = 3.92, $s_N$ = 0.90):

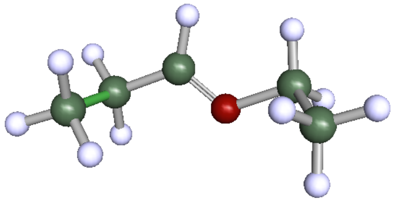


Total Energy = -232.25503968478 hartree
Enthalpy Correction = 0.120522 hartree
Entropy = 0.000123 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.31222147 | -2.71965594 | 0.53369004 | c | 6.000 | 0 |
| -1.22747802 | -1.38209165 | 0.11885682 | c | 6.000 | 0 |
| -4.94419890 | -2.42943967 | -0.66133463 | h | 1.000 | 0 |
| -3.42480949 | -4.09685407 | 2.04610708 | h | 1.000 | 0 |
| -1.10828429 | 0.00039275 | -1.39961476 | h | 1.000 | 0 |
| 0.87082865 | -1.62837228 | 1.54063750 | o | 8.000 | 0 |
| 2.97081838 | -0.11648063 | 0.76687447 | c | 6.000 | 0 |
| 2.40091824 | 1.87322088 | 0.74785050 | h | 1.000 | 0 |
| 5.10531605 | -0.54951846 | 2.59283281 | c | 6.000 | 0 |
| 3.51754132 | -0.65351353 | -1.15586841 | h | 1.000 | 0 |
| 4.55649126 | -0.00634483 | 4.50667920 | h | 1.000 | 0 |
| 6.73433915 | 0.58765097 | 2.03636194 | h | 1.000 | 0 |
| 5.67178991 | -2.53383844 | 2.60433016 | h | 1.000 | 0 |

Ethoxyethene Product:

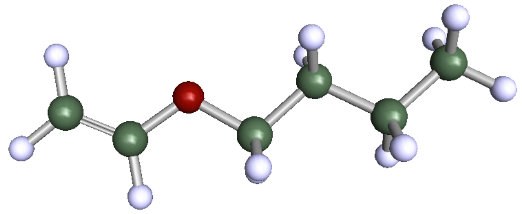
The $H_3$C-C-C-O Torsion Angle was constrained to 90°.



Total Energy = -271.96902894592 hartree
Enthalpy Correction = 0.163963 hartree
Entropy = 0.000136 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.59002127 | -2.59112629 | 0.29512688 | c | 6.000 | 0 |
| -1.25048474 | -1.22839441 | -0.16523227 | c | 6.000 | 0 |
| -1.25584913 | 0.65949060 | -1.00287214 | h | 1.000 | 0 |
| 0.80725667 | -2.13401282 | 0.53745137 | o | 8.000 | 0 |
| 3.16571988 | -0.67056630 | 0.27301406 | c | 6.000 | 0 |
| 2.70061227 | 1.06115219 | -0.74067343 | h | 1.000 | 0 |
| 4.21929312 | -0.21821411 | 2.86148783 | c | 6.000 | 0 |
| 4.36314355 | -1.87927370 | -0.88111544 | h | 1.000 | 0 |
| 2.95100904 | 0.94982663 | 3.99180090 | h | 1.000 | 0 |
| 6.01123525 | 0.78207999 | 2.65142742 | h | 1.000 | 0 |
| 4.57742328 | -1.99663414 | 3.83882469 | h | 1.000 | 0 |
| -4.94675804 | -2.09480516 | -1.17430700 | h | 1.000 | 0 |
| -3.24249848 | -4.62153935 | 0.31521114 | h | 1.000 | 0 |
| -4.58137211 | -1.71508883 | 2.89908970 | c | 6.000 | 0 |
| -4.85264551 | 0.32697833 | 2.96131025 | h | 1.000 | 0 |
| -6.40024404 | -2.62661417 | 3.21546472 | h | 1.000 | 0 |
| -3.27938221 | -2.27330164 | 4.39395699 | h | 1.000 | 0 |

1-(Vinyloxy)butane (MCA* = 327.6 kJ/mol, N = 3.76, $s_N$ = 0.91):



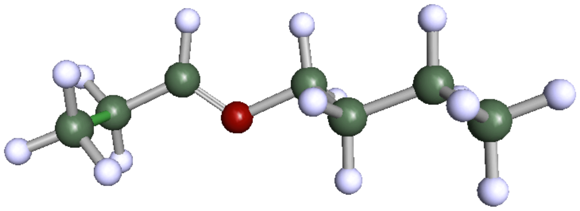
Total Energy = -310.81622657949 hartree
Enthalpy Correction = 0.180278 hartree
Entropy = 0.000146 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.03043008 | -2.81419199 | 1.64391217 | c | 6.000 | 0 |
| -2.96187811 | -3.83911478 | 0.65556914 | c | 6.000 | 0 |
| -6.85973485 | -3.58775302 | 1.16340274 | h | 1.000 | 0 |
| -4.93584639 | -1.21343912 | 2.91883171 | h | 1.000 | 0 |
| -3.05108929 | -5.44878886 | -0.62199941 | h | 1.000 | 0 |
| -0.62208726 | -2.95850793 | 1.14210858 | o | 8.000 | 0 |
| 1.39416836 | -4.38991637 | 0.06377361 | c | 6.000 | 0 |
| 1.38365616 | -6.29722746 | 0.87183846 | h | 1.000 | 0 |
| 1.09877476 | -4.55110471 | -1.98036937 | h | 1.000 | 0 |
| 3.85404522 | -3.07053078 | 0.62588979 | c | 6.000 | 0 |
| 3.79287500 | -1.16081900 | -0.17002608 | h | 1.000 | 0 |
| 4.05832765 | -2.86651093 | 2.67568032 | h | 1.000 | 0 |
| 6.10811522 | -4.49885401 | -0.43871632 | c | 6.000 | 0 |
| 6.14671137 | -6.40882431 | 0.35918830 | h | 1.000 | 0 |
| 8.59896554 | -3.17866995 | 0.10148945 | c | 6.000 | 0 |
| 5.87184284 | -4.72699530 | -2.48308945 | h | 1.000 | 0 |
| 8.62955766 | -1.28720755 | -0.73059386 | h | 1.000 | 0 |
| 8.90259149 | -2.97417100 | 2.13571350 | h | 1.000 | 0 |

```
         10.19425103   -4.23593556   -0.67258247    h       1.000     0
```

1-(Vinyloxy)butane Product :

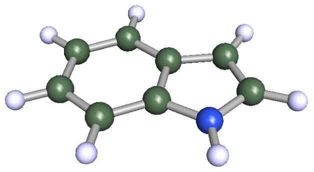
The $H_3$C-C-C-O Torsion Angle was constrained to 90°.



Total Energy = -350.53021421396 hartree
Enthalpy Correction = 0.223788 hartree
Entropy = 0.000158 hartree/K

```
                  atomic coordinates                atom    charge  isotop
         -5.21182658   -2.87282223    1.29278034    c       6.000     0
         -2.97667224   -4.17860016    0.37656565    c       6.000     0
         -2.90924212   -4.98981545   -1.52140458    h       1.000     0
         -1.02539372   -4.25419800    1.69502020    o       8.000     0
          1.32071023   -5.36397441    0.69634648    c       6.000     0
          1.76317144   -6.87066174    2.02564015    h       1.000     0
          0.89479019   -6.14714933   -1.16228765    h       1.000     0
          3.31164516   -3.33948361    0.63493658    c       6.000     0
          2.70499049   -1.81611924   -0.62595556    h       1.000     0
          3.52738626   -2.54006035    2.52886915    h       1.000     0
          5.82153616   -4.41926157   -0.26854769    c       6.000     0
          6.37879046   -5.98123576    0.96901090    h       1.000     0
          7.88847892   -2.42877985   -0.30964277    c       6.000     0
          5.58259585   -5.22083862   -2.16103089    h       1.000     0
          7.38854342   -0.86697961   -1.56631456    h       1.000     0
          8.19925611   -1.64705151    1.57749879    h       1.000     0
          9.67335549   -3.22753559   -0.96840422    h       1.000     0
         -5.28599473   -2.93918618    3.35055658    h       1.000     0
         -6.88197678   -3.75579943    0.47013163    h       1.000     0
         -5.00120037   -0.10461398    0.38379070    c       6.000     0
         -4.82908931    0.01087544   -1.66687312    h       1.000     0
         -6.72167110    0.87308919    0.95192010    h       1.000     0
         -3.38144443    0.82197685    1.25507271    h       1.000     0
```

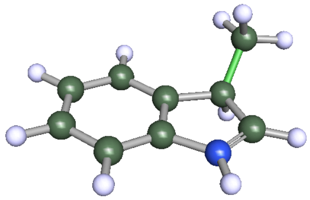
Indole (MCA* = 327.5 kJ/mol, N = 5.55, $s_N$ = 1.09):



Total Energy = -363.54829048296 hartree
Enthalpy Correction = 0.138153 hartree
Entropy = 0.000125 hartree/K

```
              atomic coordinates                 atom     charge  isotop
 0.53605265   -1.29984672   -0.02632984     c        6.000      0
-1.73051759   -2.63468281    0.05218148     c        6.000      0
-3.94321316   -1.24901092    0.14155522     c        6.000      0
-3.90650864    1.40492803    0.15298273     c        6.000      0
-1.65568160    2.72498516    0.07487953     c        6.000      0
 0.61939364    1.37797358   -0.01674789     c        6.000      0
 3.22840310    2.07464290   -0.11102974     c        6.000      0
 4.58546646   -0.12314910   -0.17229443     c        6.000      0
 2.97571180   -2.14508478   -0.12163901     n        7.000      0
-1.75815276   -4.68332558    0.04356876     h        1.000      0
-5.74137253   -2.22921190    0.20446764     h        1.000      0
-5.68003078    2.42863683    0.22479185     h        1.000      0
-1.64961361    4.77495599    0.08457473     h        1.000      0
 4.00271254    3.96145682   -0.13108739     h        1.000      0
 6.60267522   -0.41622603   -0.24923663     h        1.000      0
 3.51467525   -3.96704149   -0.15063698     h        1.000      0
```

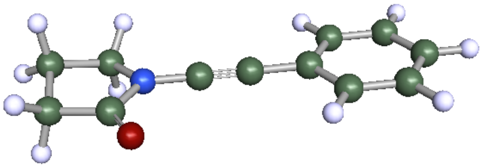
Indole Product:



Total Energy = -403.26150808094 hartree
Enthalpy Correction = 0.18096 hartree
Entropy = 0.000137 hartree/K

```
              atomic coordinates                 atom     charge  isotop
 4.41620544   -1.99945156    0.11435170     c        6.000      0
 2.58505767   -0.03690151    1.19144813     c        6.000      0
 3.00308597    2.54023601    0.18779665     c        6.000      0
 0.95028776    3.45119120   -0.74413290     n        7.000      0
-1.08106785    1.73353612   -0.55334117     c        6.000      0
-0.16093949   -0.43433591    0.61334074     c        6.000      0
-1.77337083   -2.44573379    1.01689516     c        6.000      0
-4.27372747   -2.20365540    0.23599376     c        6.000      0
-5.14608034   -0.00566214   -0.92156225     c        6.000      0
-3.54516191    2.03159424   -1.34535462     c        6.000      0
 3.99731977   -3.83674428    0.94460705     h        1.000      0
 4.21771677   -2.13310941   -1.93202351     h        1.000      0
 6.36009028   -1.49749332    0.57452393     h        1.000      0
 2.88851720    0.08342500    3.24592769     h        1.000      0
 4.74518710    3.61002172    0.19155936     h        1.000      0
 0.81007436    5.19875315   -1.51829894     h        1.000      0
-1.12241264   -4.16629525    1.91539715     h        1.000      0
-5.57182834   -3.75858385    0.53415651     h        1.000      0
-7.10404678    0.11943789   -1.50484175     h        1.000      0
-4.19490669    3.74977108   -2.24644268     h        1.000      0
```

Ynamide (MCA* = 325.8 kJ/mol, N = 3.12, $s_{N}$ = 0.85):

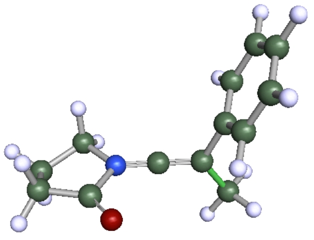


Total Energy = -593.39032246876 hartree
Enthalpy Correction = 0.216025 hartree
Entropy = 0.000174 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.80123022 | 0.56823038 | 4.55488430 | o | 8.000 | 0 |
| -4.81982856 | 0.29192325 | 2.52042938 | c | 6.000 | 0 |
| -3.54760220 | 0.08575972 | 0.25447705 | n | 7.000 | 0 |
| -1.03510966 | 0.03713031 | 0.07047292 | c | 6.000 | 0 |
| 1.23511176 | -0.00051323 | -0.13512613 | c | 6.000 | 0 |
| 3.90800651 | -0.04012783 | -0.37459373 | c | 6.000 | 0 |
| 5.45006770 | 0.17995148 | 1.76425140 | c | 6.000 | 0 |
| 8.05535597 | 0.14328041 | 1.51904932 | c | 6.000 | 0 |
| 9.16374749 | -0.11489388 | -0.84690288 | c | 6.000 | 0 |
| 7.64430762 | -0.33634792 | -2.97673663 | c | 6.000 | 0 |
| 5.03726618 | -0.29925287 | -2.75335160 | c | 6.000 | 0 |
| -5.22793239 | -0.36276730 | -1.90367553 | c | 6.000 | 0 |
| -7.79466969 | 0.47223139 | -0.88805438 | c | 6.000 | 0 |
| -7.59528412 | 0.05288758 | 1.95357097 | c | 6.000 | 0 |
| 4.58706620 | 0.37930577 | 3.61041041 | h | 1.000 | 0 |
| 9.22878735 | 0.31674290 | 3.18913768 | h | 1.000 | 0 |
| 11.20336904 | -0.14325630 | -1.03060157 | h | 1.000 | 0 |
| 8.49573067 | -0.53917823 | -4.82898162 | h | 1.000 | 0 |
| 3.85446184 | -0.47050838 | -4.41602074 | h | 1.000 | 0 |
| -4.59537522 | 0.73513033 | -3.52572341 | h | 1.000 | 0 |
| -5.18969692 | -2.36886334 | -2.39522688 | h | 1.000 | 0 |
| -9.33291935 | -0.58198665 | -1.75650329 | h | 1.000 | 0 |
| -8.07748749 | 2.47609156 | -1.28451308 | h | 1.000 | 0 |
| -8.68040127 | 1.37923778 | 3.09412217 | h | 1.000 | 0 |
| -8.16574121 | -1.86020693 | 2.49987705 | h | 1.000 | 0 |

Ynamide Product:

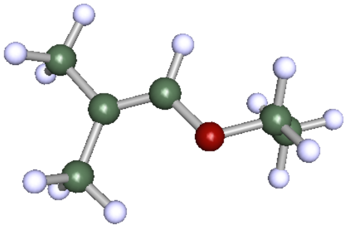
The HC-C-C-C Torsion Angle was constrained to 270°.



Total Energy = -633.10071941345 hartree
Enthalpy Correction = 0.257232 hartree
Entropy = 0.000188 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.80036158 | -1.62142242 | 3.76643362 | o | 8.000 | 0 |
| -4.62362444 | -0.41631609 | 2.07599943 | c | 6.000 | 0 |
| -7.01993192 | 0.99838817 | 1.68434794 | c | 6.000 | 0 |
| -7.25766061 | 1.33847824 | -1.16337401 | c | 6.000 | 0 |
| -4.54560867 | 1.58545135 | -2.08744908 | c | 6.000 | 0 |
| -3.13408795 | -0.04735162 | -0.31122955 | n | 7.000 | 0 |
| -1.01612384 | -1.03652657 | -0.63436248 | c | 6.000 | 0 |
| 1.18415783 | -2.06150583 | -0.81139054 | c | 6.000 | 0 |
| 1.62512844 | -4.63525640 | -1.88933017 | c | 6.000 | 0 |
| 3.34286098 | -0.49417878 | 0.11480062 | c | 6.000 | 0 |
| 4.58774042 | 1.12113882 | -1.54175642 | c | 6.000 | 0 |
| 6.64253783 | 2.50747501 | -0.69074814 | c | 6.000 | 0 |
| 7.44027159 | 2.28616086 | 1.79894364 | c | 6.000 | 0 |
| 6.18325486 | 0.67759382 | 3.44742350 | c | 6.000 | 0 |
| 4.12600589 | -0.71504573 | 2.61356382 | c | 6.000 | 0 |
| -6.78245273 | 2.81634957 | 2.65140504 | h | 1.000 | 0 |
| -8.58032255 | 0.00576825 | 2.58580789 | h | 1.000 | 0 |
| -8.35863441 | 2.99935877 | -1.66641717 | h | 1.000 | 0 |
| -8.14333363 | -0.31998082 | -2.00642483 | h | 1.000 | 0 |
| -4.23338608 | 0.93370725 | -4.00931520 | h | 1.000 | 0 |
| -3.81881950 | 3.50103026 | -1.86714934 | h | 1.000 | 0 |
| 2.89118218 | -4.46140811 | -3.51082642 | h | 1.000 | 0 |
| -0.12597834 | -5.54385054 | -2.46892070 | h | 1.000 | 0 |
| 2.57058997 | -5.78647704 | -0.45986326 | h | 1.000 | 0 |
| 3.95319491 | 1.28920608 | -3.48186819 | h | 1.000 | 0 |
| 7.61549067 | 3.76943534 | -1.97678399 | h | 1.000 | 0 |
| 9.04285223 | 3.37711619 | 2.45937169 | h | 1.000 | 0 |
| 6.79790171 | 0.50960407 | 5.39338327 | h | 1.000 | 0 |
| 3.13285067 | -1.96920631 | 3.89241705 | h | 1.000 | 0 |

1-Ethoxy-2-methylprop-1-ene (MCA* = 320.1 kJ/mol, N = 4.23, $s_N$ = 1.00):



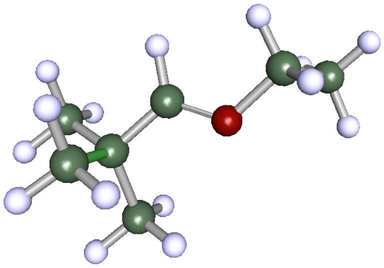
Total Energy = -310.82336714506 hartree
Enthalpy Correction = 0.179689 hartree
Entropy = 0.000144 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.95433745 | -4.55571355 | 0.47027696 | c | 6.000 | 0 |
| -1.90016934 | -3.12642437 | 0.20136241 | c | 6.000 | 0 |
| -5.70988449 | -4.94097923 | -1.70954249 | c | 6.000 | 0 |
| -4.63889425 | -5.80283542 | 2.90876261 | c | 6.000 | 0 |
| -1.42402978 | -2.25004352 | -1.59967229 | h | 1.000 | 0 |

```
  -0.30669316   -2.56913518    2.13973966     o       8.000      0
  -5.04468198   -3.97743151   -3.40864480     h       1.000      0
  -7.60742479   -4.23486145   -1.27246624     h       1.000      0
  -5.91555988   -6.95490075   -2.14473363     h       1.000      0
  -6.41076330   -5.03708793    3.65852739     h       1.000      0
  -4.94678432   -7.83005816    2.62496534     h       1.000      0
  -3.17351424   -5.55480867    4.33438254     h       1.000      0
   2.18759699   -1.90350053    1.37913227     c       6.000      0
   3.70862471   -4.17304944    0.55442672     c       6.000      0
   3.04236324   -1.00360127    3.02535467     h       1.000      0
   2.08218681   -0.49522849   -0.13840531     h       1.000      0
   2.85149029   -5.08121012   -1.08985364     h       1.000      0
   5.62174912   -3.58946572    0.04286359     h       1.000      0
   3.83497177   -5.55959453    2.07856008     h       1.000      0
```

1-Ethoxy-2-methylprop-1-ene Product:

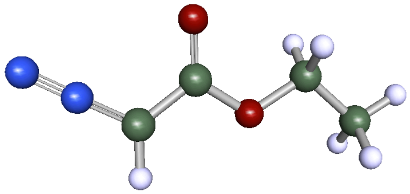
The $H_3C$-C-C-O Torsion Angle was constrained to 90°.



Total Energy = -350.53393040777 hartree
Enthalpy Correction = 0.222333 hartree
Entropy = 0.000155 hartree/K

```
                 atomic coordinates                atom    charge  isotop
  -4.27828092   -5.08761017    0.54600143     c       6.000      0
  -1.87015164   -3.79771454    0.10037407     c       6.000      0
  -1.18230158   -3.51250338   -1.82760955     h       1.000      0
  -0.64494048   -2.84573421    1.87186331     o       8.000      0
   1.68826184   -1.40293090    1.36791597     c       6.000      0
   3.85987712   -2.78101020    2.54905586     c       6.000      0
   1.32483147    0.42348653    2.23993403     h       1.000      0
   1.85214441   -1.20235164   -0.67537313     h       1.000      0
   4.14078729   -4.62439580    1.66924995     h       1.000      0
   5.56153511   -1.65197578    2.25742303     h       1.000      0
   3.57609077   -3.01777472    4.57627804     h       1.000      0
  -4.71445281   -7.04400690   -1.52729146     c       6.000      0
  -4.45482667   -6.22769978    3.18246967     c       6.000      0
  -6.19144566   -2.87638154    0.27307903     c       6.000      0
  -3.05435857   -7.72159411    3.43106822     h       1.000      0
  -4.17545463   -4.80547583    4.64683981     h       1.000      0
  -6.33052122   -7.04773526    3.42288539     h       1.000      0
  -6.60947881   -7.82627583   -1.31326154     h       1.000      0
  -4.57094082   -6.19796918   -3.40384367     h       1.000      0
  -3.35282529   -8.58673273   -1.38718177     h       1.000      0
  -5.94529988   -1.49844384    1.78439753     h       1.000      0
  -6.03197628   -1.92800593   -1.55221864     h       1.000      0
  -8.07437121   -3.70891289    0.40757927     h       1.000      0
```

Ethyl 2-diazoacetate Anion (MCA* = 310.8 kJ/mol, N = 4.91, $s_{\mathrm{N}}$ = 0.95):

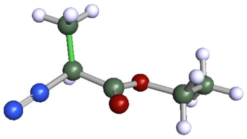


Total Energy = -415.66276991176 hartree
Enthalpy Correction = 0.114949 hartree
Entropy = 0.000143 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.13100518 | -4.30277137 | 0.80957115 | c | 6.000 | 0 |
| -2.81142675 | -2.39895977 | -0.01224650 | n | 7.000 | 0 |
| -3.92062499 | -6.07612942 | -0.17440985 | h | 1.000 | 0 |
| -5.74454165 | -3.85467080 | 2.96187670 | c | 6.000 | 0 |
| -1.69122748 | -0.74189094 | -0.69229215 | n | 7.000 | 0 |
| -6.97523684 | -5.95981051 | 3.59954348 | o | 8.000 | 0 |
| -5.96685246 | -1.84669059 | 4.05716724 | o | 8.000 | 0 |
| -8.64763810 | -5.77384779 | 5.73520097 | c | 6.000 | 0 |
| -9.83945328 | -8.32464083 | 6.11710674 | c | 6.000 | 0 |
| -7.55100000 | -5.18580696 | 7.38141267 | h | 1.000 | 0 |
| -10.05746767 | -4.31912150 | 5.34440899 | h | 1.000 | 0 |
| -11.12234620 | -8.24137857 | 7.73077956 | h | 1.000 | 0 |
| -10.92380711 | -8.89110265 | 4.45573629 | h | 1.000 | 0 |
| -8.40888965 | -9.76087042 | 6.49965235 | h | 1.000 | 0 |

Ethyl 2-diazoacetate Product Anion:

The $H_3C$-C-C-O Torsion Angle was constrained to 90°.

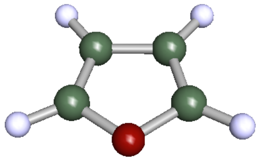


Total Energy = -455.36877342914 hartree
Enthalpy Correction = 0.157491 hartree
Entropy = 0.000157 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.37361440 | -3.99433218 | 0.84075140 | c | 6.000 | 0 |
| -1.38206957 | -2.70515115 | 2.18660984 | n | 7.000 | 0 |
| -2.17258649 | -4.92200110 | -1.63780061 | c | 6.000 | 0 |
| -5.53720156 | -2.15540586 | 0.39525273 | c | 6.000 | 0 |
| -3.88757124 | -5.55951920 | 2.08520467 | h | 1.000 | 0 |
| 0.11690624 | -1.72428232 | 3.19055311 | n | 7.000 | 0 |
| -7.01345161 | -3.21779863 | -0.57062222 | h | 1.000 | 0 |
| -4.92842106 | -0.58531854 | -0.78612307 | h | 1.000 | 0 |
| -6.26898243 | -1.46974267 | 2.19028127 | h | 1.000 | 0 |
| -0.43843944 | -3.86010977 | -2.63687731 | o | 8.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -3.43223319 | -6.88161638 | -2.43333205 | o | 8.000 | 0 |
| -2.68870875 | -7.90480694 | -4.87884397 | c | 6.000 | 0 |
| -2.87800378 | -6.39476746 | -6.26866694 | h | 1.000 | 0 |
| -4.38415867 | -10.10736961 | -5.43110574 | c | 6.000 | 0 |
| -0.70633873 | -8.45063208 | -4.74389641 | h | 1.000 | 0 |
| -6.35796190 | -9.51924546 | -5.52981953 | h | 1.000 | 0 |
| -4.18631142 | -11.57408876 | -3.99515526 | h | 1.000 | 0 |
| -3.85330117 | -10.90985336 | -7.25579254 | h | 1.000 | 0 |

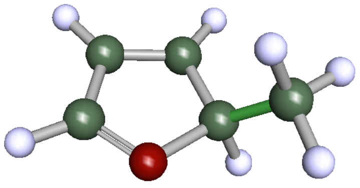
Furan (MCA* = 302.4 kJ/mol, N = 1.33, $s_N$ = 1.29):



Total Energy = -229.85701027883 hartree
Enthalpy Correction = 0.075257 hartree
Entropy = 0.000103 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.30247653 | 1.38135389 | 0.08836589 | c | 6.000 | 0 |
| -2.05142220 | -1.06214262 | -0.02446042 | c | 6.000 | 0 |
| -0.05280758 | -2.58196637 | -0.53026051 | o | 8.000 | 0 |
| 2.00786893 | -1.07566341 | -0.74259497 | c | 6.000 | 0 |
| 1.35854270 | 1.37259458 | -0.38251534 | c | 6.000 | 0 |
| -2.49136717 | 2.99534892 | 0.46013134 | h | 1.000 | 0 |
| -3.85015054 | -1.99138430 | 0.20073164 | h | 1.000 | 0 |
| 3.76866106 | -2.01658191 | -1.14734874 | h | 1.000 | 0 |
| 2.61315132 | 2.97844123 | -0.44310287 | h | 1.000 | 0 |

Furan Product:

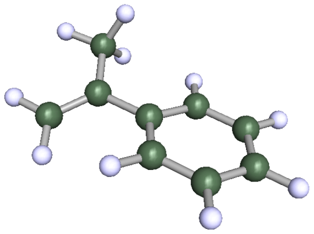


Total Energy = -269.55979531645 hartree
Enthalpy Correction = 0.117462 hartree
Entropy = 0.000116 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.21112181 | -0.78299032 | -0.40258111 | c | 6.000 | 0 |
| -0.72053801 | -0.48720922 | 0.97072733 | c | 6.000 | 0 |
| 1.11255214 | -2.27279834 | -0.03855594 | o | 8.000 | 0 |
| 3.07149384 | -1.03735836 | -0.72827018 | c | 6.000 | 0 |
| 2.87936018 | 1.58899141 | -0.33233218 | c | 6.000 | 0 |
| 0.57241207 | 1.95186492 | 0.70811839 | c | 6.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -2.98808383 | -0.36727513 | -2.40711226 | h | 1.000 | 0 |
| -3.90919475 | -2.70269757 | -0.15451666 | h | 1.000 | 0 |
| -4.56496895 | 0.53408785 | 0.41826786 | h | 1.000 | 0 |
| -0.91938957 | -0.98975281 | 2.97251881 | h | 1.000 | 0 |
| 4.62560342 | -2.11712087 | -1.51329221 | h | 1.000 | 0 |
| 4.31637188 | 2.96000202 | -0.78644423 | h | 1.000 | 0 |
| -0.26449661 | 3.72225642 | 1.29347239 | h | 1.000 | 0 |

Prop-1-en-2-ylbenzene (MCA* = 301.3 kJ/mol, N = 2.35, $s_N$ = 1.00):

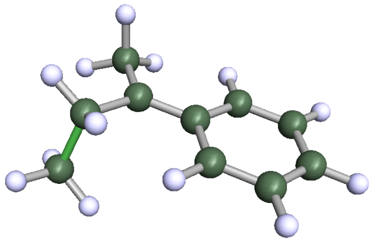


Total Energy = -348.68095674614 hartree
Enthalpy Correction = 0.171299 hartree
Entropy = 0.000138 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.13661821 | -12.33535065 | 9.85664481 | c | 6.000 | 0 |
| -2.73658779 | -13.38918815 | 9.95129948 | c | 6.000 | 0 |
| -0.67226801 | -11.91746817 | 10.61531088 | c | 6.000 | 0 |
| -1.03171096 | -9.37648740 | 11.17595999 | c | 6.000 | 0 |
| -3.42832752 | -8.33063809 | 11.08695240 | c | 6.000 | 0 |
| -5.53546994 | -9.79383625 | 10.44866704 | c | 6.000 | 0 |
| -6.71992193 | -13.52263897 | 9.33390207 | h | 1.000 | 0 |
| -2.48305269 | -15.37133566 | 9.49768693 | h | 1.000 | 0 |
| 1.20517425 | -12.73470917 | 10.67790062 | h | 1.000 | 0 |
| 0.57062142 | -8.19691278 | 11.66570882 | h | 1.000 | 0 |
| -3.66359618 | -6.33493092 | 11.48166398 | h | 1.000 | 0 |
| -8.10633700 | -8.69543636 | 10.37970047 | c | 6.000 | 0 |
| -10.04339633 | -9.99047835 | 8.76826930 | c | 6.000 | 0 |
| -8.71174537 | -6.64484468 | 11.72089910 | c | 6.000 | 0 |
| -7.37463366 | -5.71510871 | 12.96255616 | h | 1.000 | 0 |
| -10.59843294 | -5.85106571 | 11.62600274 | h | 1.000 | 0 |
| -11.78895422 | -8.89828690 | 8.71304388 | h | 1.000 | 0 |
| -9.35722167 | -10.25033448 | 6.83628761 | h | 1.000 | 0 |
| -10.49586406 | -11.86970317 | 9.50172533 | h | 1.000 | 0 |

Prop-1-en-2-ylbenzene Product:

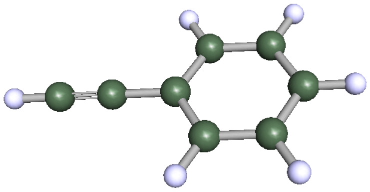
The $H_3C$-C-C-C Torsion Angle was constrained to 90°.



Total Energy = -388.38341646863 hartree
Enthalpy Correction = 0.213926 hartree
Entropy = 0.000152 hartree/K

| atomic coordinates | | | atom | charge | isoto |
|---|---|---|---|---|---|
| -4.96557449 | -5.45933999 | 2.06291003 | c | 6.000 | 0 |
| -3.23179601 | -6.60772143 | 0.44876244 | c | 6.000 | 0 |
| -1.93208831 | -5.20444670 | -1.36098991 | c | 6.000 | 0 |
| -2.37207035 | -2.65438711 | -1.57287288 | c | 6.000 | 0 |
| -4.11369741 | -1.43489441 | 0.05251908 | c | 6.000 | 0 |
| -5.39424342 | -2.90392131 | 1.88510959 | c | 6.000 | 0 |
| -5.96341952 | -6.57362028 | 3.45808034 | h | 1.000 | 0 |
| -2.88849728 | -8.62121017 | 0.60280786 | h | 1.000 | 0 |
| -0.58973059 | -6.12216938 | -2.60167630 | h | 1.000 | 0 |
| -1.36415035 | -1.58717315 | -2.99324909 | h | 1.000 | 0 |
| -4.55271051 | 1.18954998 | -0.15099066 | c | 6.000 | 0 |
| -6.73462224 | -2.03006263 | 3.15409423 | h | 1.000 | 0 |
| -6.31343838 | 2.54750570 | 1.49948769 | c | 6.000 | 0 |
| -3.23711526 | 2.76929888 | -2.03158320 | c | 6.000 | 0 |
| -8.08413337 | 2.71198206 | 0.41852558 | h | 1.000 | 0 |
| -6.73484599 | 1.63711316 | 3.28797540 | h | 1.000 | 0 |
| -5.67044718 | 4.48411362 | 1.79971736 | h | 1.000 | 0 |
| -0.77382328 | 3.77559778 | -0.84023185 | c | 6.000 | 0 |
| -4.44261085 | 4.37506406 | -2.50651727 | h | 1.000 | 0 |
| -2.80309792 | 1.74262160 | -3.75953082 | h | 1.000 | 0 |
| 0.11662078 | 5.05686085 | -2.18495386 | h | 1.000 | 0 |
| -1.15057923 | 4.81171143 | 0.90158258 | h | 1.000 | 0 |
| 0.52795243 | 2.23379691 | -0.42253141 | h | 1.000 | 0 |

Ethynylbenzene (MCA* = 295.4 kJ/mol, N = -0.04, $s_N$ = 0.77):

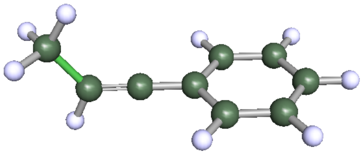


Total Energy = -308.14592005916 hartree
Enthalpy Correction = 0.117739 hartree
Entropy 0.000123 = hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -3.90476067 | c | 6.000 | 0 |
| -2.27177560 | 0.00000000 | -2.59016248 | c | 6.000 | 0 |
| -2.28229729 | 0.00000000 | 0.02702601 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.36034361 | c | 6.000 | 0 |
| 2.28229729 | 0.00000000 | 0.02702601 | c | 6.000 | 0 |
| 2.27177560 | 0.00000000 | -2.59016248 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -5.95299167 | h | 1.000 | 0 |
| -4.04861973 | 0.00000000 | -3.60903478 | h | 1.000 | 0 |
| -4.05204225 | 0.00000000 | 1.05674470 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 4.05329341 | c | 6.000 | 0 |
| 4.05204225 | 0.00000000 | 1.05674470 | h | 1.000 | 0 |

```
          4.04861973    0.00000000   -3.60903478     h      1.000     0
          0.00000000    0.00000000    6.32928014     c      6.000     0
          0.00000000    0.00000000    8.34616309     h      1.000     0
```

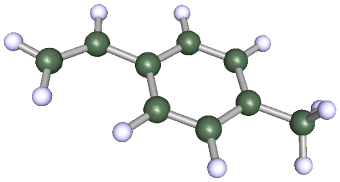
Ethynylbenzene Product:



Total Energy = -347.84484729939 hartree
Enthalpy Correction = 0.159954 hartree
Entropy 0.00014 = hartree/K

```
                   atomic coordinates               atom    charge  isotop
         -5.65149079    0.33221725    0.00000000     c      6.000     0
         -4.37346707    0.37140437   -2.30901239     c      6.000     0
         -1.78375905    0.44926283   -2.33391086     c      6.000     0
         -0.45049111    0.48808920    0.00000000     c      6.000     0
         -1.78375905    0.44926283    2.33391086     c      6.000     0
         -4.37346707    0.37140437    2.30901239     c      6.000     0
         -7.69902700    0.27031467    0.00000000     h      1.000     0
         -5.42632152    0.34021782   -4.06185152     h      1.000     0
         -0.72741477    0.48027278   -4.08550730     h      1.000     0
          2.11291130    0.54810283    0.00000000     c      6.000     0
         -0.72741477    0.48027278    4.08550730     h      1.000     0
         -5.42632152    0.34021782    4.06185152     h      1.000     0
          4.52718042    0.61751868    0.00000000     c      6.000     0
          6.26531235   -1.61925669    0.00000000     c      6.000     0
          5.35672027    2.51041634    0.00000000     h      1.000     0
          7.47015284   -1.52067291    1.67083214     h      1.000     0
          7.47015284   -1.52067291   -1.67083214     h      1.000     0
          5.22229749   -3.38979009    0.00000000     h      1.000     0
```

1-Methyl-4-vinylbenzene (MCA* = 292.5 kJ/mol, N = 1.70, $s_N$ = 1.06):



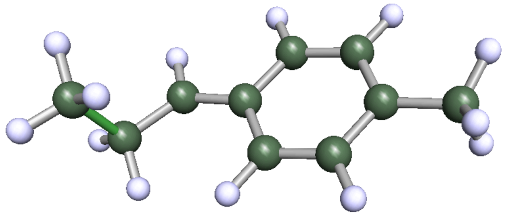
Total Energy = -348.68214301934 hartree
Enthalpy Correction = 0.170998 hartree
Entropy = 0.000141 hartree/K

```
                   atomic coordinates               atom    charge  isotop
         -4.61303871   -5.71165978    0.87442472     c      6.000     0
         -2.17932720   -6.64588485    0.71194835     c      6.000     0
         -0.11681488   -5.04700034    0.31462535     c      6.000     0
         -0.59151659   -2.47237379    0.07427805     c      6.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -3.03089114 | -1.52817096 | 0.23772428 | c | 6.000 | 0 |
| -5.09166857 | -3.12273186 | 0.64169473 | c | 6.000 | 0 |
| -6.16186947 | -7.01754073 | 1.18080695 | h | 1.000 | 0 |
| -1.86314042 | -8.66469720 | 0.89267256 | h | 1.000 | 0 |
| 2.51688521 | -6.07369949 | 0.19721188 | c | 6.000 | 0 |
| 0.97076895 | -1.18350134 | -0.24943994 | h | 1.000 | 0 |
| -3.35239310 | 0.48840963 | 0.04191118 | h | 1.000 | 0 |
| -7.62813067 | -2.02974979 | 0.79283818 | c | 6.000 | 0 |
| 3.28249219 | -6.34323248 | 2.10018011 | h | 1.000 | 0 |
| 3.77862000 | -4.78638636 | -0.80372087 | h | 1.000 | 0 |
| 2.56435222 | -7.90830802 | -0.74581094 | h | 1.000 | 0 |
| -9.79507385 | -3.26265901 | 1.14729938 | c | 6.000 | 0 |
| -7.69130156 | 0.01541127 | 0.58767651 | h | 1.000 | 0 |
| -9.88345430 | -5.29929481 | 1.36520330 | h | 1.000 | 0 |
| -11.57200492 | -2.24843358 | 1.22917892 | h | 1.000 | 0 |

1-Methyl-4-vinylbenzene Product:

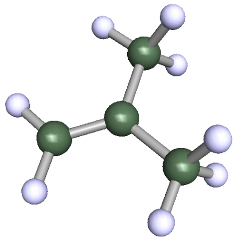
The $H_3$C-C-C-C Torsion Angle was constrained to 90°.



Total Energy = -388.38136434686 hartree
Enthalpy Correction = 0.213707 hartree
Entropy = 0.000155 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.95743284 | -6.58144945 | 0.71363618 | c | 6.000 | 0 |
| -2.53278465 | -7.46848279 | 0.82580841 | c | 6.000 | 0 |
| -0.49318138 | -5.85261493 | 0.31276270 | c | 6.000 | 0 |
| -0.95461580 | -3.30903578 | -0.32709238 | c | 6.000 | 0 |
| -3.36239744 | -2.39427047 | -0.44160321 | c | 6.000 | 0 |
| -5.44213988 | -4.01890608 | 0.06866223 | c | 6.000 | 0 |
| -6.54378794 | -7.81816956 | 1.10147001 | h | 1.000 | 0 |
| -2.16888407 | -9.42457300 | 1.30655698 | h | 1.000 | 0 |
| 2.13901641 | -6.78821594 | 0.49183268 | c | 6.000 | 0 |
| 0.63277023 | -2.07904063 | -0.72538450 | h | 1.000 | 0 |
| -3.69028458 | -0.43274662 | -0.92153747 | h | 1.000 | 0 |
| -7.92144956 | -3.22124157 | -0.06766253 | c | 6.000 | 0 |
| 3.34782038 | -5.89646515 | -0.92018278 | h | 1.000 | 0 |
| 2.23686572 | -8.83737780 | 0.31851971 | h | 1.000 | 0 |
| 2.90154731 | -6.27434330 | 2.34975509 | h | 1.000 | 0 |
| -9.35437296 | -4.63934438 | 0.33757558 | h | 1.000 | 0 |
| -8.83397615 | -0.75092812 | -0.89665032 | c | 6.000 | 0 |
| -10.62269041 | -0.33080868 | 0.04016553 | h | 1.000 | 0 |
| -9.28537251 | -0.89082655 | -3.78000598 | c | 6.000 | 0 |
| -7.48652591 | 0.75425752 | -0.49435680 | h | 1.000 | 0 |
| -7.50886447 | -1.19904381 | -4.77718406 | h | 1.000 | 0 |
| -10.10184450 | 0.89890001 | -4.39233404 | h | 1.000 | 0 |
| -10.59062621 | -2.41119581 | -4.26389323 | h | 1.000 | 0 |

2-Methylprop-1-ene (MCA* = 289.5 kJ/mol, N = 1.11, $s_N$ = 0.98):

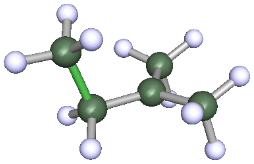


Total Energy = -157.09027283334 hartree
Enthalpy Correction = 0.114178 hartree
Entropy = 0.000109 hartree/K

```
                atomic coordinates             atom    charge  isotop
     0.00000000    0.00000000   -2.92361943    c      6.000     0
     0.00000000    0.00000000   -0.40695235    c      6.000     0
     0.00000000   -1.75189602   -3.99018869    h      1.000     0
     0.00000000    1.75189602   -3.99018869    h      1.000     0
     0.00000000   -2.39191957    1.09982271    c      6.000     0
     0.00000000    2.39191957    1.09982271    c      6.000     0
     0.00000000    4.06219864   -0.10821107    h      1.000     0
    -1.65790579    2.47116383    2.33617244    h      1.000     0
     1.65790579    2.47116383    2.33617244    h      1.000     0
     0.00000000   -4.06219864   -0.10821107    h      1.000     0
    -1.65790579   -2.47116383    2.33617244    h      1.000     0
     1.65790579   -2.47116383    2.33617244    h      1.000     0
```

2-Methylprop-1-ene Product:

The $H_3C$-C-C-C Torsion Angle was constrained to 90°.

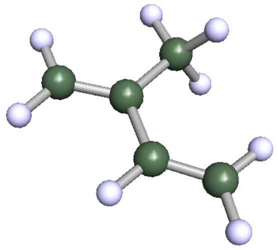


Total Energy = -196.78550865550 hartree
Enthalpy Correction = 0.155265 hartree
Entropy = 0.000127 hartree/K

```
                atomic coordinates             atom    charge  isotop
    -3.72657314   -4.09347214    0.29303961    c      6.000     0
    -1.86744540   -2.08524264    0.15449492    c      6.000     0
    -5.52097123   -3.53287095   -0.54883505    h      1.000     0
    -3.97162077   -4.76765660    2.22411783    h      1.000     0
    -2.55428125   -6.25868885   -1.32068025    c      6.000     0
    -2.05464180   -0.19904206   -1.81953385    c      6.000     0
     0.13801248   -1.96121051    2.01220445    c      6.000     0
     0.43583680   -3.73959192    3.00449020    h      1.000     0
    -0.62116833   -0.62189740    3.42813098    h      1.000     0
     1.87469234   -1.12633263    1.29149034    h      1.000     0
    -3.12323717   -0.85533668   -3.45311403    h      1.000     0
```

```
  -3.23263039    1.28587071   -0.93544582    h       1.000     0
  -0.25809512    0.66907982   -2.31587680    h       1.000     0
  -2.28543811   -5.67635299   -3.27721083    h       1.000     0
  -0.75695026   -6.89020283   -0.54000726    h       1.000     0
  -3.89322871   -7.82219955   -1.26634511    h       1.000     0
```

Isoprene (MCA* = 287.0 kJ/mol, N = 1.10, $s_N$ = 0.98):

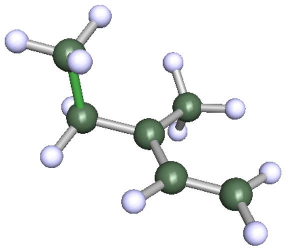


Total Energy = -195.14409287956 hartree
Enthalpy Correction = 0.120559 hartree
Entropy = 0.000117 hartree/K

```
                 atomic coordinates                atom    charge  isotop
  -3.30614637   -2.84312284   -2.05844833    c       6.000     0
  -3.57110302   -1.72520821    0.19390459    c       6.000     0
  -1.80712806   -4.20149410   -2.39554263    h       1.000     0
  -4.57431468   -2.43071902   -3.61472861    h       1.000     0
  -1.81259197   -2.34438815    2.23023983    c       6.000     0
  -5.62492316    0.15197576    0.69704607    c       6.000     0
  -1.86662567   -1.37123784    4.55444396    c       6.000     0
  -0.35926596   -3.71891516    1.75565102    h       1.000     0
  -3.27469199    0.00471687    5.12497277    h       1.000     0
  -0.48955145   -1.93007640    5.96400926    h       1.000     0
  -6.79035015    0.43615830   -0.97784198    h       1.000     0
  -4.83672518    1.97679262    1.26467959    h       1.000     0
  -6.84316456   -0.47989372    2.24327338    h       1.000     0
```

Isoprene Product:

The $H_3C$-C-C-C Torsion Angle was constrained to 90°.

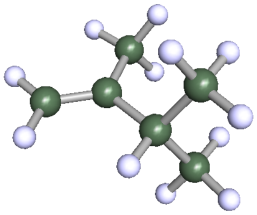


Total Energy = -234.84014495087 hartree
Enthalpy Correction = 0.162813 hartree
Entropy = 0.000133 hartree/K

```
              atomic coordinates              atom    charge  isotop
   -3.33959205   -3.78808090    0.29400307    c      6.000     0
   -1.53345754   -1.69902143    0.11945707    c      6.000     0
   -5.59460270   -2.83532256    1.89998046    c      6.000     0
   -4.03131416   -4.31378533   -1.57533086    h      1.000     0
   -2.49060358   -5.41579923    1.23062250    h      1.000     0
    0.32268559   -1.48070568    2.03209783    c      6.000     0
   -1.80212476    0.06049608   -1.98451618    c      6.000     0
    0.38749059   -2.95596855    3.45307836    h      1.000     0
    1.99182724    0.44179049    2.12842711    c      6.000     0
    1.99939860    1.96402943    0.75974063    h      1.000     0
    3.40561925    0.51618062    3.60839897    h      1.000     0
   -3.79897641    0.35413710   -2.42077260    h      1.000     0
   -0.81955363    1.84945430   -1.77506989    h      1.000     0
   -1.02700505   -0.93068836   -3.64245229    h      1.000     0
   -4.99177647   -2.31742501    3.80061945    h      1.000     0
   -6.95892513   -4.37295186    2.03135907    h      1.000     0
   -6.50240122   -1.21169148    1.01514461    h      1.000     0
```

2,3-Dimethylbut-1-ene (MCA* = 285.1 kJ/mol, N = 0.65, $s_N$ = 1.00):

The rotamer with slight $A_{1,2}$ strain leads to a lower energy product when it is held in a reactant-like conformation.

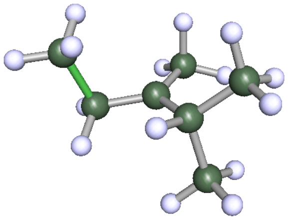


Total Energy = -235.65096097167 hartree
Enthalpy Correction = 0.173752 hartree
Entropy = 0.000134 hartree/K

```
              atomic coordinates              atom    charge  isotop
   -3.57504886   -4.16697067   -0.44242881    c      6.000     0
   -2.25112776   -2.09322210    0.08811179    c      6.000     0
   -5.16354986   -4.09636189   -1.73831333    h      1.000     0
   -3.13329063   -5.98779330    0.38267449    h      1.000     0
   -2.92545990    0.40087892   -1.07201609    c      6.000     0
   -0.02128678   -2.07027629    1.86916945    c      6.000     0
   -3.22004525    1.83111702    0.39399614    h      1.000     0
   -4.64050157    0.26184213   -2.20712540    h      1.000     0
   -1.40866807    1.10518403   -2.28715338    h      1.000     0
    2.42376244   -1.43674810    0.46065445    c      6.000     0
   -0.37043393   -0.52357975    3.21028097    h      1.000     0
    0.30981830   -4.48871633    3.38083655    c      6.000     0
   -1.39752648   -4.96998961    4.43685089    h      1.000     0
    1.85863020   -4.27071260    4.72829411    h      1.000     0
    0.77320170   -6.08376569    2.15045542    h      1.000     0
    2.84781105   -2.90313436   -0.93342071    h      1.000     0
    4.00534351   -1.33537043    1.78453924    h      1.000     0
    2.31060372    0.37214182   -0.52310420    h      1.000     0
```

2,3-Dimethylbut-1-ene Product:

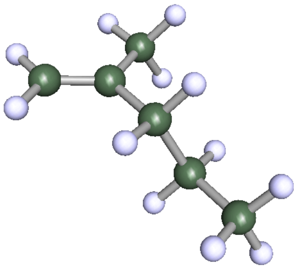
The $H_3C$-C-C-C Torsion Angle was constrained to 270°.



Total Energy = -275.34664068668 hartree
Enthalpy Correction = 0.215457 hartree
Entropy = 0.000147 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.78919813 | -3.81051508 | -0.14835463 | c | 6.000 | 0 |
| -2.12777082 | -1.66262127 | 0.27384902 | c | 6.000 | 0 |
| -2.85729703 | -5.57548675 | 0.37224615 | h | 1.000 | 0 |
| -6.03975448 | -3.40263313 | 1.69815496 | c | 6.000 | 0 |
| -4.48745095 | -3.88435897 | -2.08210429 | h | 1.000 | 0 |
| -2.45049290 | 0.63121606 | -1.18985560 | c | 6.000 | 0 |
| -0.18807967 | -1.84490041 | 2.21457757 | c | 6.000 | 0 |
| -3.37988103 | 0.31933952 | -2.99606216 | h | 1.000 | 0 |
| -3.70890812 | 1.82549955 | -0.02621192 | h | 1.000 | 0 |
| -0.70961102 | 1.71855200 | -1.36715580 | h | 1.000 | 0 |
| -0.69583552 | -3.34133814 | 3.54363757 | h | 1.000 | 0 |
| 2.08903038 | -2.86845903 | 0.63231487 | c | 6.000 | 0 |
| 0.51245635 | 0.57606398 | 3.57987416 | c | 6.000 | 0 |
| 1.25676693 | 2.00391922 | 2.29214684 | h | 1.000 | 0 |
| -1.11514083 | 1.36489290 | 4.57033433 | h | 1.000 | 0 |
| 1.97576108 | 0.15366378 | 4.96765871 | h | 1.000 | 0 |
| 1.65137913 | -4.63488159 | -0.33138607 | h | 1.000 | 0 |
| 2.71971487 | -1.46946393 | -0.74165640 | h | 1.000 | 0 |
| 3.60186116 | -3.21124912 | 1.98961271 | h | 1.000 | 0 |
| -5.40010760 | -3.32300133 | 3.65443026 | h | 1.000 | 0 |
| -7.07719447 | -1.68224067 | 1.24633080 | h | 1.000 | 0 |
| -7.29611541 | -5.01838809 | 1.47532977 | h | 1.000 | 0 |

2-Methylpent-1-ene (MCA* = 285.1 kJ/mol, N = 0.84, $s_N$ = 1.06):



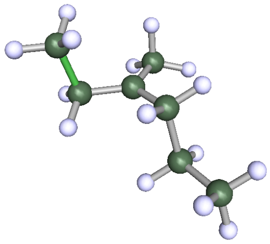
Total Energy = -235.65081485367 hartree

Enthalpy Correction = 0.174052 hartree
Entropy = 0.000135 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.03173615 | -3.68464895 | 0.06674995 | c | 6.000 | 0 |
| -2.36533121 | -1.80174717 | 0.17954906 | c | 6.000 | 0 |
| -3.81260908 | -5.37006579 | 1.21559204 | h | 1.000 | 0 |
| -5.66414060 | -3.59698666 | -1.17275708 | h | 1.000 | 0 |
| -0.10939405 | -1.91811060 | 1.89392809 | c | 6.000 | 0 |
| -2.64939454 | 0.53627623 | -1.38728222 | c | 6.000 | 0 |
| -2.65206429 | 2.22088705 | -0.18519778 | h | 1.000 | 0 |
| -1.06587290 | 0.75403780 | -2.69887374 | h | 1.000 | 0 |
| -4.39459053 | 0.50548209 | -2.48396540 | h | 1.000 | 0 |
| 2.42246969 | -1.94620103 | 0.50909197 | c | 6.000 | 0 |
| -0.14260594 | -0.27340938 | 3.15983757 | h | 1.000 | 0 |
| -0.24453433 | -3.60031722 | 3.08963006 | h | 1.000 | 0 |
| 2.60969193 | -0.23991303 | -0.64351804 | h | 1.000 | 0 |
| 2.45394615 | -3.54805966 | -0.80249699 | h | 1.000 | 0 |
| 4.64248702 | -2.12383503 | 2.31941082 | c | 6.000 | 0 |
| 6.44153035 | -2.14417069 | 1.30659318 | h | 1.000 | 0 |
| 4.66687892 | -0.51615623 | 3.61925529 | h | 1.000 | 0 |
| 4.53587505 | -3.84668121 | 3.45654704 | h | 1.000 | 0 |

2-Methylpent-1-ene Product:

The $H_3C$-C-C-C Torsion Angle was constrained to 90°.

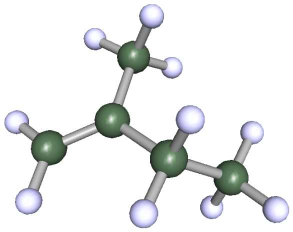


Total Energy = -275.34639497341 hartree
Enthalpy Correction = 0.215954 hartree
Entropy = 0.000149 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.94718038 | -4.15100623 | -2.03119113 | c | 6.000 | 0 |
| -0.76440415 | -1.51566704 | -1.30889940 | c | 6.000 | 0 |
| -3.16786200 | -5.59477014 | -1.35700994 | c | 6.000 | 0 |
| 1.05656610 | -5.34094635 | -3.48832227 | c | 6.000 | 0 |
| 2.89687722 | -4.51063652 | -3.08672189 | h | 1.000 | 0 |
| 1.07956692 | -7.37839606 | -3.16892659 | h | 1.000 | 0 |
| 0.37431516 | -4.86678991 | -6.30720553 | c | 6.000 | 0 |
| 0.40051323 | -2.85606509 | -6.74635446 | h | 1.000 | 0 |
| 1.80429325 | -5.82143358 | -7.43967435 | h | 1.000 | 0 |
| -1.47442311 | -5.64555250 | -6.77429427 | h | 1.000 | 0 |
| -2.02815005 | -1.01414152 | 0.23678356 | h | 1.000 | 0 |
| 1.17094693 | -0.87907556 | -1.01778231 | h | 1.000 | 0 |
| -1.48483692 | -0.49584485 | -2.98601801 | h | 1.000 | 0 |

```
   -4.84101020   -4.40312914   -1.18341027     h       1.000      0
   -3.48755349   -7.17053960   -2.64607173     h       1.000      0
   -2.54618818   -6.70037371    1.31861632     c       6.000      0
   -4.75132915   -8.29430724    2.22419840     c       6.000      0
   -0.82915279   -7.83859653    1.20592356     h       1.000      0
   -2.18614219   -5.14937184    2.63008405     h       1.000      0
   -6.47355426   -7.16731583    2.36510297     h       1.000      0
   -5.10496945   -9.87031345    0.94101994     h       1.000      0
   -4.32292126   -9.06154754    4.09147745     h       1.000      0
```

2-Methylbut-1-ene (MCA* = 283.3 kJ/mol, N = 1.00, $s_N$ = 1.00):

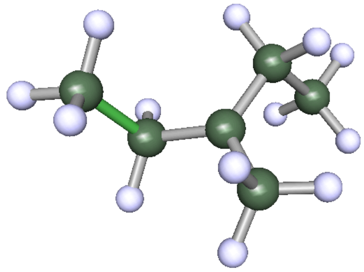


Total Energy = -196.36978715249 hartree
Enthalpy Correction = 0.144291 hartree
Entropy = 0.000123 hartree/K

```
             atomic coordinates                  atom    charge  isotop
   -4.07418272   -3.56519090    0.43433533     c       6.000      0
   -2.15097944   -1.95980429    0.19087145     c       6.000      0
   -5.39664669   -3.42204303    1.99615708     h       1.000      0
   -4.38078141   -5.07286031   -0.92276076     h       1.000      0
   -1.70185861    0.12434192    2.04992096     c       6.000      0
   -0.31476665   -2.16035731   -1.96433581     c       6.000      0
   -3.05079013    0.05413075    3.60731537     h       1.000      0
   -1.85562849    1.97727303    1.14568258     h       1.000      0
    0.21255543    0.00554770    2.82714132     h       1.000      0
   -0.73717611   -3.86188186   -3.05715482     h       1.000      0
   -0.32353588    0.13411780   -3.70958904     c       6.000      0
    1.59328301   -2.39913500   -1.18883675     h       1.000      0
    1.00496505   -0.13630753   -5.26595550     h       1.000      0
    0.22496748    1.85515571   -2.71137979     h       1.000      0
   -2.20100307    0.43719648   -4.51620323     h       1.000      0
```

2-Methylbut-1-ene Product:

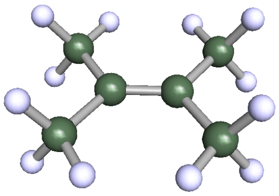
The $H_3C$-C-C-C Torsion Angle was constrained to 90°.



Total Energy = -236.06459334766 hartree
Enthalpy Correction = 0.186099 hartree
Entropy = 0.000137 hartree/K

```
                 atomic coordinates              atom    charge  isotop
 -4.61982586   -3.05337641   -2.88241936     c        6.000      0
 -2.36517827   -1.83891115   -1.88883900     c        6.000      0
 -5.81092471   -1.73648116   -3.92303568     h        1.000      0
 -3.64190372   -5.13330572   -4.71608823     c        6.000      0
 -5.67888857   -3.97752998   -1.37306028     h        1.000      0
 -1.20569311   -2.80353379    0.39929050     c        6.000      0
 -1.22521631    0.27376715   -3.20455345     c        6.000      0
 -2.57754465    1.41560338   -4.25416391     h        1.000      0
  0.01139537   -0.64677568   -4.61787875     h        1.000      0
  0.02876108    1.38563229   -2.00908080     h        1.000      0
  0.82849307   -2.47571106    0.42586312     h        1.000      0
 -2.44699612   -1.20951895    2.54070492     c        6.000      0
 -1.65454178   -4.79021876    0.70831230     h        1.000      0
 -1.64354661   -1.88132350    4.31370484     h        1.000      0
 -2.02187503    0.79378389    2.32857710     h        1.000      0
 -4.48848301   -1.47546791    2.58956262     h        1.000      0
 -2.40562794   -6.46774810   -3.74976692     h        1.000      0
 -2.64072067   -4.30329059   -6.31173697     h        1.000      0
 -5.29638643   -6.14243503   -5.41088795     h        1.000      0
```

2,3-Dimethylbut-2-ene (MCA* = 281.0 kJ/mol, N = -1.00, $s_N$ = 1.40):



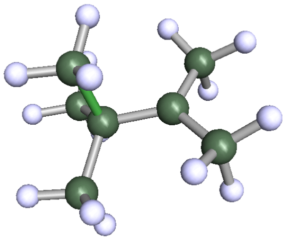
Total Energy = -235.65414457329 hartree
Enthalpy Correction = 0.173323 hartree
Entropy = 0.000133 hartree/K

```
                 atomic coordinates              atom    charge  isotop
  0.00000000    0.00000000   -1.26710270     c        6.000      0
  0.00000000    0.00000000    1.26710270     c        6.000      0
 -2.34535218   -0.00264491   -2.86211111     c        6.000      0
  2.34535218    0.00264491   -2.86211111     c        6.000      0
 -2.34535218    0.00264491    2.86211111     c        6.000      0
  2.34535218   -0.00264491    2.86211111     c        6.000      0
  2.34725293   -1.64739118    4.12085592     h        1.000      0
  2.37321180    1.66375922    4.09180432     h        1.000      0
  4.09774532   -0.02637701    1.78961543     h        1.000      0
 -2.34725293    1.64739118    4.12085592     h        1.000      0
 -2.37321180   -1.66375922    4.09180432     h        1.000      0
 -4.09774532    0.02637701    1.78961543     h        1.000      0
  2.37321180   -1.66375922   -4.09180432     h        1.000      0
  4.09774532    0.02637701   -1.78961543     h        1.000      0
  2.34725293    1.64739118   -4.12085592     h        1.000      0
```

| | | | | | |
|---|---|---|---|---|---|
| -4.09774532 | -0.02637701 | -1.78961543 | h | 1.000 | 0 |
| -2.34725293 | -1.64739118 | -4.12085592 | h | 1.000 | 0 |
| -2.37321180 | 1.66375922 | -4.09180432 | h | 1.000 | 0 |

2,3-Dimethylbut-2-ene Product:

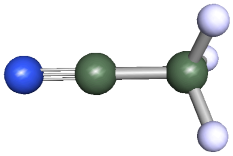
The $H_3C$-C-C-C Torsion Angle was constrained to 90°.



Total Energy = -275.34788768247 hartree
Enthalpy Correction = 0.214044 hartree
Entropy = 0.000144 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.42327056 | -4.59422889 | 0.35087133 | c | 6.000 | 0 |
| -2.60346662 | -2.52232133 | 0.17720212 | c | 6.000 | 0 |
| -4.45782159 | -6.36101083 | -1.92349636 | c | 6.000 | 0 |
| -4.30542098 | -6.09602451 | 2.80668318 | c | 6.000 | 0 |
| -6.90117462 | -2.94624281 | 0.33896545 | c | 6.000 | 0 |
| -1.59831849 | -1.33334946 | 2.43906649 | c | 6.000 | 0 |
| -1.72209663 | -1.62040610 | -2.26165453 | c | 6.000 | 0 |
| -0.93529841 | 0.58404740 | 2.11393461 | h | 1.000 | 0 |
| 0.07117108 | -2.50218441 | 2.90275906 | h | 1.000 | 0 |
| -2.83696869 | -1.47306602 | 4.07406893 | h | 1.000 | 0 |
| -1.03593054 | 0.31518615 | -2.20597582 | h | 1.000 | 0 |
| -3.05323849 | -1.94159656 | -3.79565617 | h | 1.000 | 0 |
| -0.08837168 | -2.85533465 | -2.67842986 | h | 1.000 | 0 |
| -7.00616441 | -1.68654751 | 1.96425478 | h | 1.000 | 0 |
| -8.43783712 | -4.31855708 | 0.45852145 | h | 1.000 | 0 |
| -7.10894755 | -1.86483084 | -1.40111165 | h | 1.000 | 0 |
| -5.81924308 | -7.49483307 | 2.78885829 | h | 1.000 | 0 |
| -2.50564595 | -7.09156019 | 2.96321763 | h | 1.000 | 0 |
| -4.56103457 | -4.92267973 | 4.47853603 | h | 1.000 | 0 |
| -5.95562888 | -7.74907172 | -1.64746645 | h | 1.000 | 0 |
| -2.66486821 | -7.36758913 | -2.09013416 | h | 1.000 | 0 |
| -4.83367482 | -5.38181086 | -3.69488591 | h | 1.000 | 0 |

Acetonitrile (MCA* = 280.2 kJ/mol, N = 2.23, $s_N$ = 0.84):

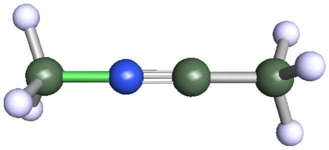


Total Energy = -132.65590935544 hartree

Enthalpy Correction = 0.049993 hartree
Entropy = 0.000092 hartree/K

```
                 atomic coordinates                atom    charge  isotop
       0.00000000    0.00000000   -0.92556463     c       6.000      0
       0.00000000    0.00000000    1.80542455     c       6.000      0
      -0.97039584    1.68077490   -1.61984751     h       1.000      0
      -0.97039584   -1.68077490   -1.61984751     h       1.000      0
       1.94079169    0.00000000   -1.61984751     h       1.000      0
       0.00000000    0.00000000    3.97941974     n       7.000      0
```

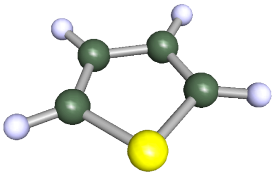
Acetonitrile Product:



Total Energy = -172.34953865565 hartree
Enthalpy Correction = 0.092416 hartree
Entropy = 0.000108 hartree/K

```
                 atomic coordinates                atom    charge  isotop
       0.00000000    0.00000000   -3.75607275     c       6.000      0
       0.00000000    0.00000000   -1.05613364     c       6.000      0
       0.04329996    1.95120530   -4.42439624     h       1.000      0
       1.66814338   -1.01310151   -4.42439624     h       1.000      0
      -1.71144334   -0.93810378   -4.42439624     h       1.000      0
       0.00000000    0.00000000    1.09281778     n       7.000      0
       0.00000000    0.00000000    3.76243343     c       6.000      0
       1.16061555    1.57046688    4.41088325     h       1.000      0
      -1.94037199    0.21988911    4.41088325     h       1.000      0
       0.77975644   -1.79035599    4.41088325     h       1.000      0
```

Thiophene (MCA* = 277.5 kJ/mol, N = -1.01, $s_N$ = 1.1):

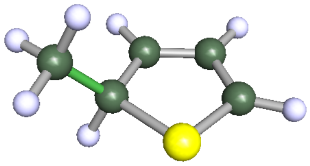


Total Energy = -552.76708970944 hartree
Enthalpy Correction = 0.072287 hartree
Entropy = 0.000108 hartree/K

```
                 atomic coordinates                atom    charge  isotop
      -1.35370062   -1.30383835   -0.09579999     c       6.000      0
      -2.31815572    1.08626368    0.00797071     c       6.000      0
       0.03170526    3.29136701    0.17170762     s      16.000      0
       2.33864634    1.03645202    0.10247747     c       6.000      0
       1.32825677   -1.33251852   -0.04152047     c       6.000      0
      -2.51743507   -2.98237213   -0.20693863     h       1.000      0
```

| | | | | | |
|---|---|---|---|---|---|
| -4.27477835 | 1.66591776 | -0.00254713 | h | 1.000 | 0 |
| 4.30600453 | 1.57427103 | 0.17105991 | h | 1.000 | 0 |
| 2.45945686 | -3.03554250 | -0.10640949 | h | 1.000 | 0 |

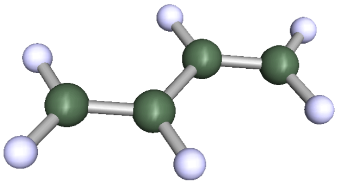
Thiophene Product:



Total Energy = -592.46005517397 hartree
Enthalpy Correction = 0.114174 hartree
Entropy = 0.000121 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.39794874 | -0.43442171 | 0.80929265 | c | 6.000 | 0 |
| -1.07759219 | -0.03425238 | -0.85972092 | c | 6.000 | 0 |
| 0.69159021 | -2.90087094 | -1.39944992 | s | 16.000 | 0 |
| 3.37649230 | -1.57329436 | -0.52845286 | c | 6.000 | 0 |
| 3.17842372 | 0.97295798 | 0.23187818 | c | 6.000 | 0 |
| 0.76647474 | 1.81787954 | 0.06800080 | c | 6.000 | 0 |
| -4.40594835 | 1.35523733 | 0.96569926 | h | 1.000 | 0 |
| -2.84559939 | -1.06608365 | 2.68957741 | h | 1.000 | 0 |
| -4.65352016 | -1.82663313 | -0.04003838 | h | 1.000 | 0 |
| -1.69582334 | 0.56218757 | -2.75700169 | h | 1.000 | 0 |
| 5.11694953 | -2.65186856 | -0.58533633 | h | 1.000 | 0 |
| 4.78731419 | 2.06630949 | 0.85366152 | h | 1.000 | 0 |
| 0.15918750 | 3.71285283 | 0.55189028 | h | 1.000 | 0 |

Buta-1,3-diene (MCA* = 260.5 kJ/mol, N = -0.87, $s_\mathrm{N}$ = 1.00):



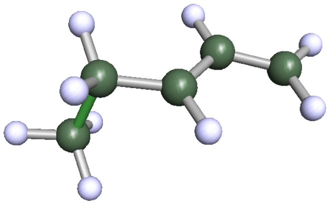
Total Energy = -155.85824429786 hartree
Enthalpy Correction = 0.09103 hartree
Entropy = 0.000105 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.52016365 | 3.43646160 | 0.00000000 | c | 6.000 | 0 |
| -0.98022722 | 0.95797734 | 0.00000000 | c | 6.000 | 0 |
| 1.40004999 | 4.16092056 | 0.00000000 | h | 1.000 | 0 |
| -2.04125821 | 4.80792966 | 0.00000000 | h | 1.000 | 0 |
| 0.98022722 | -0.95797734 | 0.00000000 | c | 6.000 | 0 |
| -2.92304146 | 0.28315058 | 0.00000000 | h | 1.000 | 0 |
| 2.92304146 | -0.28315058 | 0.00000000 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 0.52016365 | -3.43646160 | 0.00000000 | c | 6.000 | 0 |
| -1.40004999 | -4.16092056 | 0.00000000 | h | 1.000 | 0 |
| 2.04125821 | -4.80792966 | 0.00000000 | h | 1.000 | 0 |

Buta-1,3-diene Product:

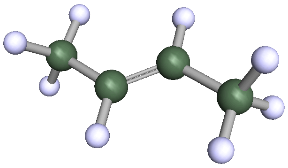
The $H_3C$-C-C-C Torsion Angle was constrained to 270°.



Total Energy = -195.54436524111 hartree
Enthalpy Correction = 0.133743 hartree
Entropy = 0.000122 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.00300032 | -5.28375529 | 0.41533835 | c | 6.000 | 0 |
| -2.86009158 | -3.69178951 | -1.59011201 | c | 6.000 | 0 |
| -1.37934365 | -5.57778776 | 1.63303907 | h | 1.000 | 0 |
| -4.72394872 | -6.30573746 | 0.85339248 | h | 1.000 | 0 |
| -0.57280576 | -2.47135984 | -2.04188223 | c | 6.000 | 0 |
| -4.46107821 | -3.38620847 | -2.83119501 | h | 1.000 | 0 |
| -0.17385998 | -0.60763363 | -3.99705495 | c | 6.000 | 0 |
| 0.96513009 | -2.84035110 | -0.72647744 | h | 1.000 | 0 |
| 1.79516987 | -0.56914770 | -4.60057270 | h | 1.000 | 0 |
| -1.44367007 | -0.88288478 | -5.59611039 | h | 1.000 | 0 |
| -0.80904505 | 1.96880009 | -2.71111041 | c | 6.000 | 0 |
| -0.43812314 | 3.43671420 | -4.10820227 | h | 1.000 | 0 |
| -2.78963344 | 2.04085826 | -2.15490647 | h | 1.000 | 0 |
| 0.37750007 | 2.29735392 | -1.06030095 | h | 1.000 | 0 |

(*E*)-But-2-ene (MCA* = 248.7 kJ/mol, N = -2.45, $s_N$ = 1.10):



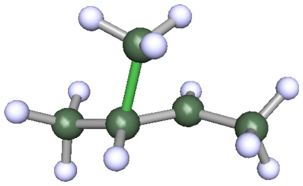
Total Energy = -157.08866598469 hartree
Enthalpy Correction = 0.114462 hartree
Entropy = 0.00011 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.87802973 | -0.89657656 | 0.00000000 | c | 6.000 | 0 |
| 0.87802973 | 0.89657656 | 0.00000000 | c | 6.000 | 0 |
| -3.65944125 | -0.44238482 | 0.00000000 | c | 6.000 | 0 |
| -0.27251407 | -2.86611513 | 0.00000000 | h | 1.000 | 0 |
| 0.27251407 | 2.86611513 | 0.00000000 | h | 1.000 | 0 |

```
   3.65944125    0.44238482    0.00000000     c       6.000      0
   4.55469624    1.29872881   -1.65736701     h       1.000      0
   4.09350882   -1.57537953    0.00000000     h       1.000      0
   4.55469624    1.29872881    1.65736701     h       1.000      0
  -4.09350882    1.57537953    0.00000000     h       1.000      0
  -4.55469624   -1.29872881   -1.65736701     h       1.000      0
  -4.55469624   -1.29872881    1.65736701     h       1.000      0
```

(*E*)-But-2-ene Product:

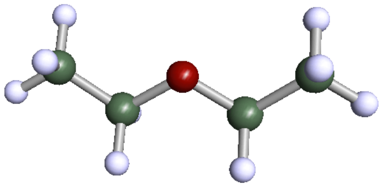
The $H_3C$-C-C-C Torsion Angle was constrained to 90°.



Total Energy = -196.77043809027 hartree
Enthalpy Correction = 0.156129 hartree
Entropy = 0.000123 hartree/K

```
            atomic coordinates                 atom    charge  isotop
  -4.13478563   -4.90750903   -0.21244991     c       6.000      0
  -2.70505878   -2.77074351    0.41390279     c       6.000      0
  -4.92484372   -4.24963767    2.74487942     c       6.000      0
  -6.29347350   -4.76192321   -2.03519440     c       6.000      0
  -3.15261232   -6.70725346   -0.12045971     h       1.000      0
  -0.16336916   -2.83248594    1.53905100     c       6.000      0
  -3.48333314   -0.93470259   -0.08026442     h       1.000      0
   1.13196024   -2.29337689    0.01213152     h       1.000      0
   0.35984104   -4.70793694    2.20495936     h       1.000      0
   0.04484796   -1.42421744    3.02733535     h       1.000      0
  -7.22986944   -2.92733837   -1.94783322     h       1.000      0
  -5.56534415   -5.03980815   -3.94530682     h       1.000      0
  -7.66906695   -6.24518593   -1.64666073     h       1.000      0
  -3.93583750   -5.55737594    3.96869914     h       1.000      0
  -6.96274004   -4.50997366    2.63733764     h       1.000      0
  -4.71270689   -2.32198157    3.49592509     h       1.000      0
```

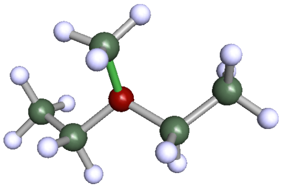
Ethoxyethane (MCA* = 246.8 kJ/mol, N = -5.10, $s_N$ = 0.80):



Total Energy = -233.48281342807 hartree
Enthalpy Correction = 0.144524 hartree
Entropy = 0.000124 hartree/K

```
              atomic coordinates            atom    charge  isotop
    0.00000000    0.00000000   -0.62063906    o      8.000     0
    2.18268290   -0.39900439    0.86106663    c      6.000     0
   -2.18268290    0.39900439    0.86106663    c      6.000     0
    1.89619573   -2.04430323    2.09798754    h      1.000     0
    2.50415316    1.24595222    2.08924685    h      1.000     0
    4.41344601   -0.81480803   -0.85978487    c      6.000     0
    4.72011754    0.82849388   -2.07127196    h      1.000     0
    6.12052540   -1.12376715    0.25798228    h      1.000     0
    4.11456612   -2.46819150   -2.05916685    h      1.000     0
   -2.50415316   -1.24595222    2.08924685    h      1.000     0
   -4.41344601    0.81480803   -0.85978487    c      6.000     0
   -1.89619573    2.04430323    2.09798754    h      1.000     0
   -4.72011754   -0.82849388   -2.07127196    h      1.000     0
   -4.11456612    2.46819150   -2.05916685    h      1.000     0
   -6.12052540    1.12376715    0.25798228    h      1.000     0
```

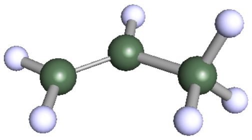
Ethoxyethane Product:



Total Energy = -273.16321241006 hartree
Enthalpy Correction = 0.188554 hartree
Entropy = 0.000136 hartree/K

```
              atomic coordinates            atom    charge  isotop
   -0.12382414    0.01174955   -0.13683534    o      8.000     0
    1.71747982    2.11711004   -0.40012991    c      6.000     0
    0.55118812   -2.19572959   -1.63701555    c      6.000     0
   -0.72256858   -0.58560808    2.53884806    c      6.000     0
    1.32255660    3.45057767   -2.86323922    c      6.000     0
    1.31344808    3.33750159    1.20110128    h      1.000     0
    3.59069594    1.28347440   -0.19164967    h      1.000     0
    1.77196860    2.27621934   -4.49433959    h      1.000     0
   -0.60933896    4.14900193   -3.02166236    h      1.000     0
    2.60260512    5.06928680   -2.89033634    h      1.000     0
   -2.91098408   -2.36962676    2.70912800    c      6.000     0
    1.01064120   -1.32808900    3.37345364    h      1.000     0
   -1.17169894    1.24888497    3.34635042    h      1.000     0
   -3.44674648   -2.46729508    4.69951444    h      1.000     0
   -4.52998934   -1.66614539    1.64438883    h      1.000     0
   -2.44246734   -4.27840721    2.09599966    h      1.000     0
    2.11637886   -3.16570269   -0.71594574    h      1.000     0
    1.07931873   -1.51138155   -3.49443325    h      1.000     0
   -1.11866637   -3.37582026   -1.76319873    h      1.000     0
```

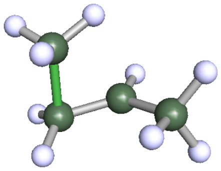
Prop-1-ene (MCA* = 246.6 kJ/mol, N = -2.41, $s_N$ = 1.00):



Total Energy = -117.80340555362 hartree
Enthalpy Correction = 0.084805 hartree
Entropy = 0.0001 hartree/K

```
                 atomic coordinates                atom    charge  isotop
   -4.23566687   -3.34190294    0.31738208    c      6.000      0
   -1.99055772   -1.64582243    0.22533824    c      6.000      0
   -4.35659107   -4.49454118   -1.39618073    h      1.000      0
   -5.98540700   -2.24209071    0.40734823    h      1.000      0
   -4.16809709   -4.60085802    1.95100906    h      1.000      0
   -1.91720228   -0.32565915   -1.35174247    h      1.000      0
   -0.11820065   -1.63687129    1.89584430    c      6.000      0
   -0.11090841   -2.92014813    3.49913979    h      1.000      0
    1.46808910   -0.35076775    1.72027151    h      1.000      0
```

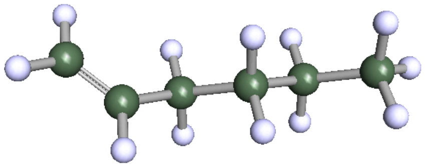
Prop-1-ene Product:



Total Energy = -157.48492731413 hartree
Enthalpy Correction = 0.126716 hartree
Entropy = 0.000112 hartree/K

```
                 atomic coordinates                atom    charge  isotop
   -2.70939807    0.20650879    1.18289114    c      6.000      0
   -2.00615135   -2.09336523   -0.18304103    c      6.000      0
   -1.76026275    1.88516876    0.46607380    h      1.000      0
   -4.74842977    0.41282240    0.83593630    h      1.000      0
   -2.47866985    0.00006348    3.21835776    h      1.000      0
   -2.60982527   -3.89462733    0.59648109    h      1.000      0
   -0.64904124   -2.12839517   -2.46806227    c      6.000      0
   -0.52099515   -0.38449240   -3.53337171    h      1.000      0
   -0.71447768   -3.84203013   -3.58154688    h      1.000      0
    1.63323314   -2.24278509   -0.45319493    c      6.000      0
    1.16855147   -2.80550843    1.50244418    h      1.000      0
    2.51042739   -0.39387109   -0.37059076    h      1.000      0
    2.82942298   -3.77266969   -1.12768906    h      1.000      0
```

Hex-1-ene (MCA* = 244.6 kJ/mol, N = -2.77, $s_N$ = 1.41):

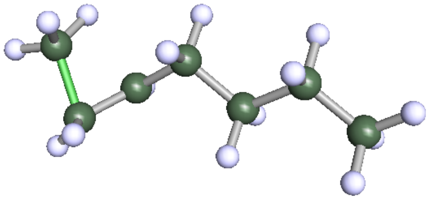


Total Energy = -235.64564341762 hartree
Enthalpy Correction = 0.174533 hartree
Entropy = 0.000135 hartree/K

```
               atomic coordinates              atom    charge  isotop
    3.18671566    0.14744741   -2.28206859     c      6.000     0
    2.38977822   -0.46372110   -4.07330458     h      1.000     0
    5.22862703    0.28579121   -2.16641720     h      1.000     0
    1.71821485    0.70318122   -0.32474529     c      6.000     0
   -1.09602820    0.54906412   -0.30523958     c      6.000     0
    2.59531678    1.30158526    1.44003286     h      1.000     0
   -1.87468037    2.43087327    0.09171058     h      1.000     0
   -1.77979488   -0.00242580   -2.17886150     h      1.000     0
   -2.09776650   -1.28361502    1.68260316     c      6.000     0
   -1.36981674   -3.18256221    1.28615060     h      1.000     0
   -4.96651793   -1.35888333    1.79176874     c      6.000     0
   -1.35298397   -0.75059329    3.54174676     h      1.000     0
   -5.67858320    0.54668469    2.18300574     h      1.000     0
   -5.70347670   -1.88044236   -0.07240316     h      1.000     0
   -5.95940589   -3.18742749    3.76928282     c      6.000     0
   -5.29317439   -2.67011237    5.65657494     h      1.000     0
   -8.02371429   -3.20890951    3.81302488     h      1.000     0
   -5.31630482   -5.11433126    3.38573641     h      1.000     0
```

Hex-1-ene Product:

The $H_3C$-C-C-C Torsion Angle was constrained to 90°.

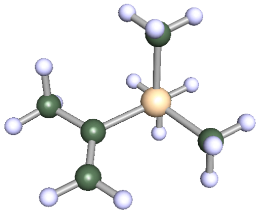


Total Energy = -275.32675995269 hartree
Enthalpy Correction = 0.216814 hartree
Entropy = 0.000147 hartree/K

```
               atomic coordinates              atom    charge  isotop
    3.32643870   -0.57758445   -2.34835310     c      6.000     0
    1.83728905    0.66150074   -0.52747869     c      6.000     0
   -0.93722450    0.73845700   -0.55971040     c      6.000     0
    2.80397528    1.56735384    1.04245996     h      1.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -1.61050444 | 2.62448754 | -0.06544548 | h | 1.000 | 0 |
| -1.67082155 | 0.19446723 | -2.40911536 | h | 1.000 | 0 |
| -1.85348592 | -1.15155740 | 1.45748292 | c | 6.000 | 0 |
| -1.16483774 | -3.04472335 | 0.99164426 | h | 1.000 | 0 |
| -4.72345850 | -1.17128192 | 1.61905160 | c | 6.000 | 0 |
| -1.05362308 | -0.64730315 | 3.29674885 | h | 1.000 | 0 |
| -5.38730631 | 0.73451537 | 2.07509532 | h | 1.000 | 0 |
| -5.50266841 | -1.64086366 | -0.23926508 | h | 1.000 | 0 |
| -5.67705396 | -3.03704359 | 3.57901423 | c | 6.000 | 0 |
| -4.95502271 | -2.57335372 | 5.45880556 | h | 1.000 | 0 |
| -7.73899921 | -3.02584792 | 3.67208939 | h | 1.000 | 0 |
| -5.07362482 | -4.96105204 | 3.12749015 | h | 1.000 | 0 |
| 2.40776283 | -1.93566013 | -3.57569952 | h | 1.000 | 0 |
| 5.26773371 | -0.99895165 | -1.86343724 | h | 1.000 | 0 |
| 3.09032139 | 2.19535755 | -3.58253591 | c | 6.000 | 0 |
| 2.50612963 | 3.76448310 | -2.33402923 | h | 1.000 | 0 |
| 1.74726142 | 2.10234984 | -5.12563177 | h | 1.000 | 0 |
| 5.01895856 | 2.68597106 | -4.09985038 | h | 1.000 | 0 |

2-(Trimethylsilyl)propene (MCA* = 239.5 kJ/mol, N = -1.46, $s_{\mathrm{N}}$ = 1.05):

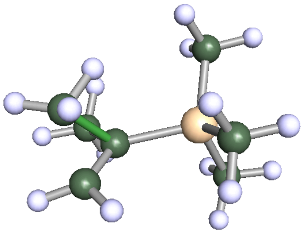


Total Energy = -526.27638002233 hartree
Enthalpy Correction = 0.193767 hartree
Entropy = 0.000159 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.98990325 | -1.70372765 | -0.66838892 | c | 6.000 | 0 |
| -2.29716186 | -0.47397382 | 0.73790852 | c | 6.000 | 0 |
| 1.09597242 | -0.19316026 | -0.30027003 | si | 14.000 | 0 |
| 3.16987515 | -1.64587100 | 2.18039164 | c | 6.000 | 0 |
| 1.57692401 | -1.84535639 | -3.39029986 | c | 6.000 | 0 |
| 1.90329711 | 3.24261499 | -0.63024384 | c | 6.000 | 0 |
| -3.04250358 | 0.73016776 | 3.19648215 | c | 6.000 | 0 |
| -3.49045510 | -2.58813644 | -2.45112474 | h | 1.000 | 0 |
| -5.95783137 | -1.87598797 | -0.08717811 | h | 1.000 | 0 |
| 2.92281434 | -0.70642320 | 4.00402341 | h | 1.000 | 0 |
| 5.15935629 | -1.47976843 | 1.64496818 | h | 1.000 | 0 |
| 2.73416562 | -3.65072637 | 2.42562097 | h | 1.000 | 0 |
| 3.55234175 | -1.67108848 | -3.97354509 | h | 1.000 | 0 |
| 0.40062572 | -1.02586300 | -4.87773635 | h | 1.000 | 0 |
| 1.13197596 | -3.85750338 | -3.24713085 | h | 1.000 | 0 |
| 0.71114378 | 4.14706419 | -2.05501539 | h | 1.000 | 0 |
| 3.87614523 | 3.46680926 | -1.20484589 | h | 1.000 | 0 |
| 1.64477558 | 4.24758894 | 1.15637055 | h | 1.000 | 0 |
| -2.65361011 | 2.76225965 | 3.17924826 | h | 1.000 | 0 |
| -1.95192039 | -0.05416316 | 4.77025412 | h | 1.000 | 0 |
| -5.05015183 | 0.46000416 | 3.60415012 | h | 1.000 | 0 |

2-(Trimethylsilyl)propene Product:

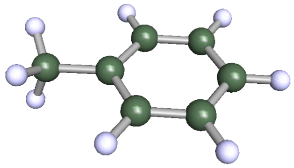
The H-$CH_2$-C-$CH_3$ Torsion Angle was constrained to 90°.



Total Energy = -565.95576434157 hartree
Enthalpy Correction = 0.235632 hartree
Entropy = 0.000169 hartree/K

```
                  atomic coordinates              atom    charge  isotop
  3.28116342   -0.33210280   -1.97522723    c       6.000     0
  1.58679170   -0.89461691   -0.01786813    c       6.000     0
 -1.89824750    0.16833083   -0.23024058    si     14.000     0
 -2.08769931    2.86394662   -2.47862883    c       6.000     0
 -2.92445916    1.06164856    3.01110066    c       6.000     0
 -3.53422033   -2.70776895   -1.42932577    c       6.000     0
  3.84638825    1.80567185    0.27227258    c       6.000     0
  2.31295847   -2.74164232    1.96837846    c       6.000     0
  5.14525014   -1.18480995   -2.02776369    h       1.000     0
  2.63078569    0.58267654   -3.68422216    h       1.000     0
 -0.95687307    4.47511839   -1.85415210    h       1.000     0
 -1.49116603    2.32952705   -4.38102398    h       1.000     0
 -4.05408423    3.49014526   -2.59047681    h       1.000     0
 -2.79274384   -0.53267096    4.31525101    h       1.000     0
 -4.89753691    1.67250632    2.95175244    h       1.000     0
 -1.80442297    2.62454775    3.76572444    h       1.000     0
 -5.54026098   -2.28376285   -1.68906744    h       1.000     0
 -3.37952766   -4.27778524   -0.09835223    h       1.000     0
 -2.76165380   -3.30269043   -3.24877048    h       1.000     0
  3.90061044    3.54278008   -0.82588655    h       1.000     0
  2.45970287    2.19976264    1.77131910    h       1.000     0
  5.60946721    1.26380731    1.15728978    h       1.000     0
  1.62589483   -2.20435823    3.83436002    h       1.000     0
  1.36949608   -4.51326004    1.45472937    h       1.000     0
  4.34200479   -3.10266243    2.02339157    h       1.000     0
```

Toluene (MCA* = 218.6 kJ/mol, N = -4.36, $s_N$ = 1.77):

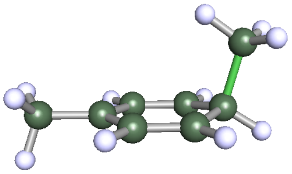


Total Energy = -271.34484117648 hartree
Enthalpy Correction = 0.135629 hartree
Entropy = 0.000123 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.74720889 | -2.12570052 | -0.16019211 | c | 6.000 | 0 |
| 1.57785034 | -3.00330845 | 0.67845744 | c | 6.000 | 0 |
| 3.49013294 | -1.30850219 | 1.27871140 | c | 6.000 | 0 |
| 3.05107603 | 1.26667474 | 1.03569178 | c | 6.000 | 0 |
| 0.72126277 | 2.13401549 | 0.19591943 | c | 6.000 | 0 |
| -1.21097094 | 0.45445172 | -0.42083734 | c | 6.000 | 0 |
| -2.23259050 | -3.46498406 | -0.61706136 | h | 1.000 | 0 |
| 1.89530194 | -5.01908378 | 0.87049016 | h | 1.000 | 0 |
| 4.52585519 | 2.60912296 | 1.50848801 | h | 1.000 | 0 |
| 0.39275979 | 4.15143513 | 0.02014928 | h | 1.000 | 0 |
| -3.70489711 | 1.39163420 | -1.38140342 | c | 6.000 | 0 |
| 5.30561684 | -1.99021743 | 1.93938344 | h | 1.000 | 0 |
| -4.09196129 | 3.30603128 | -0.71907730 | h | 1.000 | 0 |
| -3.72300867 | 1.43500169 | -3.44934738 | h | 1.000 | 0 |
| -5.24921665 | 0.16342963 | -0.77937175 | h | 1.000 | 0 |

Toluene Product:

Both $H_3C$-CH-CH-CH bond angles were constrained to 100° and 260° respectively.

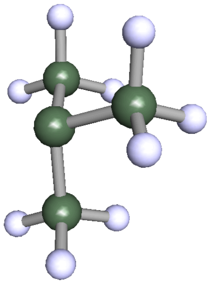


Total Energy = -311.01515269409 hartree
Enthalpy Correction = 0.17701 hartree
Entropy = 0.000135 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 5.52549627 | -0.40380286 | 0.07421567 | c | 6.000 | 0 |
| 2.75328481 | -0.24879261 | -0.13629261 | c | 6.000 | 0 |
| 1.60610904 | 2.07009432 | -0.79775254 | c | 6.000 | 0 |
| -0.94501460 | 2.23823923 | -0.96395096 | c | 6.000 | 0 |
| -2.58727123 | 0.14421792 | -0.22031928 | c | 6.000 | 0 |
| -3.55809229 | 0.84836548 | 2.51547926 | c | 6.000 | 0 |
| -1.29356417 | -2.27820427 | 0.07818046 | c | 6.000 | 0 |
| 1.26026480 | -2.42829872 | 0.24117029 | c | 6.000 | 0 |
| 6.32839940 | 1.35253881 | 0.79309734 | h | 1.000 | 0 |
| 6.12897130 | -2.00889889 | 1.21145148 | h | 1.000 | 0 |
| 6.28328119 | -0.66723409 | -1.84129443 | h | 1.000 | 0 |
| 2.79126700 | 3.69397392 | -1.18077907 | h | 1.000 | 0 |
| -1.83500020 | 4.02184572 | -1.44156677 | h | 1.000 | 0 |
| -4.27305050 | -0.00000883 | -1.40692051 | h | 1.000 | 0 |
| -4.82934067 | -0.63200043 | 3.16774778 | h | 1.000 | 0 |
| -4.57947204 | 2.63148412 | 2.41554579 | h | 1.000 | 0 |
| -1.96284785 | 1.02363917 | 3.80315663 | h | 1.000 | 0 |
| -2.44925813 | -3.94092366 | 0.39561620 | h | 1.000 | 0 |
| 2.18227449 | -4.20970094 | 0.64622316 | h | 1.000 | 0 |

## Energies and Coordinates of Molecules with *Nu** values Calculated at the PBE0(disp)/def2-TZVP COSMO (∞) level of theory.

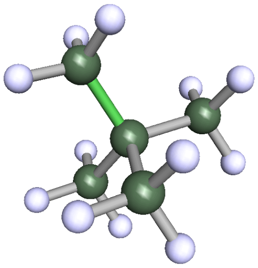
2-Methylpropan-2-ide Anion (MCA* = 718.3 kJ/mol):



Total Energy = -157.73494885670 hartree
Enthalpy Correction = 0.121918 hartree
Entropy = 0.000108 hartree/K

```
                  atomic coordinates             atom    charge  isotop
    0.00000000    0.00000000   -1.18296004    c      6.000     0
    1.32881419    2.30157369   -0.14862951    c      6.000     0
    1.32881419   -2.30157369   -0.14862951    c      6.000     0
   -2.65762838    0.00000000   -0.14862951    c      6.000     0
    3.31914361    2.41305242   -0.72209102    h      1.000     0
    1.33250591    2.30796794    1.97823742    h      1.000     0
    0.43019289    4.08098890   -0.72209102    h      1.000     0
    3.31914361   -2.41305242   -0.72209102    h      1.000     0
    1.33250591   -2.30796794    1.97823742    h      1.000     0
    0.43019289   -4.08098890   -0.72209102    h      1.000     0
   -3.74933651    1.66793648   -0.72209102    h      1.000     0
   -3.74933651   -1.66793648   -0.72209102    h      1.000     0
   -2.66501182    0.00000000    1.97823742    h      1.000     0
```

2-Methylpropan-2-ide Anion Product:

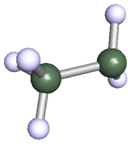


Total Energy = -197.60069491045 hartree
Enthalpy Correction = 0.167212 hartree
Entropy = 0.000116 hartree/K

```
                  atomic coordinates             atom    charge  isotop
    0.00000000    0.00000000    0.00000000    c      6.000     0
    1.66539033   -1.66539033    1.66539033    c      6.000     0
   -1.66539033    1.66539033    1.66539033    c      6.000     0
    1.66539033    1.66539033   -1.66539033    c      6.000     0
```

```
              -1.66539033   -1.66539033   -1.66539033    c       6.000      0
               0.51521396   -2.88018124    2.88018124    h       1.000      0
               2.88018124   -0.51521396    2.88018124    h       1.000      0
               2.88018124   -2.88018124    0.51521396    h       1.000      0
               2.88018124    0.51521396   -2.88018124    h       1.000      0
               2.88018124    2.88018124   -0.51521396    h       1.000      0
               0.51521396    2.88018124   -2.88018124    h       1.000      0
              -0.51521396   -2.88018124   -2.88018124    h       1.000      0
              -2.88018124   -0.51521396   -2.88018124    h       1.000      0
              -2.88018124   -2.88018124   -0.51521396    h       1.000      0
              -2.88018124    2.88018124    0.51521396    h       1.000      0
              -2.88018124    0.51521396    2.88018124    h       1.000      0
              -0.51521396    2.88018124    2.88018124    h       1.000      0
```

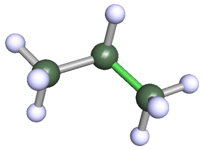
Ethanide Anion (MCA* = 701.2 kJ/mol):



Total Energy = -79.17650626097 hartree
Enthalpy Correction = 0.063779 hartree
Entropy = 0.000091 hartree/K

```
                          atomic coordinates            atom    charge  isotop
               1.69010960   -0.72200058    0.00000000    c       6.000      0
              -1.11600943   -0.02556321    0.00000000    c       6.000      0
               2.60177286    0.18030226   -1.64939905    h       1.000      0
               2.60177286    0.18030226    1.64939905    h       1.000      0
              -2.09889957   -0.81264775    1.65038445    h       1.000      0
              -1.57827929    2.01846822    0.00000000    h       1.000      0
              -2.09889957   -0.81264775   -1.65038445    h       1.000      0
```

Ethanide Anion Product:

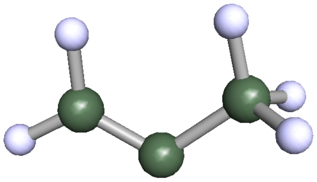


Total Energy = -119.03468196859 hartree
Enthalpy Correction = 0.108878 hartree
Entropy = 0.000102 hartree/K

```
                          atomic coordinates            atom    charge  isotop
               0.00000000    2.38856802   -0.43043981    c       6.000      0
               0.00000000    0.00000000    1.16284726    c       6.000      0
               0.00000000   -2.38856802   -0.43043981    c       6.000      0
               0.00000000    4.08787193    0.74341345    h       1.000      0
               1.66818101    2.46467538   -1.65010934    h       1.000      0
              -1.66818101    2.46467538   -1.65010934    h       1.000      0
               1.65493827    0.00000000    2.40605137    h       1.000      0
```

```
-1.65493827    0.00000000    2.40605137    h      1.000      0
 0.00000000   -4.08787193    0.74341345    h      1.000      0
 1.66818101   -2.46467538   -1.65010934    h      1.000      0
-1.66818101   -2.46467538   -1.65010934    h      1.000      0
```

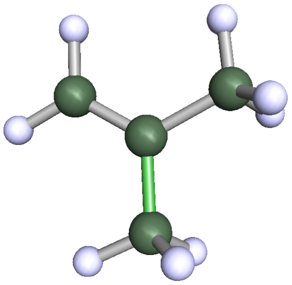
Prop-1-en-2-ide Anion (MCA* = 678.9 kJ/mol):



Total Energy = -117.24145763984 hartree
Enthalpy Correction = 0.070224 hartree
Entropy = 0.000099 hartree/K

```
                  atomic coordinates                atom    charge  isotop
-3.36203203   -0.04599491    0.06190429    c      6.000      0
-1.59350563   -1.86030810    0.21620699    c      6.000      0
-3.41988990    1.36100921   -1.48557390    h      1.000      0
-4.87588491    0.17953621    1.44987833    h      1.000      0
 0.31968539   -1.83020248   -1.89827354    c      6.000      0
 0.01999810   -0.30549485   -3.30468663    h      1.000      0
 2.24943041   -1.62625600   -1.16378209    h      1.000      0
 0.32863014   -3.63099468   -2.92896555    h      1.000      0
```

Prop-1-en-2-ide Anion Product:

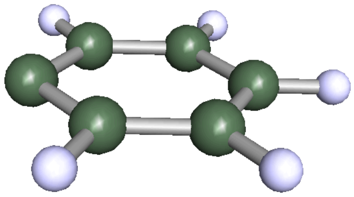


Total Energy = -157.09027338588 hartree
Enthalpy Correction = 0.114189 hartree
Entropy = 0.000109 hartree/K

```
                  atomic coordinates                atom    charge  isotop
 0.00000000    0.00000000   -2.92401812    c      6.000      0
 0.00000000    0.00000000   -0.40734656    c      6.000      0
 0.00000000   -1.75198920   -3.99042837    h      1.000      0
 0.00000000    1.75198920   -3.99042837    h      1.000      0
 0.00000000   -2.39242156    1.09864863    c      6.000      0
 0.00000000    2.39242156    1.09864863    c      6.000      0
-1.65774620    2.47298001    2.33512114    h      1.000      0
 1.65774620    2.47298001    2.33512114    h      1.000      0
 0.00000000    4.06214656   -0.11029979    h      1.000      0
```

| | | | | | |
|---|---|---|---|---|---|
| 1.65774620 | -2.47298001 | 2.33512114 | h | 1.000 | 0 |
| 0.00000000 | -4.06214656 | -0.11029979 | h | 1.000 | 0 |
| -1.65774620 | -2.47298001 | 2.33512114 | h | 1.000 | 0 |

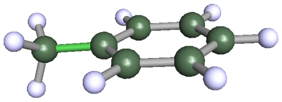
Benzen-1-ide Anion (MCA* = 672.5 kJ/mol):



Total Energy = -231.50113225040 hartree
Enthalpy Correction = 0.092571 hartree
Entropy = 0.000107 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -2.23199554 | c | 6.000 | 0 |
| -2.25496724 | 0.00000000 | -0.88813608 | c | 6.000 | 0 |
| -2.22199254 | 0.00000000 | 1.74914030 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 3.22724030 | c | 6.000 | 0 |
| 2.22199254 | 0.00000000 | 1.74914030 | c | 6.000 | 0 |
| 2.25496724 | 0.00000000 | -0.88813608 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -4.28344160 | h | 1.000 | 0 |
| -4.04376544 | 0.00000000 | -1.90267898 | h | 1.000 | 0 |
| -4.06249524 | 0.00000000 | 2.68518856 | h | 1.000 | 0 |
| 4.06249524 | 0.00000000 | 2.68518856 | h | 1.000 | 0 |
| 4.04376544 | 0.00000000 | -1.90267898 | h | 1.000 | 0 |

Benzen-1-ide Anion Product:

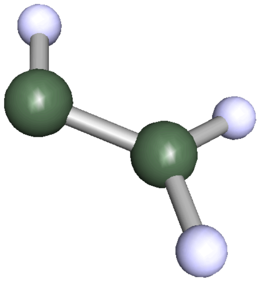


Total Energy = -271.34484117648 hartree
Enthalpy Correction = 0.135629 hartree
Entropy = 0.000123 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.74720889 | -2.12570052 | -0.16019211 | c | 6.000 | 0 |
| 1.57785034 | -3.00330845 | 0.67845744 | c | 6.000 | 0 |
| 3.49013294 | -1.30850219 | 1.27871140 | c | 6.000 | 0 |
| 3.05107603 | 1.26667474 | 1.03569178 | c | 6.000 | 0 |
| 0.72126277 | 2.13401549 | 0.19591943 | c | 6.000 | 0 |
| -1.21097094 | 0.45445172 | -0.42083734 | c | 6.000 | 0 |
| -2.23259050 | -3.46498406 | -0.61706136 | h | 1.000 | 0 |
| 1.89530194 | -5.01908378 | 0.87049016 | h | 1.000 | 0 |
| 4.52585519 | 2.60912296 | 1.50848801 | h | 1.000 | 0 |
| 0.39275979 | 4.15143513 | 0.02014928 | h | 1.000 | 0 |
| -3.70489711 | 1.39163420 | -1.38140342 | c | 6.000 | 0 |
| 5.30561684 | -1.99021743 | 1.93938344 | h | 1.000 | 0 |
| -4.09196129 | 3.30603128 | -0.71907730 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -3.72300867 | 1.43500169 | -3.44934738 | h | 1.000 | 0 |
| -5.24921665 | 0.16342963 | -0.77937175 | h | 1.000 | 0 |

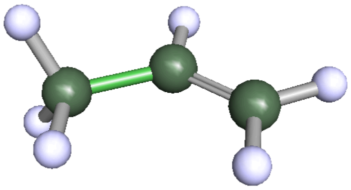
Ethenide Anion (MCA* = 668.6 kJ/mol):



Total Energy = -77.95937463089 hartree
Enthalpy Correction = 0.040802 hartree
Entropy = 0.000087 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.79245383 | 0.01144018 | 0.00000000 | c | 6.000 | 0 |
| 1.45206321 | 1.21348361 | 0.00000000 | c | 6.000 | 0 |
| -1.05908093 | -2.05160558 | 0.00000000 | h | 1.000 | 0 |
| -2.58959862 | 1.04354429 | 0.00000000 | h | 1.000 | 0 |
| 2.98907018 | -0.21686249 | 0.00000000 | h | 1.000 | 0 |

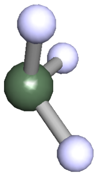
Ethenide Anion Product:



Total Energy = -117.80341211793 hartree
Enthalpy Correction = 0.084813 hartree
Entropy = 0.0001 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.57943047 | 0.46907536 | 0.00000000 | c | 6.000 | 0 |
| -0.48054082 | -0.90618780 | 0.00000000 | c | 6.000 | 0 |
| -4.43337749 | -0.40524905 | 0.00000000 | h | 1.000 | 0 |
| -2.51167008 | 2.52144874 | 0.00000000 | h | 1.000 | 0 |
| -0.64080519 | -2.95777585 | 0.00000000 | h | 1.000 | 0 |
| 2.13655669 | 0.13192690 | 0.00000000 | c | 6.000 | 0 |
| 3.18767106 | -0.52428634 | 1.65660408 | h | 1.000 | 0 |
| 2.13392524 | 2.19533437 | 0.00000000 | h | 1.000 | 0 |
| 3.18767106 | -0.52428634 | -1.65660408 | h | 1.000 | 0 |

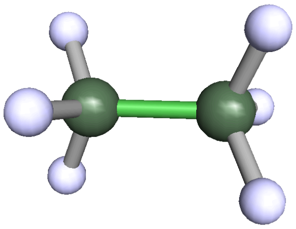
Methanide Anion (MCA* = 665.5 kJ/mol):



Total Energy = -39.90909816942 hartree
Enthalpy Correction = 0.033249 hartree
Entropy = 0.000074 hartree/K

```
                   atomic coordinates            atom    charge  isotop
         0.00000000    0.00000000    0.60369755    c       6.000     0
        -0.96200051   -1.66623376   -0.20072885    h       1.000     0
        -0.96200051    1.66623376   -0.20072885    h       1.000     0
         1.92400102    0.00000000   -0.20072885    h       1.000     0
```

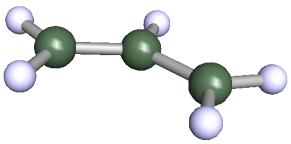
Methanide Anion Product:



Total Energy = -79.75379462066 hartree
Enthalpy Correction = 0.079099 hartree
Entropy = 0.000087 hartree/K

```
                   atomic coordinates            atom    charge  isotop
         0.00000000    0.00000000   -1.43605736    c       6.000     0
         0.00000000    0.00000000    1.43605736    c       6.000     0
         1.66642460   -0.96211069   -2.18669270    h       1.000     0
         0.00000000    1.92422138   -2.18669270    h       1.000     0
        -1.66642460   -0.96211069   -2.18669270    h       1.000     0
         1.66642460    0.96211069    2.18669270    h       1.000     0
        -1.66642460    0.96211069    2.18669270    h       1.000     0
         0.00000000   -1.92422138    2.18669270    h       1.000     0
```

Prop-2-en-1-ide Anion (MCA* = 599.7 kJ/mol):



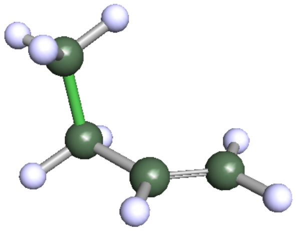
Total Energy = -117.26411619283 hartree

Enthalpy Correction = 0.06977 hartree
Entropy = 0.000097 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.38824794 | 0.00000000 | 0.30939821 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -0.77220155 | c | 6.000 | 0 |
| 4.07564098 | 0.00000000 | -0.85265593 | h | 1.000 | 0 |
| 2.63852147 | 0.00000000 | 2.35087345 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | -2.84297289 | h | 1.000 | 0 |
| -2.38824794 | 0.00000000 | 0.30939821 | c | 6.000 | 0 |
| -4.07564098 | 0.00000000 | -0.85265593 | h | 1.000 | 0 |
| -2.63852147 | 0.00000000 | 2.35087345 | h | 1.000 | 0 |

Prop-2-en-1-ide Anion Product:

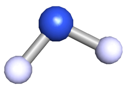
The $H_3$C-C-C-C Torsion Angle was constrained to 270°.



Total Energy = -157.08210869810 hartree
Enthalpy Correction = 0.114867 hartree
Entropy = 0.000113 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.84602233 | -2.50048859 | 0.56816514 | c | 6.000 | 0 |
| -1.66340139 | -1.27226448 | 0.41434873 | c | 6.000 | 0 |
| -5.31369692 | -2.26578829 | -0.84337261 | h | 1.000 | 0 |
| -4.23236428 | -3.80262838 | 2.10927167 | h | 1.000 | 0 |
| -1.36808993 | 0.03205106 | -1.15049966 | h | 1.000 | 0 |
| 0.39103892 | -1.39073992 | 2.35463454 | c | 6.000 | 0 |
| 2.23319825 | -1.19031523 | 1.43773138 | h | 1.000 | 0 |
| 0.08904368 | 0.65211168 | 4.37052750 | c | 6.000 | 0 |
| 0.36698136 | -3.24545907 | 3.27008410 | h | 1.000 | 0 |
| -1.69004851 | 0.40476022 | 5.38769406 | h | 1.000 | 0 |
| 0.07974307 | 2.53858351 | 3.52727005 | h | 1.000 | 0 |
| 1.63591781 | 0.57295632 | 5.73629169 | h | 1.000 | 0 |

Amide Anion (MCA* = 577.1 kJ/mol):

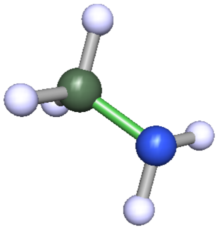


Total Energy = -55.97780776431 hartree
Enthalpy Correction = 0.023018 hartree
Entropy = 0.000072 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | 0.80946622 | n | 7.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -1.50335249 | 0.00000000 | -0.40472449 | h | 1.000 | 0 |
| 1.50335249 | 0.00000000 | -0.40472449 | h | 1.000 | 0 |

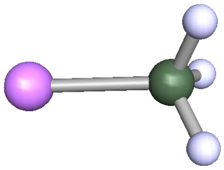
Amide Anion Product:



Total Energy = -95.78704451254 hartree
Enthalpy Correction = 0.068833 hartree
Entropy = 0.000091 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.07537958 | 0.03053886 | 0.00000000 | c | 6.000 | 0 |
| 1.61956496 | 0.61375034 | 0.00000000 | n | 7.000 | 0 |
| -1.96372443 | 0.87005968 | -1.66358884 | h | 1.000 | 0 |
| -1.51662883 | -1.99682200 | 0.00000000 | h | 1.000 | 0 |
| -1.96372443 | 0.87005968 | 1.66358884 | h | 1.000 | 0 |
| 2.45002723 | -0.19395619 | 1.52556173 | h | 1.000 | 0 |
| 2.45002723 | -0.19395619 | -1.52556173 | h | 1.000 | 0 |

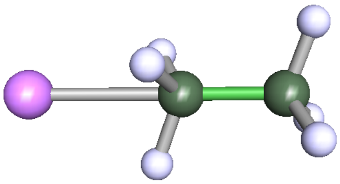
Methyl lithium (MCA* = 567.7 kJ/mol):



Total Energy = -47.3755795353 hartree
Enthalpy Correction = 0.036359 hartree
Entropy = 0.000091 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.62697886 | -0.03792947 | 0.04543359 | li | 3.000 | 0 |
| -0.28922976 | 0.00280810 | -0.00445023 | c | 6.000 | 0 |
| -1.11370558 | -1.40301699 | -1.30324614 | h | 1.000 | 0 |
| -1.08604702 | 1.83586080 | -0.59406124 | h | 1.000 | 0 |
| -1.13799650 | -0.39772244 | 1.85632402 | h | 1.000 | 0 |

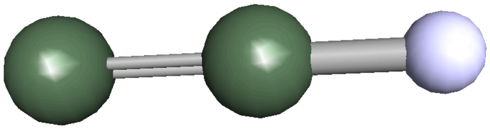
Methyl Lithium Product:



Total Energy = -87.18086544411 hartree
Enthalpy Correction = 0.082119 hartree
Entropy = 0.000111 hartree/K

```
               atomic coordinates                atom    charge  isotop
     0.03628285   -0.37184834   -0.00023221     c       6.000     0
     0.01641866    2.49776986   -0.03089640     c       6.000     0
     0.04897454   -4.59804212    0.06814107     li      3.000     0
     1.97386043   -1.06440857   -0.26794937     h       1.000     0
    -1.16308553   -1.09992963   -1.52783501     h       1.000     0
     0.08649342   -0.37111794    0.03559421     q       0.000     0
    -0.68722117   -1.05763731    1.81933656     h       1.000     0
    -1.89618918    3.22114344    0.23795131     h       1.000     0
     1.20409018    3.25694776    1.47440920     h       1.000     0
     0.72466859    3.21782370   -1.82888128     h       1.000     0
```

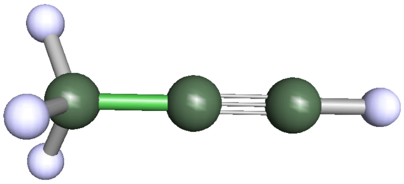
Ethynide Anion (MCA* = 552.5 kJ/mol):



Total Energy = -76.75921537101 hartree
Enthalpy Correction = 0.018846 hartree
Entropy = 0.000077 hartree/K

```
               atomic coordinates                atom    charge  isotop
     0.00000000    0.00000000   -0.10155021     c       6.000     0
     0.00000000    0.00000000    2.22852203     c       6.000     0
     0.00000000    0.00000000   -2.12697182     h       1.000     0
```

Ethynide Anion Product:

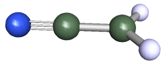


Total Energy = -116.55607369016 hartree

Enthalpy Correction = 0.060789 hartree
Entropy = 0.000093 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -3.21516951 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -0.94229940 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -5.23149425 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 1.79879953 | c | 6.000 | 0 |
| -0.96519182 | 1.67176127 | 2.52981090 | h | 1.000 | 0 |
| -0.96519182 | -1.67176127 | 2.52981090 | h | 1.000 | 0 |
| 1.93038364 | 0.00000000 | 2.52981090 | h | 1.000 | 0 |

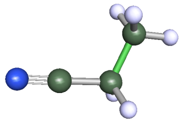
Vinylideneamide Anion (MCA* = 540.5 kJ/mol):



Total Energy = -132.14015391495 hartree
Enthalpy Correction = 0.035514 hartree
Entropy = 0.000093 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -1.06518685 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.51055000 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 3.74389585 | n | 7.000 | 0 |
| -1.76685152 | 0.00000000 | -2.09461742 | h | 1.000 | 0 |
| 1.76685152 | 0.00000000 | -2.09461742 | h | 1.000 | 0 |

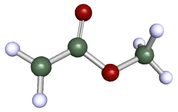
Vinylideneamide Anion Product:



Total Energy = -171.93549447553 hartree
Enthalpy Correction = 0.080183 hartree
Entropy = 0.000108 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 4.65277056 | 1.60215958 | 0.00000000 | n | 7.000 | 0 |
| 2.83500390 | 0.40828423 | 0.00000000 | c | 6.000 | 0 |
| 0.51859699 | -1.06106314 | 0.00000000 | c | 6.000 | 0 |
| -1.83461621 | 0.60590896 | 0.00000000 | c | 6.000 | 0 |
| 0.55810294 | -2.28843159 | -1.66137531 | h | 1.000 | 0 |
| 0.55810294 | -2.28843159 | 1.66137531 | h | 1.000 | 0 |
| -1.88880574 | 1.80659675 | 1.67423934 | h | 1.000 | 0 |
| -1.88880574 | 1.80659675 | -1.67423934 | h | 1.000 | 0 |
| -3.51052216 | -0.59224819 | 0.00000000 | h | 1.000 | 0 |

1-Methoxyethen-1-olate Anion (MCA* = 539.3 kJ/mol):

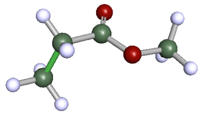


Total Energy = -267.69340478302 hartree
Enthalpy Correction = 0.08289 hartree
Entropy = 0.000117 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.52895770 | -3.63326992 | 0.48910054 | c | 6.000 | 0 |
| -5.37129618 | -3.92809327 | 2.29834352 | c | 6.000 | 0 |
| -1.94629842 | -1.88909135 | 0.22982297 | o | 8.000 | 0 |
| -3.47139257 | -5.59977540 | -1.28205632 | o | 8.000 | 0 |
| -6.61468912 | -5.55170944 | 2.28696786 | h | 1.000 | 0 |
| -5.57329542 | -2.51378100 | 3.76205113 | h | 1.000 | 0 |
| -1.62815081 | -5.38125417 | -3.19524881 | c | 6.000 | 0 |
| -1.84103941 | -7.04696389 | -4.39081189 | h | 1.000 | 0 |
| -1.90069597 | -3.68203718 | -4.33947386 | h | 1.000 | 0 |
| 0.28723427 | -5.33738336 | -2.42114306 | h | 1.000 | 0 |

1-Methoxyethen-1-olate Anion Product:

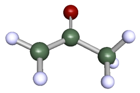
The $H_3C$-C-C-O Torsion Angle was constrained to 90°.



Total Energy = -307.48845355331 hartree
Enthalpy Correction = 0.127431 hartree
Entropy = 0.000131 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.47953232 | -3.27192202 | 0.16572862 | c | 6.000 | 0 |
| -4.55688839 | -1.05348004 | -0.38285893 | o | 8.000 | 0 |
| -4.26055332 | -4.08853340 | 2.53606922 | o | 8.000 | 0 |
| -4.52411257 | -5.40374551 | -1.69779892 | c | 6.000 | 0 |
| -4.06993403 | -2.18406830 | 4.44379219 | c | 6.000 | 0 |
| -2.40935616 | -1.00825018 | 4.12028969 | h | 1.000 | 0 |
| -5.75840413 | -1.00376652 | 4.45027458 | h | 1.000 | 0 |
| -3.89634786 | -3.19326673 | 6.22442027 | h | 1.000 | 0 |
| -5.61794427 | -4.78272015 | -3.33061025 | h | 1.000 | 0 |
| -5.46278992 | -7.03244839 | -0.85086204 | h | 1.000 | 0 |
| -1.84061310 | -6.10476776 | -2.49812459 | c | 6.000 | 0 |
| -0.88004141 | -4.49082538 | -3.35258662 | h | 1.000 | 0 |
| -0.72777356 | -6.74537528 | -0.88312558 | h | 1.000 | 0 |
| -1.89673408 | -7.62865889 | -3.88546428 | h | 1.000 | 0 |

Prop-1-en-2-olate Anion (MCA* = 518.7 kJ/mol):

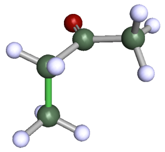


Total Energy = -192.51161272845 hartree
Enthalpy Correction = 0.076888 hartree
Entropy = 0.000107 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.73630585 | -0.99617896 | 0.66641856 | c | 6.000 | 0 |
| 0.50106889 | 0.80018347 | 0.62178672 | c | 6.000 | 0 |
| -1.86856105 | -2.17206960 | -1.02429150 | h | 1.000 | 0 |
| -1.60281209 | -2.22656391 | 2.32453011 | h | 1.000 | 0 |
| -3.48904468 | 0.08554105 | 0.86337476 | h | 1.000 | 0 |
| 2.05865780 | 0.76723599 | -1.44879592 | c | 6.000 | 0 |
| 0.74268674 | 2.22345251 | 2.56806223 | o | 8.000 | 0 |
| 1.71177222 | -0.50162885 | -3.01870597 | h | 1.000 | 0 |
| 3.68014926 | 2.02384996 | -1.55518924 | h | 1.000 | 0 |

Prop-1-en-2-olate Anion Product:

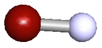
The $H_3C$-C-C-O Torsion Angle was constrained to 90°.



Total Energy = -232.29720459052 hartree
Enthalpy Correction = 0.120421 hartree
Entropy = 0.000123 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.64162262 | -3.34193481 | 0.72129081 | c | 6.000 | 0 |
| -0.06888251 | -1.09735430 | 0.90868736 | c | 6.000 | 0 |
| 3.55112680 | -2.76252933 | 0.18912092 | h | 1.000 | 0 |
| 0.94930283 | -4.56188087 | -0.80001289 | h | 1.000 | 0 |
| 1.67430300 | -4.39729835 | 2.48698270 | h | 1.000 | 0 |
| -1.49869086 | -0.80785865 | 2.68333484 | o | 8.000 | 0 |
| 0.09436866 | 0.82624006 | -1.17908290 | c | 6.000 | 0 |
| 2.10254291 | 2.80647022 | -0.54918032 | c | 6.000 | 0 |
| -1.75031553 | 1.72989855 | -1.37372569 | h | 1.000 | 0 |
| 0.56859280 | -0.10983748 | -2.95774510 | h | 1.000 | 0 |
| 1.63955238 | 3.78561740 | 1.20724927 | h | 1.000 | 0 |
| 2.21483835 | 4.20699247 | -2.05830499 | h | 1.000 | 0 |
| 3.96837337 | 1.94878406 | -0.33954176 | h | 1.000 | 0 |

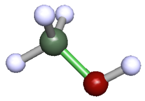
Hydroxide Anion (MCA* = 487.9 kJ/mol):



Total Energy = -75.87582711746 hartree
Enthalpy Correction = 0.012078 hartree
Entropy = 0.000066 hartree/K

```
                 atomic  coordinates                  atom    charge  isotop
        0.00000000    0.00000000   -0.90764766     o       8.000      0
        0.00000000    0.00000000    0.90764766     h       1.000      0
```

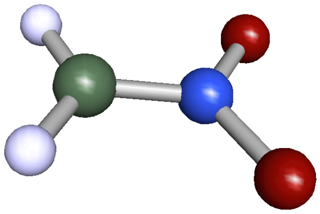
Hydroxide Anion Product:



Total Energy = -115.64758950633 hartree
Enthalpy Correction = 0.055895 hartree
Entropy = 0.00009 hartree/K

```
                 atomic  coordinates                  atom    charge  isotop
        1.73895799   -1.06773376   -0.33295109     o       8.000      0
       -0.68057301    0.03964971   -0.03596230     c       6.000      0
        2.97778344    0.11097902    0.28159142     h       1.000      0
       -2.06632598   -1.31879943   -0.72995839     h       1.000      0
       -0.86797472    1.78572970   -1.13126043     h       1.000      0
       -1.10186772    0.45017476    1.94854080     h       1.000      0
```

Nitromethanide Anion (MCA* = 478.5 kJ/mol):

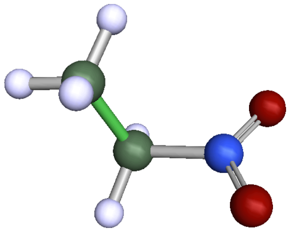


Total Energy = -244.38149919168 hartree
Enthalpy Correction = 0.041682 hartree
Entropy = 0.000099 hartree/K

```
                 atomic  coordinates                  atom    charge  isotop
        0.00000000    0.00000000   -1.33844572     c       6.000      0
        0.00000000    0.00000000    1.14481375     n       7.000      0
       -2.06941365    0.00000000    2.39275371     o       8.000      0
        2.06941365    0.00000000    2.39275371     o       8.000      0
       -1.79753319    0.00000000   -2.29620958     h       1.000      0
        1.79753319    0.00000000   -2.29620958     h       1.000      0
```

Nitromethanide Anion Product:

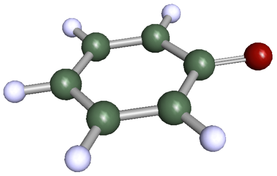
The C-C-N-O Torsion Angle was constrained to 90°.



Total Energy = -284.15168673478 hartree
Enthalpy Correction = 0.085716 hartree
Entropy = 0.000117 hartree/K

```
                  atomic coordinates            atom    charge  isotop
     -2.09985009    0.48229247    0.25197293     c      6.000     0
      0.25420830   -0.52837403   -1.02352231     c      6.000     0
      2.47816464   -0.09365215    0.64971131     n      7.000     0
      3.62751759    1.87520639    0.41625522     o      8.000     0
      2.97914506   -1.70090794    2.20458965     o      8.000     0
     -1.94578920    2.50915001    0.59289879     h      1.000     0
     -3.70478843    0.15116795   -0.99735655     h      1.000     0
     -2.45080871   -0.48867732    2.03611399     h      1.000     0
      0.66454601    0.45439359   -2.78116214     h      1.000     0
      0.15798308   -2.55909556   -1.32422609     h      1.000     0
```

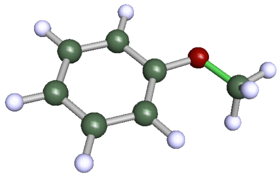
Phenoxide (MCA* = 408.8 kJ/mol):



Total Energy = -306.76761861163 hartree
Enthalpy Correction = 0.098469 hartree
Entropy = 0.000117 hartree/K

```
                  atomic coordinates            atom    charge  isotop
      4.70885683    2.01844714    0.31535160     o      8.000     0
      2.48701659    1.06601644    0.16514702     c      6.000     0
      0.26183129    2.58433388    0.04887372     c      6.000     0
     -2.13251711    1.54177449   -0.10919132     c      6.000     0
     -2.48925235   -1.06694327   -0.16379058     c      6.000     0
     -0.35694725   -2.60890039   -0.05627291     c      6.000     0
      2.04914699   -1.59376870    0.10210112     c      6.000     0
      0.49658332    4.62488665    0.08859365     h      1.000     0
     -3.76242749    2.78917000   -0.19132945     h      1.000     0
     -4.36857942   -1.87232173   -0.28727306     h      1.000     0
     -0.57992876   -4.65063055   -0.09664132     h      1.000     0
      3.68621736   -2.83206396    0.18443152     h      1.000     0
```

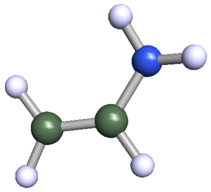
Phenoxide Product:



Total Energy = -346.51076781999 hartree
Enthalpy Correction = 0.141135 hartree
Entropy = 0.000132 hartree/K

```
               atomic coordinates               atom    charge  isotop
 5.05017649   -0.24637577    0.19824270     c      6.000     0
 3.13797378    1.57267525   -0.23847224     o      8.000     0
 0.70497021    0.79211663   -0.14592683     c      6.000     0
-0.03266861   -1.68249956    0.35766259     c      6.000     0
-2.59167099   -2.28272112    0.41004089     c      6.000     0
-4.41529709   -0.45701598   -0.03122063     c      6.000     0
-3.65960088    2.01170817   -0.53418053     c      6.000     0
-1.12337969    2.63957278   -0.59278860     c      6.000     0
 6.83861782    0.75518217    0.03791318     h      1.000     0
 4.88740191   -1.06397583    2.08968276     h      1.000     0
 4.98062061   -1.75815160   -1.21024000     h      1.000     0
 1.35351896   -3.14345570    0.70823737     h      1.000     0
-3.14832016   -4.21507077    0.80424142     h      1.000     0
-6.40351311   -0.94401090    0.01397597     h      1.000     0
-5.06166784    3.46469997   -0.88432027     h      1.000     0
-0.51716140    4.55732225   -0.98284777     h      1.000     0
```

Ethenamine (MCA* = 400.2 kJ/mol):

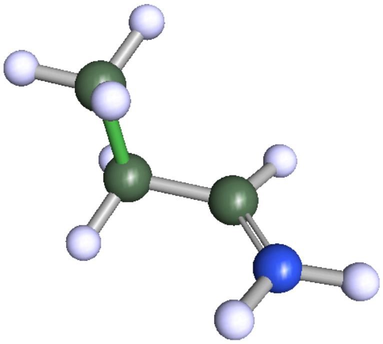


Total Energy = -133.85005102927 hartree
Enthalpy Correction = 0.074266 hartree
Entropy = 0.000098 hartree/K

```
               atomic coordinates               atom    charge  isotop
-3.40608459   -3.65891706    0.45120471     n      7.000     0
-1.55469335   -1.86071023    0.14639832     c      6.000     0
-3.15923644   -5.29950859   -0.48914547     h      1.000     0
-4.03128566   -3.91598861    2.23037891     h      1.000     0
-1.62963030   -0.36224418    1.54966655     h      1.000     0
 0.16162765   -1.75691170   -1.70687377     c      6.000     0
 0.29569298   -3.21760251   -3.14113590     h      1.000     0
 1.45154162   -0.17504744   -1.81876898     h      1.000     0
```

Ethenamine Product:

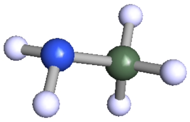
The C-C-C-N Torsion Angle was constrained to 90°.



Total Energy = -173.59218026353 hartree
Enthalpy Correction = 0.118881 hartree
Entropy = 0.000112 hartree/K

```
                  atomic coordinates             atom    charge  isotop
   0.56194123   -0.03206290   -2.89609349     c       6.000     0
  -1.21371335   -0.21951370   -3.92460981     h       1.000     0
   1.77571687   -1.64120376   -3.33744617     h       1.000     0
   1.79449640    2.33032868   -3.67098851     c       6.000     0
   0.66540186    3.98329999   -4.12614258     h       1.000     0
   4.18267582    2.62584203   -3.69092243     n       7.000     0
   4.97894181    4.30873328   -4.13079472     h       1.000     0
   5.37898118    1.18169477   -3.29634746     h       1.000     0
   0.05572448    0.06726884   -0.03837221     c       6.000     0
   1.82521724    0.16389963    1.01295221     h       1.000     0
  -1.10460939    1.69601518    0.46504122     h       1.000     0
  -0.95172448   -1.64298643    0.51104978     h       1.000     0
```

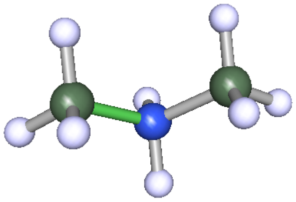
Methanamine (MCA* = 389.2 kJ/mol):



Total Energy = -95.78704451254 hartree
Enthalpy Correction = 0.068833 hartree
Entropy = 0.000091 hartree/K

```
                  atomic coordinates             atom    charge  isotop
  -1.07537958    0.03053886    0.00000000     c       6.000     0
   1.61956496    0.61375034    0.00000000     n       7.000     0
  -1.96372443    0.87005968   -1.66358884     h       1.000     0
  -1.51662883   -1.99682200    0.00000000     h       1.000     0
  -1.96372443    0.87005968    1.66358884     h       1.000     0
   2.45002723   -0.19395619    1.52556173     h       1.000     0
   2.45002723   -0.19395619   -1.52556173     h       1.000     0
```

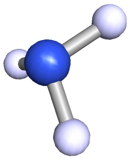
Methanamine Product:



Total Energy = -135.52824241474 hartree
Enthalpy Correction = 0.115209 hartree
Entropy = 0.0001 hartree/K

```
                  atomic coordinates           atom    charge  isotop
   0.00000000   -2.33642745   -0.43270688     c       6.000     0
   0.00000000    0.00000000    1.10110823     n       7.000     0
   0.00000000    2.33642745   -0.43270688     c       6.000     0
   0.00000000   -3.95823508    0.82739164     h       1.000     0
  -1.68688140   -2.33615153   -1.60696732     h       1.000     0
   1.68688140   -2.33615153   -1.60696732     h       1.000     0
   1.53352452    0.00000000    2.26671839     h       1.000     0
  -1.53352452    0.00000000    2.26671839     h       1.000     0
   0.00000000    3.95823508    0.82739164     h       1.000     0
  -1.68688140    2.33615153   -1.60696732     h       1.000     0
   1.68688140    2.33615153   -1.60696732     h       1.000     0
```

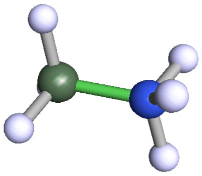
Ammonia (MCA* = 375.6 kJ/mol):



Total Energy = -56.52300480668 hartree
Enthalpy Correction = 0.038344 hartree
Entropy = 0.000073 hartree/K

```
                  atomic coordinates           atom    charge  isotop
   0.00000000    0.00000000   -0.55420265     n       7.000     0
  -0.88452007    1.53203371    0.18448474     h       1.000     0
  -0.88452007   -1.53203371    0.18448474     h       1.000     0
   1.76904015    0.00000000    0.18448474     h       1.000     0
```

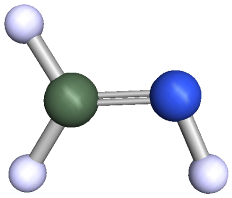
Ammonia Product:



Total Energy = -96.25779423342 hartree
Enthalpy Correction = 0.08527 hartree
Entropy = 0.000088 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -1.37610166 | n | 7.000 | 0 |
| 0.00000000 | 0.00000000 | 1.41774334 | c | 6.000 | 0 |
| -0.89512833 | 1.55040775 | -2.08448543 | h | 1.000 | 0 |
| -0.89512833 | -1.55040775 | -2.08448543 | h | 1.000 | 0 |
| 1.79025667 | 0.00000000 | -2.08448543 | h | 1.000 | 0 |
| -1.94654710 | 0.00000000 | 2.07083608 | h | 1.000 | 0 |
| 0.97327355 | -1.68575924 | 2.07083608 | h | 1.000 | 0 |
| 0.97327355 | 1.68575924 | 2.07083608 | h | 1.000 | 0 |

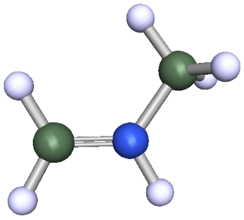
Methanimine (MCA* = 374.4 kJ/mol):



Total Energy = -94.56000459072 hartree
Enthalpy Correction = 0.044182 hartree
Entropy = 0.000087 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -0.74160284 | -0.03176542 | 0.00000000 | c | 6.000 | 0 |
| 1.32620659 | 1.16407073 | 0.00000000 | n | 7.000 | 0 |
| -0.88666961 | -2.09347907 | 0.00000000 | h | 1.000 | 0 |
| -2.51507564 | 1.02102309 | 0.00000000 | h | 1.000 | 0 |
| 2.81714149 | -0.05984933 | 0.00000000 | h | 1.000 | 0 |

Methanimine Product:

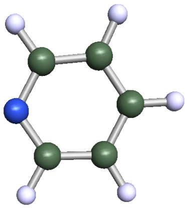


Total Energy = -134.29252258899 hartree
Enthalpy Correction = 0.088711 hartree
Entropy = 0.0001 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.85208057 | -3.63882471 | 0.33588506 | c | 6.000 | 0 |
| -1.71936169 | -1.73242575 | -0.55514603 | n | 7.000 | 0 |
| -1.89884447 | -5.44927800 | 0.34808487 | h | 1.000 | 0 |
| -4.75241911 | -3.43237700 | 1.07151112 | h | 1.000 | 0 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -2.73541785 | 0.80429834 | -0.70257729 | c | 6.000 | 0 |
| 0.06163491 | -1.97187073 | -1.23345988 | h | 1.000 | 0 |
| -4.63937704 | 0.81982324 | 0.06717656 | h | 1.000 | 0 |
| -1.50640452 | 2.06127442 | 0.36969851 | h | 1.000 | 0 |
| -2.74316915 | 1.38856230 | -2.67702767 | h | 1.000 | 0 |

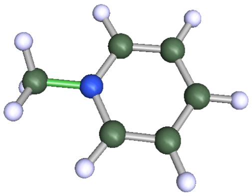
Pyridine (MCA* = 371.6 kJ/mol):



Total Energy = -248.09291778524 hartree
Enthalpy Correction = 0.094839 hartree
Entropy = 0.000107 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.25211260 | 0.00000000 | -0.90516394 | c | 6.000 | 0 |
| -2.15191543 | 0.00000000 | 1.71396712 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 3.02159127 | n | 7.000 | 0 |
| 2.15191543 | 0.00000000 | 1.71396712 | c | 6.000 | 0 |
| 2.25211260 | 0.00000000 | -0.90516394 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -2.24318683 | c | 6.000 | 0 |
| -4.06059986 | 0.00000000 | -1.86438390 | h | 1.000 | 0 |
| -3.88646898 | 0.00000000 | 2.81190435 | h | 1.000 | 0 |
| 3.88646898 | 0.00000000 | 2.81190435 | h | 1.000 | 0 |
| 4.06059986 | 0.00000000 | -1.86438390 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | -4.29154950 | h | 1.000 | 0 |

Pyridine Product:

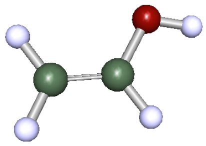


Total Energy = -287.82291499180 hartree
Enthalpy Correction = 0.138517 hartree
Entropy = 0.000122 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -5.45618159 | -5.20546487 | 0.36068716 | c | 6.000 | 0 |
| -3.01643216 | -6.10080409 | 0.33455340 | c | 6.000 | 0 |
| -1.05480500 | -4.49829302 | 0.31758427 | n | 7.000 | 0 |
| -1.41241592 | -1.98904787 | 0.32538518 | c | 6.000 | 0 |
| -3.81169807 | -0.99474313 | 0.35202639 | c | 6.000 | 0 |
| -5.86791142 | -2.61909495 | 0.37004752 | c | 6.000 | 0 |
| -7.00421010 | -6.53870375 | 0.36799813 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| -2.56309997 | -8.09230624 | 0.32435391 | h | 1.000 | 0 |
| 1.52662512 | -5.49398602 | 0.36687115 | c | 6.000 | 0 |
| 0.27145522 | -0.83264539 | 0.30759340 | h | 1.000 | 0 |
| -4.04746529 | 1.03477375 | 0.35295989 | h | 1.000 | 0 |
| -7.77365552 | -1.87492336 | 0.38626736 | h | 1.000 | 0 |
| 2.19240352 | -5.53263359 | 2.31429286 | h | 1.000 | 0 |
| 2.73211321 | -4.27544257 | -0.76474511 | h | 1.000 | 0 |
| 1.52182340 | -7.39327707 | -0.41203554 | h | 1.000 | 0 |

Ethanol (MCA* = 313.5 kJ/mol):

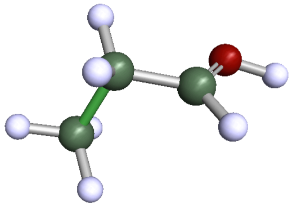


Total Energy = -153.70792739458 hartree
Enthalpy Correction = 0.06155 hartree
Entropy = 0.000097 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.67442150 | 1.02212943 | 0.00000000 | c | 6.000 | 0 |
| 0.64452730 | 0.06467868 | 0.00000000 | c | 6.000 | 0 |
| -1.92472244 | 3.05027298 | 0.00000000 | h | 1.000 | 0 |
| -3.33395969 | -0.17966397 | 0.00000000 | h | 1.000 | 0 |
| 2.31586130 | 1.25750683 | 0.00000000 | h | 1.000 | 0 |
| 1.08995083 | -2.45621540 | 0.00000000 | o | 8.000 | 0 |
| 2.88276421 | -2.75870855 | 0.00000000 | h | 1.000 | 0 |

Ethanol Product:

The C-C-C-O Torsion Angle was constrained to 90°.

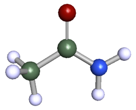


Total Energy = -193.41603655462 hartree
Enthalpy Correction = 0.105161 hartree
Entropy = 0.000111 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.80990755 | -0.07261959 | -2.66899855 | c | 6.000 | 0 |
| 2.05205112 | 2.30346287 | -3.19839625 | c | 6.000 | 0 |
| 1.07729317 | 4.10558897 | -2.97905292 | h | 1.000 | 0 |
| 4.35454988 | 2.33296767 | -3.77264185 | o | 8.000 | 0 |
| 5.04223741 | 4.03271225 | -3.96759871 | h | 1.000 | 0 |
| 1.11401148 | -0.52914416 | 0.20879871 | c | 6.000 | 0 |
| 1.70081586 | -1.60392404 | -3.72061103 | h | 1.000 | 0 |

```
         -1.18888706    0.09227352   -3.13860530    h       1.000      0
          3.09932453   -0.77131305    0.69574787    h       1.000      0
          0.08493616   -2.25324393    0.66325702    h       1.000      0
          0.32343577    1.02107908    1.31171309    h       1.000      0
```

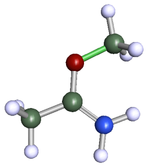
Acetamide (O attack) (MCA* = 281.4 kJ/mol):



Total Energy = -209.08745076041 hartree
Enthalpy Correction = 0.080398 hartree
Entropy = 0.000109 hartree/K

```
                   atomic coordinates            atom    charge  isotop
          2.45547314    0.62368808   -0.23987145    n       7.000      0
          0.33539241    0.18801319    1.07202562    c       6.000      0
         -1.95325527   -0.54380488   -0.44109614    c       6.000      0
          0.25325149    0.36415843    3.38782670    o       8.000      0
          4.05280460    1.10316744    0.67775245    h       1.000      0
          2.50822279    0.47559365   -2.13199514    h       1.000      0
         -1.62572040   -0.51191865   -2.47316655    h       1.000      0
         -2.53159902   -2.44245613    0.12244099    h       1.000      0
         -3.49456973    0.74355887    0.02608352    h       1.000      0
```

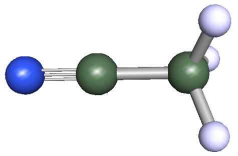
Acetamide (O attack) Product:



Total Energy = -248.78409217573 hartree
Enthalpy Correction = 0.123882 hartree
Entropy = 0.00012 hartree/K

```
                   atomic coordinates            atom    charge  isotop
         -3.32490220   -1.81738397   -0.40579239    n       7.000      0
         -1.18678784   -0.65704905   -0.14340384    c       6.000      0
         -0.77967638    1.91381570   -1.13183083    c       6.000      0
          0.71843684   -1.66749629    0.99417484    o       8.000      0
          0.49673988   -4.17459747    2.02467632    c       6.000      0
         -3.64159474   -3.57868518    0.25725807    h       1.000      0
         -4.76770701   -0.95892317   -1.30891615    h       1.000      0
         -0.25357249    3.14909322    0.43387800    h       1.000      0
         -2.46421753    2.63370844   -2.06072196    h       1.000      0
          0.79637865    1.86932420   -2.46168813    h       1.000      0
          0.10142775   -5.51707553    0.51237044    h       1.000      0
          2.32028650   -4.57656404    2.87009403    h       1.000      0
         -0.97776342   -4.20882554    3.46409912    h       1.000      0
```

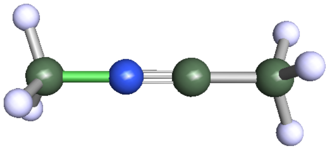
Acetonitrile (MCA* = 280.2 kJ/mol):



Total Energy = -132.65590935544 hartree
Enthalpy Correction = 0.049993 hartree
Entropy = 0.000092 hartree/K

```
                  atomic coordinates              atom    charge  isotop
          0.00000000    0.00000000   -0.92556463    c       6.000     0
          0.00000000    0.00000000    1.80542455    c       6.000     0
         -0.97039584    1.68077490   -1.61984751    h       1.000     0
         -0.97039584   -1.68077490   -1.61984751    h       1.000     0
          1.94079169    0.00000000   -1.61984751    h       1.000     0
          0.00000000    0.00000000    3.97941974    n       7.000     0
```

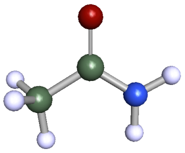
Acetonitrile Product:



Total Energy = -172.34953865565 hartree
Enthalpy Correction = 0.092416 hartree
Entropy = 0.000108 hartree/K

```
                  atomic coordinates              atom    charge  isotop
          0.00000000    0.00000000   -3.75607275    c       6.000     0
          0.00000000    0.00000000   -1.05613364    c       6.000     0
          0.04329996    1.95120530   -4.42439624    h       1.000     0
          1.66814338   -1.01310151   -4.42439624    h       1.000     0
         -1.71144334   -0.93810378   -4.42439624    h       1.000     0
          0.00000000    0.00000000    1.09281778    n       7.000     0
          0.00000000    0.00000000    3.76243343    c       6.000     0
          1.16061555    1.57046688    4.41088325    h       1.000     0
         -1.94037199    0.21988911    4.41088325    h       1.000     0
          0.77975644   -1.79035599    4.41088325    h       1.000     0
```

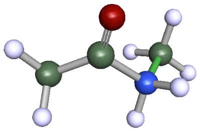
Acetamide (N attack) (MCA* = 265.9 kJ/mol):



Total Energy = -209.08745076041 hartree
Enthalpy Correction = 0.080398 hartree
Entropy = 0.000109 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.45547314 | 0.62368808 | -0.23987145 | n | 7.000 | 0 |
| 0.33539241 | 0.18801319 | 1.07202562 | c | 6.000 | 0 |
| -1.95325527 | -0.54380488 | -0.44109614 | c | 6.000 | 0 |
| 0.25325149 | 0.36415843 | 3.38782670 | o | 8.000 | 0 |
| 4.05280460 | 1.10316744 | 0.67775245 | h | 1.000 | 0 |
| 2.50822279 | 0.47559365 | -2.13199514 | h | 1.000 | 0 |
| -1.62572040 | -0.51191865 | -2.47316655 | h | 1.000 | 0 |
| -2.53159902 | -2.44245613 | 0.12244099 | h | 1.000 | 0 |
| -3.49456973 | 0.74355887 | 0.02608352 | h | 1.000 | 0 |

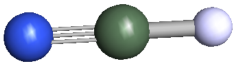
Acetamide (N attack) Product:



Total Energy = -248.77855737885 hartree
Enthalpy Correction = 0.12455 hartree
Entropy = 0.000121 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.60006884 | -0.15015921 | 3.74400152 | o | 8.000 | 0 |
| 1.03008157 | 0.04758924 | 1.55392807 | c | 6.000 | 0 |
| 3.18646852 | -0.90125787 | 0.06843074 | c | 6.000 | 0 |
| -0.90451655 | 1.44192361 | -0.00674671 | n | 7.000 | 0 |
| -2.98083924 | -0.26926232 | -0.83793875 | c | 6.000 | 0 |
| 4.40610044 | -2.04545665 | 1.25896259 | h | 1.000 | 0 |
| 4.23482952 | 0.71213338 | -0.68965229 | h | 1.000 | 0 |
| 2.51005573 | -2.00118513 | -1.54414496 | h | 1.000 | 0 |
| -0.07622527 | 2.26856672 | -1.53994833 | h | 1.000 | 0 |
| -1.62829714 | 2.86058821 | 1.08463893 | h | 1.000 | 0 |
| -2.18163321 | -1.75625140 | -2.00920471 | h | 1.000 | 0 |
| -4.32256894 | 0.84634729 | -1.91897350 | h | 1.000 | 0 |
| -3.87352427 | -1.05357587 | 0.83664742 | h | 1.000 | 0 |

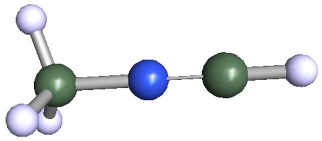
Hydrogen Cyanide (MCA* = 256.5 kJ/mol):



Total Energy = -93.35645307915 hartree
Enthalpy Correction = 0.020142 hartree
Entropy = 0.000077 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | 2.11950366 | n | 7.000 | 0 |
| 0.00000000 | 0.00000000 | -0.04533030 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -2.07417336 | h | 1.000 | 0 |

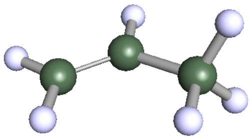
Hydrogen Cyanide Product:



Total Energy = -133.04084291172 hartree
Enthalpy Correction = 0.062342 hartree
Entropy = 0.000093 hartree/K

| | atomic coordinates | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -3.03205844 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -0.89482067 | n | 7.000 | 0 |
| 0.00000000 | 0.00000000 | -5.06847121 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 1.77191498 | c | 6.000 | 0 |
| 0.97868406 | -1.69513052 | 2.40744170 | h | 1.000 | 0 |
| 0.97868406 | 1.69513052 | 2.40744170 | h | 1.000 | 0 |
| -1.95736812 | 0.00000000 | 2.40744170 | h | 1.000 | 0 |

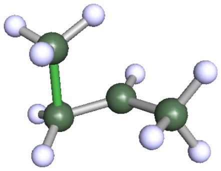
Prop-1-ene (MCA* = 246.6 kJ/mol):



Total Energy = -117.80340555362 hartree
Enthalpy Correction = 0.084805 hartree
Entropy = 0.0001 hartree/K

| | atomic coordinates | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.23566687 | -3.34190294 | 0.31738208 | c | 6.000 | 0 |
| -1.99055772 | -1.64582243 | 0.22533824 | c | 6.000 | 0 |
| -4.35659107 | -4.49454118 | -1.39618073 | h | 1.000 | 0 |
| -5.98540700 | -2.24209071 | 0.40734823 | h | 1.000 | 0 |
| -4.16809709 | -4.60085802 | 1.95100906 | h | 1.000 | 0 |
| -1.91720228 | -0.32565915 | -1.35174247 | h | 1.000 | 0 |
| -0.11820065 | -1.63687129 | 1.89584430 | c | 6.000 | 0 |
| -0.11090841 | -2.92014813 | 3.49913979 | h | 1.000 | 0 |
| 1.46808910 | -0.35076775 | 1.72027151 | h | 1.000 | 0 |

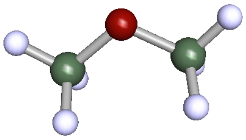
Prop-1-ene Product:



Total Energy = -157.48492731413 hartree
Enthalpy Correction = 0.126716 hartree
Entropy = 0.000112 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -2.70939807 | 0.20650879 | 1.18289114 | c | 6.000 | 0 |
| -2.00615135 | -2.09336523 | -0.18304103 | c | 6.000 | 0 |
| -1.76026275 | 1.88516876 | 0.46607380 | h | 1.000 | 0 |
| -4.74842977 | 0.41282240 | 0.83593630 | h | 1.000 | 0 |
| -2.47866985 | 0.00006348 | 3.21835776 | h | 1.000 | 0 |
| -2.60982527 | -3.89462733 | 0.59648109 | h | 1.000 | 0 |
| -0.64904124 | -2.12839517 | -2.46806227 | c | 6.000 | 0 |
| -0.52099515 | -0.38449240 | -3.53337171 | h | 1.000 | 0 |
| -0.71447768 | -3.84203013 | -3.58154688 | h | 1.000 | 0 |
| 1.63323314 | -2.24278509 | -0.45319493 | c | 6.000 | 0 |
| 1.16855147 | -2.80550843 | 1.50244418 | h | 1.000 | 0 |
| 2.51042739 | -0.39387109 | -0.37059076 | h | 1.000 | 0 |
| 2.82942298 | -3.77266969 | -1.12768906 | h | 1.000 | 0 |

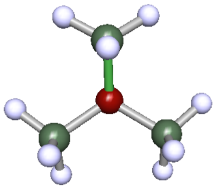
Methoxymethane (MCA* = 235.1 kJ/mol):



Total Energy = -154.91171346282 hartree
Enthalpy Correction = 0.085259 hartree
Entropy = 0.0001 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | -2.19982639 | 0.08790807 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.58000301 | o | 8.000 | 0 |
| 1.68307408 | -2.28475451 | -1.12265972 | h | 1.000 | 0 |
| -1.68307408 | -2.28475451 | -1.12265972 | h | 1.000 | 0 |
| 0.00000000 | -3.82270210 | 1.35717096 | h | 1.000 | 0 |
| 0.00000000 | 2.19982639 | 0.08790807 | c | 6.000 | 0 |
| 1.68307408 | 2.28475451 | -1.12265972 | h | 1.000 | 0 |
| 0.00000000 | 3.82270210 | 1.35717096 | h | 1.000 | 0 |
| -1.68307408 | 2.28475451 | -1.12265972 | h | 1.000 | 0 |

Methoxymethane product:

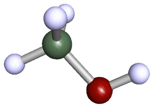


Total Energy = -194.59236563923 hartree
Enthalpy Correction = 0.129781 hartree

Entropy = 0.000109 hartree/K

```
                   atomic coordinates              atom    charge  isotop
          0.00000000   0.00000000  -0.78131259     o      8.000     0
          1.32969945  -2.30310701  -0.04174179     c      6.000     0
          1.32969945   2.30310701  -0.04174179     c      6.000     0
         -2.65939890   0.00000000  -0.04174179     c      6.000     0
          1.38687256  -2.40213374   2.01342607     h      1.000     0
          3.20797987  -2.17490349  -0.85612444     h      1.000     0
          0.27953174  -3.86564381  -0.85612444     h      1.000     0
          3.20797987   2.17490349  -0.85612444     h      1.000     0
          0.27953174   3.86564381  -0.85612444     h      1.000     0
          1.38687256   2.40213374   2.01342607     h      1.000     0
         -3.48751161   1.69074032  -0.85612444     h      1.000     0
         -2.77374512   0.00000000   2.01342607     h      1.000     0
         -3.48751161  -1.69074032  -0.85612444     h      1.000     0
```

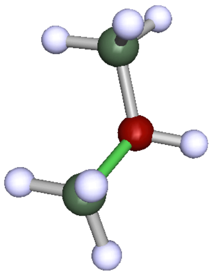
Methanol (MCA* = 234.8 kJ/mol):



Total Energy = -115.64758950633 hartree
Enthalpy Correction = 0.055895 hartree
Entropy = 0.00009 hartree/K

```
                   atomic coordinates              atom    charge  isotop
          1.73895799  -1.06773376  -0.33295109     o      8.000     0
         -0.68057301   0.03964971  -0.03596230     c      6.000     0
          2.97778344   0.11097902   0.28159142     h      1.000     0
         -2.06632598  -1.31879943  -0.72995839     h      1.000     0
         -0.86797472   1.78572970  -1.13126043     h      1.000     0
         -1.10186772   0.45017476   1.94854080     h      1.000     0
```

Methanol Product:

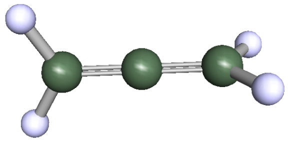


Total Energy = -155.32672815194 hartree
Enthalpy Correction = 0.100223 hartree
Entropy = 0.000103 hartree/K

```
                   atomic coordinates              atom    charge  isotop
         -0.02621568  -0.26279889  -2.33444408     c      6.000     0
```

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| -0.57948793 | 1.10949469 | 0.00000000 | o | 8.000 | 0 |
| -0.02621568 | -0.26279889 | 2.33444408 | c | 6.000 | 0 |
| -0.44365950 | 1.03047486 | -3.86920818 | h | 1.000 | 0 |
| -1.29373514 | -1.87483675 | -2.35971458 | h | 1.000 | 0 |
| 1.94858994 | -0.83212462 | -2.32107691 | h | 1.000 | 0 |
| 0.20973853 | 2.76980845 | 0.00000000 | h | 1.000 | 0 |
| 1.94858994 | -0.83212462 | 2.32107691 | h | 1.000 | 0 |
| -1.29373514 | -1.87483675 | 2.35971458 | h | 1.000 | 0 |
| -0.44365950 | 1.03047486 | 3.86920818 | h | 1.000 | 0 |

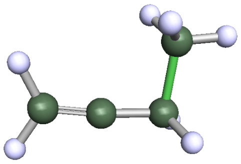
Propa-1,2-diene (MCA* = 234.2 kJ/mol):



Total Energy = -116.55664034976 hartree
Enthalpy Correction = 0.059985 hartree
Entropy = 0.000092 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -2.45813215 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 0.00000000 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 2.45813215 | c | 6.000 | 0 |
| -1.24199272 | 1.24199272 | -3.51913540 | h | 1.000 | 0 |
| 1.24199272 | -1.24199272 | -3.51913540 | h | 1.000 | 0 |
| -1.24199272 | -1.24199272 | 3.51913540 | h | 1.000 | 0 |
| 1.24199272 | 1.24199272 | 3.51913540 | h | 1.000 | 0 |

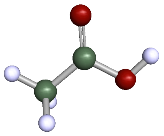
Propa-1,2-diene Product:



Total Energy = -156.22987316791 hartree
Enthalpy Correction = 0.101016 hartree
Entropy = 0.000113 hartree/K

| atomic coordinates |  |  | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.80442857 | 2.43604877 | 1.65505403 | c | 6.000 | 0 |
| 0.26686247 | 1.46262326 | 0.95680001 | c | 6.000 | 0 |
| 2.65452187 | 0.58140324 | 0.32393176 | c | 6.000 | 0 |
| -3.57094514 | 1.56001091 | 1.04715701 | h | 1.000 | 0 |
| -1.87532338 | 4.11803753 | 2.84080837 | h | 1.000 | 0 |
| 3.07127872 | -1.27607914 | 1.11364094 | h | 1.000 | 0 |
| 4.24639919 | 2.65745579 | 1.79584021 | c | 6.000 | 0 |
| 3.06230697 | 0.71561149 | -1.69150541 | h | 1.000 | 0 |
| 3.90585224 | 2.56384015 | 3.81986046 | h | 1.000 | 0 |
| 6.19677925 | 2.13183281 | 1.39190033 | h | 1.000 | 0 |
| 3.87367033 | 4.54356671 | 1.07043433 | h | 1.000 | 0 |

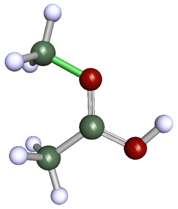
Acetic acid (carbonyl anti lone pair) (MCA* = 231.6 kJ/mol):



Total Energy = -228.94712944124 hartree
Enthalpy Correction = 0.067638 hartree
Entropy = 0.000107 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.89103092 | -0.61753735 | -0.08931205 | o | 8.000 | 0 |
| 1.02677870 | 1.08368894 | -0.10339694 | c | 6.000 | 0 |
| -1.51691893 | -0.12309113 | 0.01111534 | c | 6.000 | 0 |
| 1.42783939 | 3.33047508 | -0.21136438 | o | 8.000 | 0 |
| 4.48941329 | 0.27325782 | -0.18456640 | h | 1.000 | 0 |
| -2.97450325 | 1.31568976 | 0.16353496 | h | 1.000 | 0 |
| -1.61257339 | -1.41314061 | 1.61686854 | h | 1.000 | 0 |
| -1.81335652 | -1.24082010 | -1.69891447 | h | 1.000 | 0 |

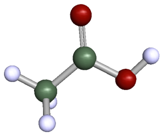
Acetic acid (carbonyl anti lone pair) Product:



Total Energy = -268.62444893590 hartree
Enthalpy Correction = 0.110755 hartree
Entropy = 0.000118 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.54285718 | -1.07489595 | -1.53133151 | o | 8.000 | 0 |
| 1.43525533 | -0.34217737 | -0.61483757 | c | 6.000 | 0 |
| 1.01665098 | 2.36878822 | -0.27408096 | c | 6.000 | 0 |
| -0.16248925 | -2.04290973 | -0.05991298 | o | 8.000 | 0 |
| -2.60351333 | -1.36600030 | 0.99234382 | c | 6.000 | 0 |
| 3.63783507 | -2.90902452 | -1.68577053 | h | 1.000 | 0 |
| 0.62663972 | 2.74753428 | 1.71903983 | h | 1.000 | 0 |
| 2.66154279 | 3.42482922 | -0.89610228 | h | 1.000 | 0 |
| -0.65460869 | 2.93565608 | -1.34839153 | h | 1.000 | 0 |
| -3.62581957 | -0.21072575 | -0.36597153 | h | 1.000 | 0 |
| -2.32081549 | -0.37533913 | 2.77114558 | h | 1.000 | 0 |
| -3.55353475 | -3.15573505 | 1.29386965 | h | 1.000 | 0 |

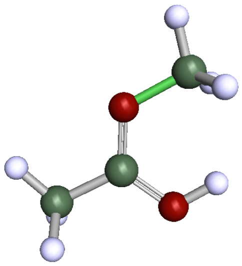
Acetic acid (carbonyl syn lone pair) (MCA* = 223.5 kJ/mol):



Total Energy = -228.94712944124 hartree
Enthalpy Correction = 0.067638 hartree
Entropy = 0.000107 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.89103092 | -0.61753735 | -0.08931205 | o | 8.000 | 0 |
| 1.02677870 | 1.08368894 | -0.10339694 | c | 6.000 | 0 |
| -1.51691893 | -0.12309113 | 0.01111534 | c | 6.000 | 0 |
| 1.42783939 | 3.33047508 | -0.21136438 | o | 8.000 | 0 |
| 4.48941329 | 0.27325782 | -0.18456640 | h | 1.000 | 0 |
| -2.97450325 | 1.31568976 | 0.16353496 | h | 1.000 | 0 |
| -1.61257339 | -1.41314061 | 1.61686854 | h | 1.000 | 0 |
| -1.81335652 | -1.24082010 | -1.69891447 | h | 1.000 | 0 |

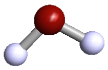
Acetic acid (carbonyl syn lone pair) Product:



Total Energy = -268.62114549455 hartree
Enthalpy Correction = 0.110542 hartree
Entropy = 0.000118 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.81588419 | -0.97398926 | -1.08712807 | o | 8.000 | 0 |
| 1.52363363 | -0.37673158 | -0.62172433 | c | 6.000 | 0 |
| 0.91971933 | 2.30809055 | -0.33734387 | c | 6.000 | 0 |
| -0.23630415 | -1.98614128 | -0.37858442 | o | 8.000 | 0 |
| 0.28951528 | -4.66654771 | -0.61254126 | c | 6.000 | 0 |
| 4.13371415 | -2.78025990 | -1.23463022 | h | 1.000 | 0 |
| 1.86287329 | 2.99378011 | 1.36921942 | h | 1.000 | 0 |
| 1.69819267 | 3.34500073 | -1.94019220 | h | 1.000 | 0 |
| -1.10810584 | 2.57932433 | -0.18614100 | h | 1.000 | 0 |
| 1.61720397 | -5.22898408 | 0.85693160 | h | 1.000 | 0 |
| 1.00417792 | -5.05672415 | -2.50350555 | h | 1.000 | 0 |
| -1.51992102 | -5.58399968 | -0.33015128 | h | 1.000 | 0 |

Water (MCA* = 221.4 kJ/mol):

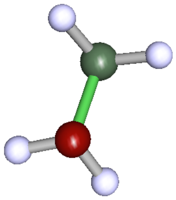


Total Energy = -76.39029062986 hartree
Enthalpy Correction = 0.025157 hartree
Entropy = 0.000072 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -0.74387058 | o | 8.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 1.43549637 | 0.00000000 | 0.37192627 | h | 1.000 | 0 |
| -1.43549637 | 0.00000000 | 0.37192627 | h | 1.000 | 0 |

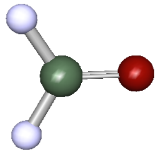
Water Product:



Total Energy = -116.06339310746 hartree
Enthalpy Correction = 0.070347 hartree
Entropy = 0.000091 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -4.09639497 | -4.37796856 | 0.24751063 | o | 8.000 | 0 |
| -2.21233805 | -2.33266240 | 0.18799761 | c | 6.000 | 0 |
| -5.04426150 | -4.41788581 | 1.82326936 | h | 1.000 | 0 |
| -3.34518441 | -6.03631244 | -0.01582821 | h | 1.000 | 0 |
| -1.36695311 | -2.42223899 | -1.67640022 | h | 1.000 | 0 |
| -3.27577961 | -0.60127460 | 0.45276894 | h | 1.000 | 0 |
| -0.84457009 | -2.64865051 | 1.68497964 | h | 1.000 | 0 |

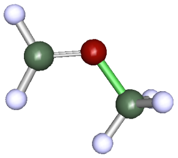
Formaldehyde (MCA* = 216.4 kJ/mol):



Total Energy = -114.42708201049 hartree
Enthalpy Correction = 0.030769 hartree
Entropy = 0.000083 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -0.02024812 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 2.25403608 | o | 8.000 | 0 |
| -1.77497720 | 0.00000000 | -1.11681804 | h | 1.000 | 0 |
| 1.77497720 | 0.00000000 | -1.11681804 | h | 1.000 | 0 |

Formaldehyde Product:

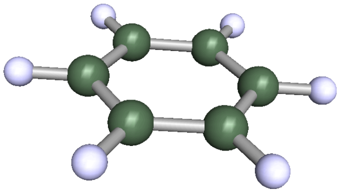


Total Energy = -154.09767278059 hartree
Enthalpy Correction = 0.074747 hartree

Entropy = 0.0001 hartree/K

```
                   atomic coordinates             atom    charge  isotop
    -2.36623646    0.64459709    0.00000000    c       6.000     0
    -0.15537381    1.37361171    0.00000000    o       8.000     0
    -3.80937727    2.10742681    0.00000000    h       1.000     0
    -2.82302610   -1.36477777    0.00000000    h       1.000     0
     1.93604948   -0.42376996    0.00000000    c       6.000     0
     3.01594479   -0.00013475    1.69378732    h       1.000     0
     1.18607457   -2.33681838    0.00000000    h       1.000     0
     3.01594479   -0.00013475   -1.69378732    h       1.000     0
```

Benzene (MCA* = 199.2 kJ/mol):

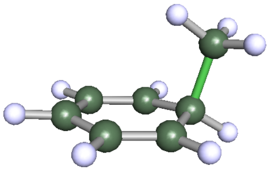


Total Energy = -232.05992848067 hartree
Enthalpy Correction = 0.106511 hartree
Entropy = 0.000102 hartree/K

```
                   atomic coordinates             atom    charge  isotop
    -2.27335799    1.31252385    0.00000000    c       6.000     0
    -2.27335799   -1.31252385    0.00000000    c       6.000     0
     0.00000000   -2.62504769    0.00000000    c       6.000     0
     2.27335799   -1.31252385    0.00000000    c       6.000     0
     2.27335799    1.31252385    0.00000000    c       6.000     0
     0.00000000    2.62504769    0.00000000    c       6.000     0
    -4.04810320    2.33717348    0.00000000    h       1.000     0
    -4.04810320   -2.33717348    0.00000000    h       1.000     0
     0.00000000   -4.67434695    0.00000000    h       1.000     0
     4.04810320   -2.33717348    0.00000000    h       1.000     0
     4.04810320    2.33717348    0.00000000    h       1.000     0
     0.00000000    4.67434695    0.00000000    h       1.000     0
```

Benzene Product:

The $CH_3$-CH-CH-CH Torsion Angles were constrained to 98° and 262°.

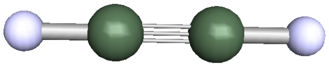


Total Energy = -271.72052183158 hartree
Enthalpy Correction = 0.148232 hartree

Entropy = 0.000123 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.61814161 | -0.90080023 | 2.18541990 | c | 6.000 | 0 |
| 1.26506294 | -0.07217481 | -0.38050843 | c | 6.000 | 0 |
| -0.48980627 | -2.13342981 | -0.88680022 | c | 6.000 | 0 |
| -2.97785505 | -1.95500336 | -0.24220878 | c | 6.000 | 0 |
| -3.89788542 | 0.34902675 | 0.67956169 | c | 6.000 | 0 |
| -2.38244918 | 2.50958413 | 0.88247391 | c | 6.000 | 0 |
| 0.10792360 | 2.34791128 | 0.24282568 | c | 6.000 | 0 |
| 3.56815717 | -2.69517317 | 1.85952545 | h | 1.000 | 0 |
| 1.22508470 | -1.09137249 | 3.68573813 | h | 1.000 | 0 |
| 4.00328838 | 0.53826111 | 2.67288825 | h | 1.000 | 0 |
| 2.78121780 | 0.07721859 | -1.77375607 | h | 1.000 | 0 |
| 0.28638946 | -3.89956069 | -1.57797690 | h | 1.000 | 0 |
| -4.24107914 | -3.54814593 | -0.45409579 | h | 1.000 | 0 |
| -5.86584641 | 0.47046433 | 1.23970501 | h | 1.000 | 0 |
| -3.19857265 | 4.27371494 | 1.51566484 | h | 1.000 | 0 |
| 1.33708630 | 3.97918002 | 0.40773858 | h | 1.000 | 0 |

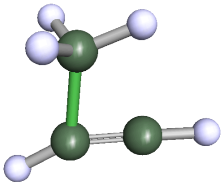
Ethyne (MCA* = 196.3 kJ/mol):



Total Energy = -77.26361121560 hartree
Enthalpy Correction = 0.031074 hartree
Entropy = 0.000076 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -1.13329062 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.13329062 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -3.15150770 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 3.15150770 | h | 1.000 | 0 |

Ethyne Product:

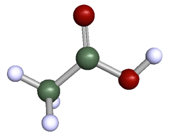


Total Energy = -116.92113891844 hartree
Enthalpy Correction = 0.071418 hartree
Entropy = 0.000099 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.95521420 | -0.94398277 | 0.00000000 | c | 6.000 | 0 |
| 1.32556841 | 1.30268886 | 0.00000000 | c | 6.000 | 0 |
| -1.41031761 | 0.02353034 | 0.00000000 | c | 6.000 | 0 |
| 2.55064368 | -2.88628512 | 0.00000000 | h | 1.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 1.65644934 | 3.30763151 | 0.00000000 | h | 1.000 | 0 |
| -2.28764350 | 0.63004932 | -1.75642588 | h | 1.000 | 0 |
| -1.50227101 | -2.06368147 | 0.00000000 | h | 1.000 | 0 |
| -2.28764350 | 0.63004932 | 1.75642588 | h | 1.000 | 0 |

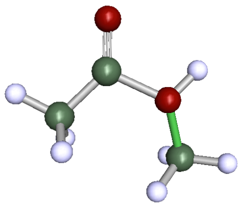
Acetic acid (OH attack) (MCA* = 156.9 kJ/mol):



Total Energy = -228.94712944124 hartree
Enthalpy Correction = 0.067638 hartree
Entropy = 0.000107 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 2.89103092 | -0.61753735 | -0.08931205 | o | 8.000 | 0 |
| 1.02677870 | 1.08368894 | -0.10339694 | c | 6.000 | 0 |
| -1.51691893 | -0.12309113 | 0.01111534 | c | 6.000 | 0 |
| 1.42783939 | 3.33047508 | -0.21136438 | o | 8.000 | 0 |
| 4.48941329 | 0.27325782 | -0.18456640 | h | 1.000 | 0 |
| -2.97450325 | 1.31568976 | 0.16353496 | h | 1.000 | 0 |
| -1.61257339 | -1.41314061 | 1.61686854 | h | 1.000 | 0 |
| -1.81335652 | -1.24082010 | -1.69891447 | h | 1.000 | 0 |

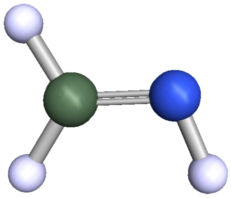
Acetic acid (OH attack) Product:



Total Energy = -268.59405416894 hartree
Enthalpy Correction = 0.109709 hartree
Entropy = 0.000121 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 3.00500639 | 0.52351718 | -0.80352185 | o | 8.000 | 0 |
| 1.17728029 | 0.96345025 | 0.36531216 | c | 6.000 | 0 |
| 0.54172179 | 2.83932783 | 2.30319456 | c | 6.000 | 0 |
| -0.95798186 | -0.76912633 | -0.14955623 | o | 8.000 | 0 |
| -3.63707680 | -0.25827130 | 0.37346092 | c | 6.000 | 0 |
| -1.00519738 | 4.03846056 | 1.64666109 | h | 1.000 | 0 |
| 2.21002474 | 3.98055234 | 2.66397141 | h | 1.000 | 0 |
| -0.06320404 | 1.88764083 | 4.03127897 | h | 1.000 | 0 |
| -0.63504443 | -1.78743391 | -1.65140785 | h | 1.000 | 0 |
| -4.22139043 | 1.36516005 | -0.73714733 | h | 1.000 | 0 |
| -3.79108553 | 0.05480349 | 2.39232941 | h | 1.000 | 0 |
| -4.62235973 | -1.96805304 | -0.18163581 | h | 1.000 | 0 |

Methanimine (pi bond) (MCA* = 144.2 kJ/mol):

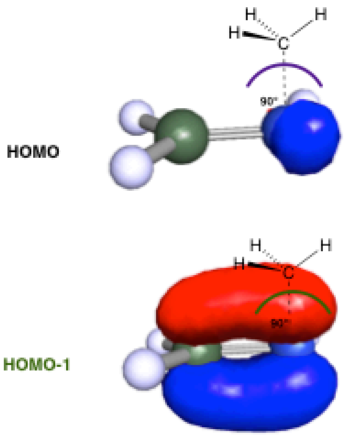


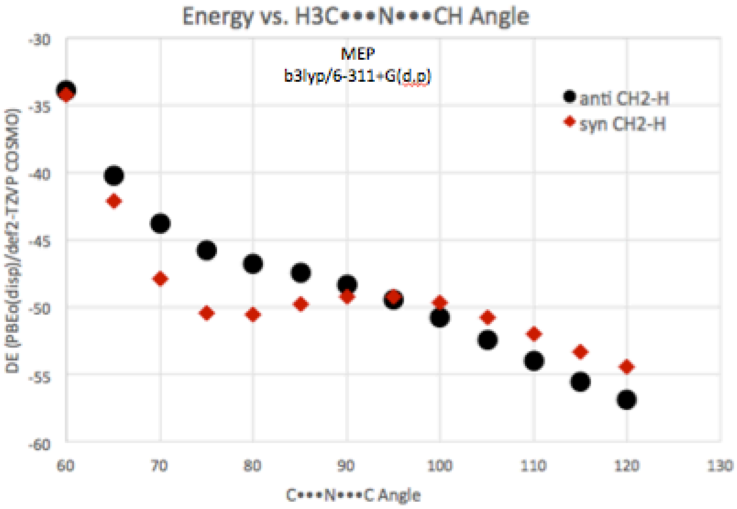
Total Energy = -94.56000459072 hartree
Enthalpy Correction = 0.044182 hartree
Entropy = 0.000087 hartree/K

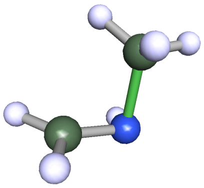
```
                  atomic coordinates                  atom    charge  isotop
   -0.74160284    -0.03176542     0.00000000       c       6.000     0
    1.32620659     1.16407073     0.00000000       n       7.000     0
   -0.88666961    -2.09347907     0.00000000       h       1.000     0
   -2.51507564     1.02102309     0.00000000       h       1.000     0
    2.81714149    -0.05984933     0.00000000       h       1.000     0
```

Methanimine (pi bond) Product:

The H-$CH_2$-N-C torsion angle was constrained to 180° (anti, black curve) to prevent backbonding (red curve) of the $H_2C$-H bond into $\pi^*_{NC}$. For the anti mode of addition there are increasing contributions from the lone pair (HOMO) when the $H_3C$-N-C attack angle is greater than 90°. The $H_3C$-N-C angle was constrained to 90° for nucleophilic addition of $\pi_{NC}$ (HOMO-1)





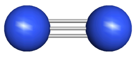


Total Energy = -134.20045968995 hartree

Enthalpy Correction = 0.083429 hartree
Entropy = 0.000097 hartree/K

```
                   atomic coordinates            atom    charge  isotop
    1.84653645    0.45873660    0.08465368      c      6.000     0
    0.09432546   -1.28850980   -0.19669776      n      7.000     0
   -2.02777596    0.81271730   -0.02961725      c      6.000     0
    2.56579415    1.03845658    1.92930934      h      1.000     0
    2.59990496    1.35412185   -1.60720019      h      1.000     0
   -0.14303642   -2.29735506    1.43010192      h      1.000     0
   -1.88039481    2.10623074   -1.62216259      h      1.000     0
   -3.72779267   -0.32982168   -0.23673703      h      1.000     0
   -1.99765358    1.78067577    1.78214388      h      1.000     0
```

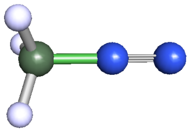
Nitrogen Gas (MCA* = 141.5 kJ/mol):



Total Energy = -109.44739913466 hartree
Enthalpy Correction = 0.003305 hartree
Entropy = 0.000077 hartree/K

```
                   atomic coordinates            atom    charge  isotop
    1.02891756    0.00000000    0.00000000      n      7.000     0
   -1.02891756    0.00000000    0.00000000      n      7.000     0
```

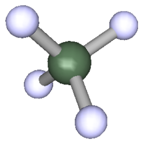
Nitrogen Gas Product:



Total Energy = -149.08385934175 hartree
Enthalpy Correction = 0.042259 hartree
Entropy = 0.000096 hartree/K

```
                   atomic coordinates            atom    charge  isotop
    3.78484175   -0.02606047   -0.08399346      n      7.000     0
    1.73254522   -0.01199227   -0.03880229      n      7.000     0
   -0.94297624    0.00653126    0.02104965      c      6.000     0
   -1.56641641   -1.34595109   -1.40296108      h      1.000     0
   -1.48625854   -0.55619130    1.92724279      h      1.000     0
   -1.52173577    1.93366388   -0.42253561      h      1.000     0
```

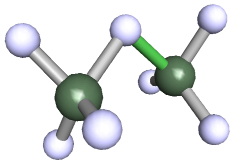
Methane (C-H) (MCA* = 109.9 kJ/mol):



Total Energy = -40.47590085673 hartree
Enthalpy Correction = 0.048492 hartree
Entropy = 0.000071 hartree/K

```
                 atomic coordinates              atom    charge  isotop
   0.00000000    0.00000000    0.00000000     c       6.000     0
   1.18953632   -1.18953632    1.18953632     h       1.000     0
  -1.18953632    1.18953632    1.18953632     h       1.000     0
  -1.18953632   -1.18953632   -1.18953632     h       1.000     0
   1.18953632    1.18953632   -1.18953632     h       1.000     0
```

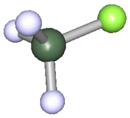
Methane (C-H) Product:



Total Energy = -80.09938754097 hartree
Enthalpy Correction = 0.088906 hartree
Entropy = 0.000098 hartree/K

```
                 atomic coordinates              atom    charge  isotop
  -2.56728011   -3.06940324    0.04350838     c       6.000     0
  -0.75234859   -1.62357899    0.31669696     h       1.000     0
  -1.86569251   -4.93313483   -0.41390090     h       1.000     0
  -4.36734532   -2.56578191   -0.78146590     h       1.000     0
  -2.66220673   -2.76072082    2.09280287     h       1.000     0
  -0.76404380   -0.94560057   -1.91741470     c       6.000     0
  -0.69970423   -2.20863113   -3.52211273     h       1.000     0
   1.17738985   -0.43526848   -1.39128931     h       1.000     0
  -1.95172797    0.70383747   -2.12317144     h       1.000     0
```

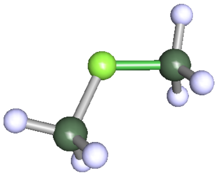
Fluoromethane (MCA* = 92.5 kJ/mol):



Total Energy = -139.65950807059 hartree
Enthalpy Correction = 0.043239 hartree
Entropy = 0.000085 hartree/K

```
                 atomic coordinates              atom    charge  isotop
   0.00000000    0.00000000   -0.13246875     c       6.000     0
   0.00000000    0.00000000    2.49808070     f       9.000     0
   0.97686084   -1.69197261   -0.78830062     h       1.000     0
   0.97686084    1.69197261   -0.78830062     h       1.000     0
  -1.95372169    0.00000000   -0.78830062     h       1.000     0
```

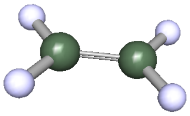
Fluoromethane Product:



Total Energy = -179.28098740789 hartree
Enthalpy Correction = 0.085603 hartree
Entropy = 0.000103 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | -2.42320560 | -0.00703970 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.47096891 | f | 9.000 | 0 |
| 1.72765499 | -2.35996552 | -1.10682394 | h | 1.000 | 0 |
| 0.00000000 | -3.82133513 | 1.48791014 | h | 1.000 | 0 |
| -1.72765499 | -2.35996552 | -1.10682394 | h | 1.000 | 0 |
| 0.00000000 | 2.42320560 | -0.00703970 | c | 6.000 | 0 |
| 0.00000000 | 3.82133513 | 1.48791014 | h | 1.000 | 0 |
| -1.72765499 | 2.35996552 | -1.10682394 | h | 1.000 | 0 |
| 1.72765499 | 2.35996552 | -1.10682394 | h | 1.000 | 0 |

Ethene (C-H) (MCA* = 78.2 kJ/mol):

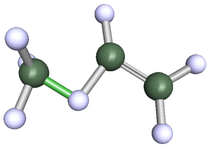


Total Energy = -78.51691383717 hartree
Enthalpy Correction = 0.055139 hartree
Entropy = 0.000083 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.25196806 | 0.00000000 | 0.00000000 | c | 6.000 | 0 |
| 1.25196806 | 0.00000000 | 0.00000000 | c | 6.000 | 0 |
| -2.32724003 | -1.74679821 | 0.00000000 | h | 1.000 | 0 |
| -2.32724003 | 1.74679821 | 0.00000000 | h | 1.000 | 0 |
| 2.32724003 | -1.74679821 | 0.00000000 | h | 1.000 | 0 |
| 2.32724003 | 1.74679821 | 0.00000000 | h | 1.000 | 0 |

Ethene (C-H) Product:

The $CH_3$-H-C-C Torsion Angle was constrained to 180°.

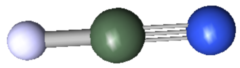


Total Energy = -118.12830310565 hartree
Enthalpy Correction = 0.093455 hartree

Entropy = 0.000103 hartree/K

```
                   atomic coordinates                  atom    charge  isotop
     -0.59355498    -0.49576853     0.07345544      c      6.000      0
     -2.19975291    -2.38112427     0.26890314      c      6.000      0
     -2.31363628     1.09544754    -0.49709438      h      1.000      0
      1.42310823    -0.49564374     0.33898344      h      1.000      0
     -4.21781873    -2.21857537    -0.03198345      h      1.000      0
     -1.43475859    -4.21677335     0.76587355      h      1.000      0
     -0.87655235     2.80469642    -0.67759561      c      6.000      0
     -0.11210582     3.55951639     1.06259588      h      1.000      0
      0.33643875     2.82652945    -2.32394895      h      1.000      0
     -2.69024893     3.73484460    -1.11936985      h      1.000      0
```

Hydrogen Cyanide (pi) (MCA* = 74.5 kJ/mol):

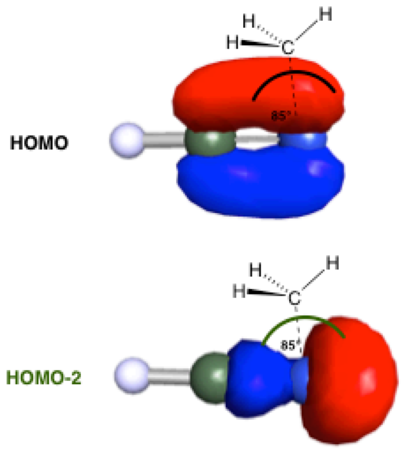


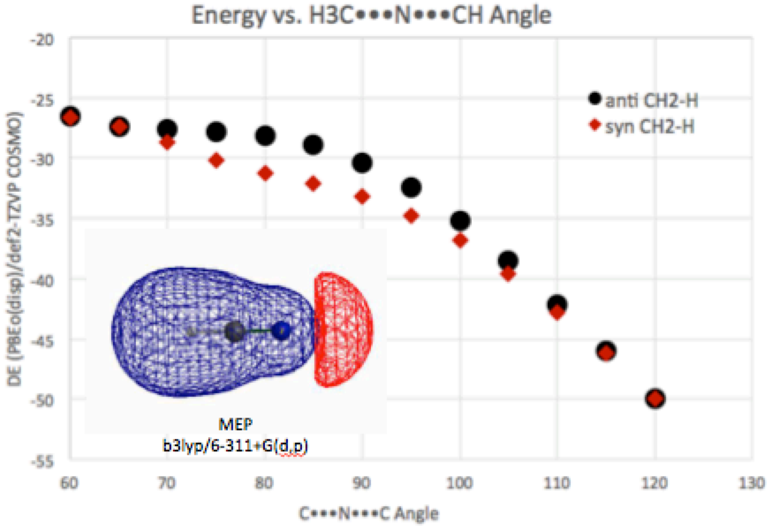
Total Energy = -93.35645307915 hartree
Enthalpy Correction = 0.020142 hartree
Entropy = 0.000077 hartree/K

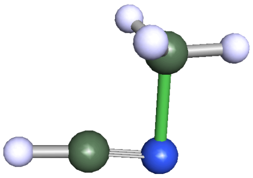
```
                   atomic coordinates                  atom    charge  isotop
      0.00000000     0.00000000     2.11950366      n      7.000      0
      0.00000000     0.00000000    -0.04533030      c      6.000      0
      0.00000000     0.00000000    -2.07417336      h      1.000      0
```

Hydrogen Cyanide (pi) Product:

The H-$CH_2$-N-C torsion angle was constrained to 180° (anti, black curve) to prevent backbonding (red curve) of the $H_2C$-H bond into $\pi^*_{NC}$. For the anti mode of addition, there are increasing contributions from both the lone pair (HOMO-2) and Coulombic effects beyond a $H_3C$-N-C angle of 85°. The C-N-C bond angle was constrained to 85°.



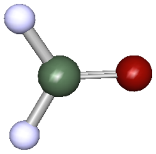




Total Energy = -132.96604309925 hartree
Enthalpy Correction = 0.057742 hartree
Entropy = 0.000096 hartree/K

```
                   atomic coordinates              atom    charge  isotop
  -0.54215590   -0.00025859   -1.80130616    c       6.000     0
   1.32223077   -0.00006707   -0.62960189    n       7.000     0
  -0.64068252   -0.00002063    1.96132150    c       6.000     0
  -2.20444126    0.00041573   -3.00013275    h       1.000     0
   0.90068532    0.00016226    3.31615298    h       1.000     0
  -1.71588203   -1.74307211    1.99524650    h       1.000     0
  -1.71615021    1.74283770    1.99496660    h       1.000     0
```

Formaldehyde (pi) (MCA* = 68.7 kJ/mol):

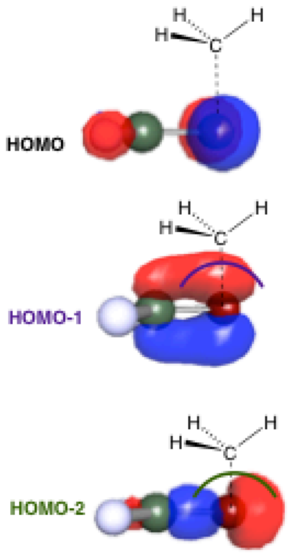


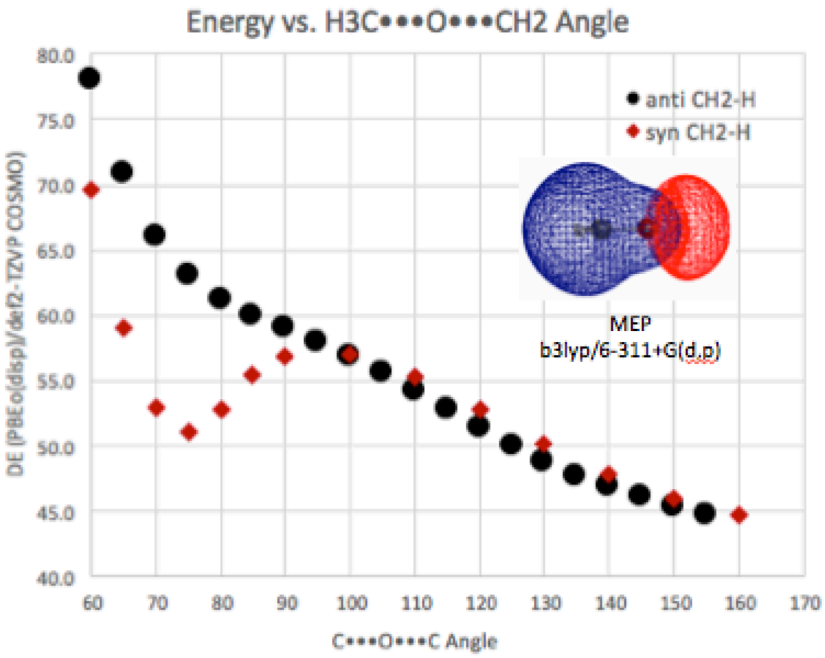
Total Energy = -114.42708201049 hartree
Enthalpy Correction = 0.030769 hartree
Entropy = 0.000083 hartree/K

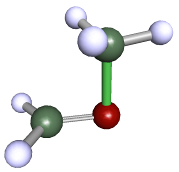
```
                   atomic coordinates              atom    charge  isotop
   0.00000000    0.00000000   -0.02024812    c       6.000     0
   0.00000000    0.00000000    2.25403608    o       8.000     0
  -1.77497720    0.00000000   -1.11681804    h       1.000     0
   1.77497720    0.00000000   -1.11681804    h       1.000     0
```

Formaldehyde (pi) Product:

The H-CH$_2$-O-C torsion angle was constrained to 180° (anti, black curve) to prevent backbonding (red curve) of the H$_2$C-H bond into $\pi^*_{OC}$. For the anti mode of addition, there are increasing contributions from both the lone pair (HOMO-2) and Coulombic effects beyond a H$_3$C-O-C angle of 90°. The C-O-C bond angle was constrained to 90°. We predict no net contribution from the HOMO, which is orthogonal to H$_3$C+.



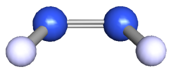




Total Energy = -154.03681576924 hartree
Enthalpy Correction = 0.068657 hartree
Entropy = 0.000095 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 1.49226406 | 0.21818450 | -0.47851382 | c | 6.000 | 0 |
| 0.66663995 | 0.03233532 | 1.76423685 | o | 8.000 | 0 |
| -2.07290791 | -0.26566314 | 0.73103334 | c | 6.000 | 0 |
| 1.62762606 | 2.07920746 | -1.37418557 | h | 1.000 | 0 |
| 2.06565078 | -1.48330351 | -1.50810619 | h | 1.000 | 0 |
| -3.06666453 | -0.45517754 | 2.52141765 | h | 1.000 | 0 |
| -2.19821792 | -1.98823560 | -0.38674755 | h | 1.000 | 0 |
| -2.62170628 | 1.45392034 | -0.25648762 | h | 1.000 | 0 |

Diazene (pi) (MCA* = 74.1 kJ/mol):

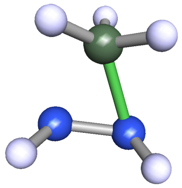


Total Energy = -110.56395684706 hartree
Enthalpy Correction = 0.032422 hartree
Entropy = 0.000083 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.16242628 | 0.00000000 | -0.90238875 | n | 7.000 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 1.16242628 | 0.00000000 | -0.90238875 | n | 7.000 | 0 |
| -1.90871059 | 0.00000000 | 0.90219218 | h | 1.000 | 0 |
| 1.90871059 | 0.00000000 | 0.90219218 | h | 1.000 | 0 |

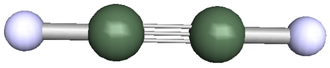
Diazene (pi) Product:



Total Energy = -150.17555330380 hartree
Enthalpy Correction = 0.071913 hartree
Entropy = 0.000101 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.49664070 | -0.98553226 | 0.77545628 | c | 6.000 | 0 |
| 0.52252101 | 0.92330076 | -0.57264649 | n | 7.000 | 0 |
| 1.46104855 | -1.29955776 | -0.06340602 | n | 7.000 | 0 |
| -2.23758326 | 0.68025374 | 1.81406239 | h | 1.000 | 0 |
| -2.70181637 | -1.81793552 | -0.63825263 | h | 1.000 | 0 |
| -1.04267030 | -2.15091555 | 2.46069311 | h | 1.000 | 0 |
| 1.11470028 | 2.29915011 | 0.67422727 | h | 1.000 | 0 |
| 2.63013154 | -1.28917730 | 1.49638426 | h | 1.000 | 0 |

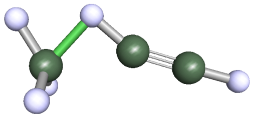
Ethyne (C-H sigma) (MCA* = 38.6 kJ/mol):



Total Energy = -77.26361121560 hartree
Enthalpy Correction = 0.031074 hartree
Entropy = 0.000076 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| 0.00000000 | 0.00000000 | -1.13329062 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | 1.13329062 | c | 6.000 | 0 |
| 0.00000000 | 0.00000000 | -3.15150770 | h | 1.000 | 0 |
| 0.00000000 | 0.00000000 | 3.15150770 | h | 1.000 | 0 |

Ethyne (C-H sigma) product

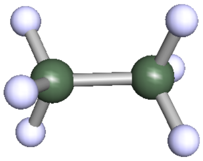


The $CH_3$-H-C Bond Angle was constrained to 92°.

Total Energy = -116.85705563013 hartree
Enthalpy Correction = 0.067692 hartree
Entropy = 0.0001 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -3.62420001 | 4.60634370 | -0.67979379 | c | 6.000 | 0 |
| -4.38685292 | 2.47159202 | -0.79515822 | c | 6.000 | 0 |
| -2.90562083 | 6.49740491 | -0.56765442 | h | 1.000 | 0 |
| -4.24622842 | 0.40397503 | -0.70584796 | h | 1.000 | 0 |
| -6.75766499 | 0.11784571 | -1.27519619 | c | 6.000 | 0 |
| -8.04927155 | 0.66328720 | 0.22017186 | h | 1.000 | 0 |
| -6.00398356 | -1.79471180 | -1.04564072 | h | 1.000 | 0 |
| -7.25797702 | 0.56331761 | -3.21251312 | h | 1.000 | 0 |

Ethane (C-C sigma) (MCA* = 20.1 kJ/mol):

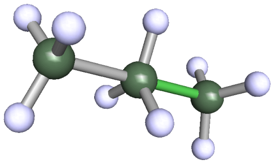


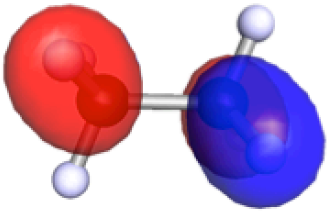
Total Energy = -79.75380002333 hartree
Enthalpy Correction = 0.078264 hartree
Entropy = 0.00009 hartree/K

| atomic coordinates | | | atom | charge | isotop |
|---|---|---|---|---|---|
| -1.43527362 | 0.02028181 | -0.03067898 | c | 6.000 | 0 |
| 1.43526354 | -0.02029273 | 0.03066817 | c | 6.000 | 0 |
| -2.23002227 | -0.18340800 | 1.86492451 | h | 1.000 | 0 |
| -2.14473570 | 1.79375978 | -0.81633950 | h | 1.000 | 0 |
| -2.18338182 | -1.51785119 | -1.18854365 | h | 1.000 | 0 |
| 2.18331691 | 1.51748698 | 1.18903065 | h | 1.000 | 0 |
| 2.23007046 | 0.18401880 | -1.86484407 | h | 1.000 | 0 |
| 2.14476250 | -1.79399544 | 0.81578286 | h | 1.000 | 0 |

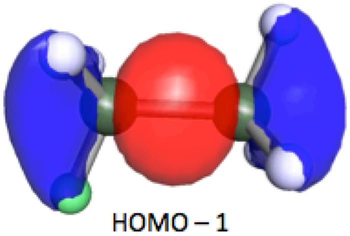
Ethane (C-C sigma) Product:

$H_3C^+$ will have optimal overlap with the CC sigma bond of ethane by adding at a 180° orientation. There are other higher energy orbitals that will also have some interaction. This means the energy will be a higher bound of a CC sigma bond. The C-C-C bond angle was constrained to 180 °.

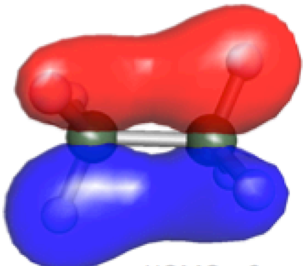




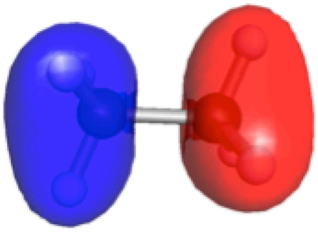
HOMO



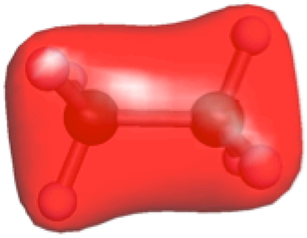
HOMO – 1



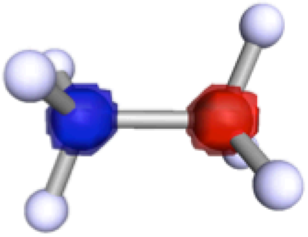
HOMO – 2



HOMO – 3



HOMO – 4



HOMO – 5

Total Energy = -119.34766955001 hartree
Enthalpy Correction = 0.116699 hartree
Entropy = 0.000095 hartree/K

```
                 atomic coordinates                atom    charge  isotop
     2.63686438   -0.26497276    0.88199025     c      6.000     0
     0.04522625    0.26241684   -0.90814658     c      6.000     0
    -2.54641189    0.78980660   -2.69828331     c      6.000     0
     3.67608943    1.49962525    0.88975506     h      1.000     0
     1.93609766   -0.78655945    2.73420038     h      1.000     0
     3.65115107   -1.78395227   -0.04406817     h      1.000     0
    -0.54379611    1.75756848    0.38464295     h      1.000     0
     1.25109123    0.70888912   -2.52073863     h      1.000     0
    -0.57046729   -1.67970817   -0.58797737     h      1.000     0
    -4.14899370    0.45799447   -1.46727881     h      1.000     0
    -2.43624896   -0.54990603   -4.24360935     h      1.000     0
    -2.40647964    2.73627362   -3.31956439     h      1.000     0
```