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Lifetime of the $2s2p^3 3s\ ^6S$ Metastable Autoionizing State of Nitrogen*

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September 1973

ABSTRACT

The lifetime of the $2s2p^3 3s\ ^6S$ metastable autoionizing state of nitrogen has been measured using the time-of-flight technique. The velocity distribution of metastable atoms resulting from the dissociation of excited nitrogen molecules is sampled and detected at two positions, 0.68 and 1.83 m from the pulsed electron gun used to bombard the ground state molecules effusing from a source slit. A comparison of the number of metastables within specific velocity intervals at the two detectors determines the number which decay in flight and yields an experimental plot of the number which decay vs time of flight.The lifetime τ is then obtained from the slope ($= -1/\tau$) of a straight line least-squares fitted to the decay plot. The result is 87 ± 10 μsec.

The same time-of-flight technique previously employed to measure the lifetime of the 2 $^1S_0$ metastable state[1] of He has been used to investigate the lifetime of the $2s2p^3 3s$ ^6S metastable autoionizing state of nitrogen. The 3s ^6S state, with a predicted energy[2] of about 17 eV, is in the first ionization continuum and is metastable against both radiative decay and autoionization. Two other nitrogen metastable states, the ^2D at 2.4 and the ^2P at 3.6 eV, both have an excitation energy less than the work function of our Auger detector and are therefore not observed in this experiment.

A complete description of our apparatus, data-collection scheme, data analysis, and time-of-flight theory has been described previously.[1] The experiment is based on the time-of-flight technique where an atom or molecule is assumed to leave the metastable state only by decay as it drifts over a 1.15-m path between two fixed detectors. Neutral, ground-state nitrogen molecules effuse from a source slit and are immediately excited by a pulse of magnetically focused electrons. The metastable N(^6S) atoms resulting from the dissociation[3] of the excited N_2 molecules are then collimated while passing through three buffer chambers and finally detected at both ends of the 1.15-m drift region. The first detector consists of a 60% transmitting Ta mesh target. The secondary electrons which are Auger-ejected from the Ta surface by the metastable atoms are collected by a electron multiplier. The second detector is a solid Ta target and intercepts the transmitted metastable atoms which survive the flight between the two detectors.

The data-taking and timing aspects of the experiment are controlled by an on-line computer. An example of the data collected is shown in Fig. 1, and represents about 10^7 separate collection sweeps during a total collection time of 24 h. The electron gun is pulsed on only during channel 0 and counts are then collected simultaneously at both detectors into 199 channels, not all of which are shown. Previously,[1] the minimum dwell time per channel was 8.25 μsec. However, the addition of two, 256-bit static shift registers as intermediate data storage buffers now allows the acquisition of time-of-flight distributions with a minimum time per channel of 0.5 μsec. For the present experiment, all channel widths are equal to 2.0 μsec. The amount of background subtraction is obtained from the tail of the time-of-flight distributions.

The following two expressions represent the number of metastable atoms counted by detectors 1 and 2:

$$n_1(v) = \int_{\text{surface}} \varepsilon_1 \, n_0(v) \, dS_1$$

$$n_2(v) = \int_{\text{surface}} \varepsilon_2 \, n_0(v) \, e^{-t/\tau} \, dS_2$$

where ε is a detector efficiency factor. The initial velocity distribution $n_0(v)$ of the $N(^6S)$ metastable atoms is determined by the dissociation [3] of the excited N_2 molecules. The exponential factor in the expression for the number of counts at detector 2 allows for decay of the metastable beam between the two detectors.

After assuring that n_0 is uniform across the beam, the time and velocity dependence can be extracted from the integrals. Then, taking a ratio of detector-2 counts to detector-1 counts for atoms of the same velocity, we obtain

$$R(t) = \frac{n_2(v)}{n_1(v)} = C\ e^{-t/\tau}$$

where t is the time of flight between detectors and C is a constant independent of the initial velocity distribution. The natural logarithm of this ratio gives the equation of a straight line; a straight line is least-squares fitted to the data and the lifetime τ determined from the slope ($= -1/\tau$).

The initial step in the data analysis involves partitioning the detector-2 data to correspond to the channel width at detector 1 for metastable atoms with the same velocity. The correct partitioning of the data, followed by calculation of the ratio R for metastable atoms of the same velocity, then leads to a plot of ln(R) vs time of flight, as shown in Fig. 2. The first several points are omitted from the least-squares fit because these points are influenced by the tail of the fast peak shown in Fig. 1(b).

The result for the lifetime of the $2s2p^3 3s\ ^6S$ metastable state of nitrogen is $\tau = 87 \pm 10$ μsec. The error results from an uncertainity in the amount of background subtraction at detector 2. Other experimental parameters such as electron gun voltage (80 - 130 V), beam flow rate, and drift region pressure have no effect on the measured lifetime. This result agrees well with an earlier, less accurate, experiment.[3]

References

* Work supported by the U.S. Atomic Energy Commission.

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Figure Captions

Fig. 1. N(^{6}S) time-of-flight distributions, representing about 10^7 separate data-collection sweeps. The tail of a large peak appearing in the first few channels of the distributions represents neutral atoms or molecules with kinetic energies greater than 20 eV: they result from the acceleration of either N^+ or N_2^+ ions in the electron gun followed by charge exchange in the source chamber region.

Fig. 2. Decay plot. The ratio of detector-2 to detector-1 metastable atom time-of-flight distributions is a straight line on a logarithmic plot. The measured lifetime τ is obtained from the slope ($= -1/\tau$) of the least-squares-fitted straight line.

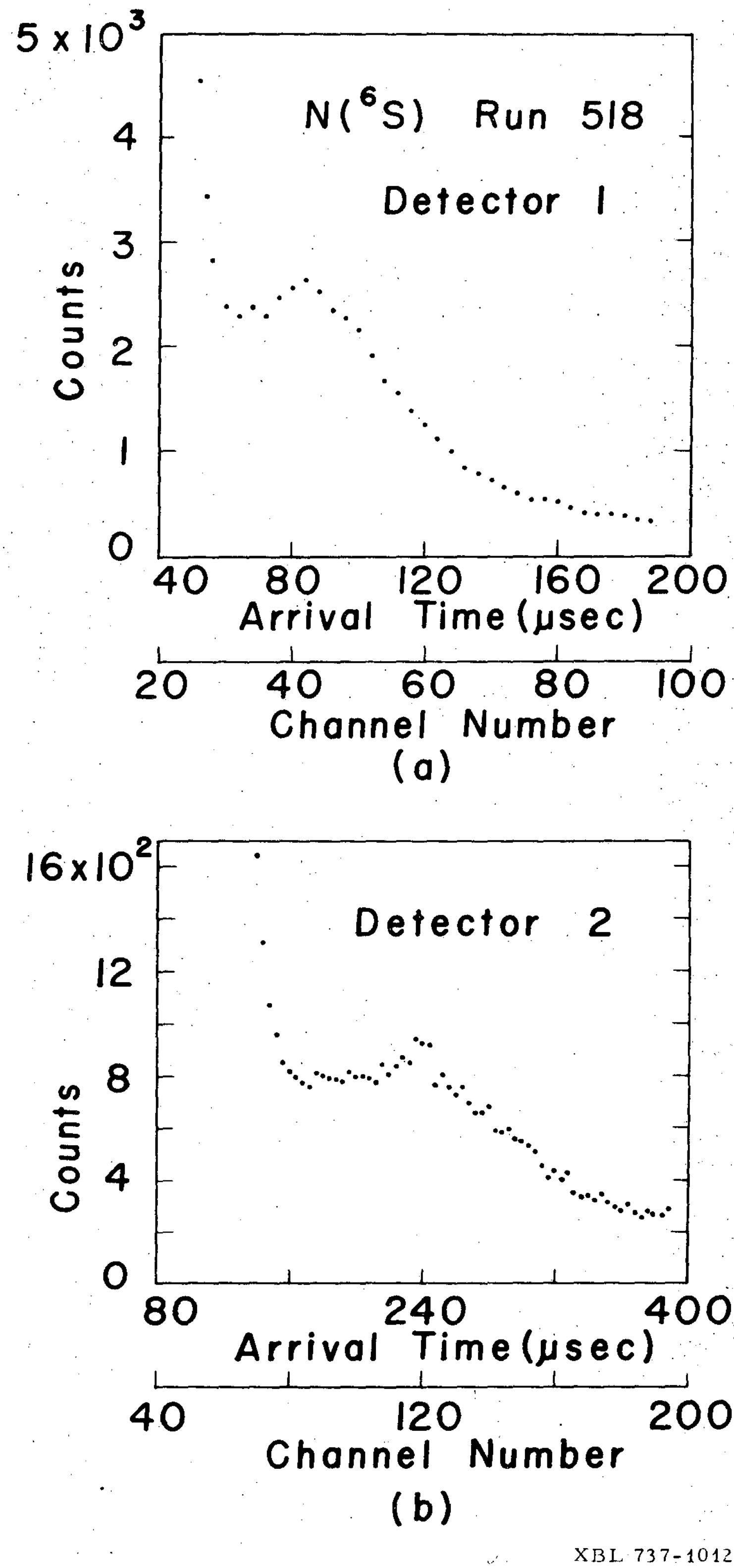
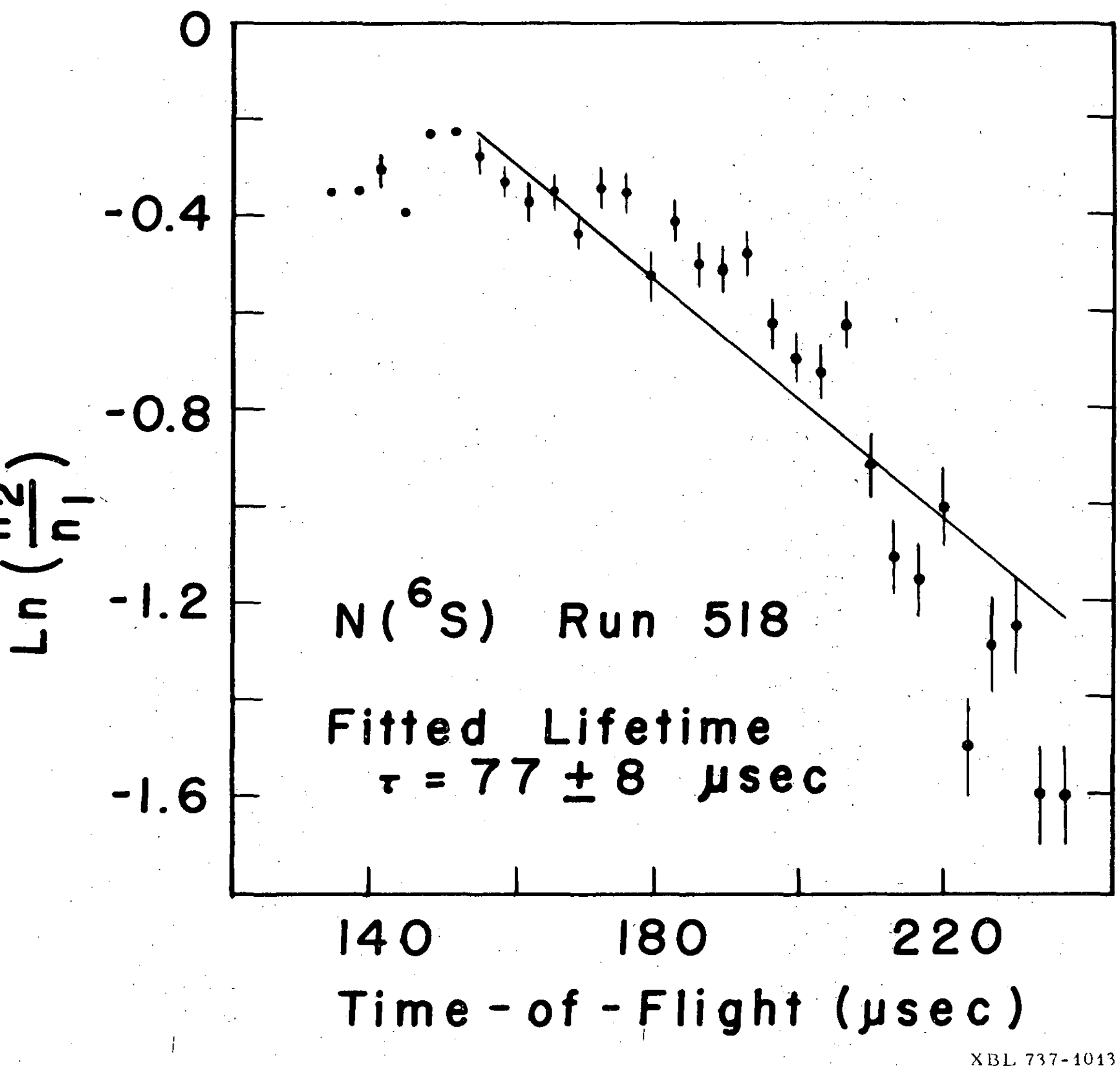

5 x 10^3
4
3
2
1
0
Counts
N(⁶S) Run 518
Detector 1
40
80
120
160
200
Arrival Time (μsec)
20
40
60
80
100
Channel Number
(a)
16x10^2
12
8
4
0
Counts
Detector 2
80
240
400
Arrival Time (μsec)
40
120
200
Channel Number
(b)
XBL 737-1012

Fig. 1



0
-0.4
-0.8
-1.2
-1.6
Ln (n2/n1)
N(6S) Run 518
Fitted Lifetime
τ = 77 ± 8 μsec
140
180
220
Time - of - Flight (μsec)
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Fig. 2

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