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The Journey from Classical to Quantum Thinking: An Analysis of Student Understanding Through the Lens of Atomic Spectra

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By

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Committee in charge:

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Abstract

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This dissertation aims to explore how students think about atomic absorption and emission of light in the area of introductory quantum chemistry. In particular, the impact of classical ideas of electron position and energy on student understanding of spectra is studied. The analysis was undertaken to discover how student learning can be characterized along different dimensions of competence, and to determine the strength of the correlations between these dimensions.

The research in this dissertation study comes from a set of semi-structured clinical interviews after a unit on quantum chemistry using a stratified random sample. Open-ended questions were asked on the topic of atomic spectra to a representative sample (N=65) of students from a large introductory chemistry class. Data was examined using elements of grounded theory. Three dimensions were found, Continuous to Discrete, Interpreting Spectra, and Energy/Force, that explain how student thinking about atomic spectra can be characterized. A fourth dimension, Deterministic to Probabilistic, had been discussed in the research before.

Students who exhibited a mastery of discrete energy absorption predominantly were skilled with a difference reasoning, an understanding that the energy values of the spectral lines correlate to differences of energy levels. Students who successfully interpreted spectra did not necessarily have a probabilistic view of electron position, signaling that those two concepts, as least as they were assessed, do not strongly impact each other.

Using grounded methods on ten student interviews, four main types of representation use and conceptual understanding in the topic of atomic spectra were discovered: Literal Reasoning, Threshold Reasoning, Exact Difference Reasoning, and Meta-Reasoning.

Threshold reasoning was indicative of an influence of classical ideas of energy absorption, while Exact-Difference reasoning consisted of a full appreciation of the all or nothing discrete absorption process. Advanced students recognized the stark difference of the quantum behavior from their classical understandings. While some classical ideas, such as threshold reasoning, hindered students from fully understanding the quantum nature of bound electrons, other more productive classical ideas, such as energy conservation, Coulombic attraction of the electron to the nucleus, and the spatial model of the atom, strengthened student understanding.

In an exploratory study, data was analyzed from two students who initially struggled with interpreting spectra. Their interaction with a representation designed to scaffold their understanding of spectra was studied, and their successes and obstacles were explored. One student transitioned from a literal type of thinking to an exact difference type of thinking through interaction with the representation. The second student remained holding onto a threshold type of thinking, despite the representation, signaling possible limitations of such curricular tools.

This dissertation highlights the deeply rooted and persistent nature of students' classical ideas as they learn about quantum concepts. Understanding the impact of classical ideas on the learning of atomic energy absorption will help instructors better understand the issues students face and will assist in developing better curriculum to address and challenge students' classical notions.

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Chapter 1: Introduction

1.1 Quantum Chemistry and Atomic Spectra

From grade school through college science, learners are exposed to instruction that continuously pushes their understanding of the nature of matter. In elementary and middle school, students are introduced to the particulate nature of matter, and learn about atoms and molecules. This understanding is extended in high school with the inclusion of subatomic particles: electrons, protons and neutrons. In college, this is pushed even further with the quantum model of the atom and the notion that matter has a wave-like nature and energy states of atoms are discrete or quantized rather than continuous.

This last step is a significantly challenging one, and strong student-held classical ideas are pushed and tested. Often students fail to comprehend the significance of quantum theory. Niels Bohr once stated, "Anyone who is not shocked by quantum theory has not understood it." Though work has been done, this last transition is not extensively researched – how are students making sense of the new quantum ideas and reconciling them with the classical ones they hold?

The problem of failing to grasp quantum mechanical ideas is compounded by the fact that quantum concepts are hard to visualize through macroscopic analogies. Chemists use atomic spectra as one way to justify to students the existence of discrete energy levels. It affords clear, relatively easy to produce data on the discrete absorption and emission of light that shows the remarkableness of quantum theory, and is a staple of introductory chemistry labs.

Spectra offer visual evidence of quantum mechanics, and offer a pathway to the "Big Idea" of quantum chemistry, the existence of discrete energy levels. In addition, students find the colors in the spectra engaging and interesting, and it offers a rich and exciting classroom context to teach quantum principles. Spectra provide easily attainable experimental evidence of the quantum model, and thus are a part of almost all introductory general chemistry instruction. Spectroscopy is important in identifying and characterizing molecules and materials, and quantum ideas are a way to understand spectra.

To date, little research has been done to explore what meaning students are making of atomic spectra, and the types of ways they understand them. In particular, how is the student transition from a classical way of thinking to a quantum way of thinking manifest through students' interpretation of atomic spectra? What classical concepts might be hindering their understanding? Alternatively, what classical concepts may be productive or useful footholds to assist them? Answers to these questions provide valuable insight that can be capitalized upon to design better curriculum and instruction in quantum chemistry.

1.2 Literature Review on Student Quantum Understanding

Prior research on quantum chemistry has centered on student conceptions of the atom and electron position. Researchers have found that students are strongly influenced by classical ideas of matter when describing electrons.

Leading up to instruction in quantum chemistry, learners have not been exposed to ideas that significantly challenge their classical outlook on the world. Objects have definite size, trajectory, and kinetic energy and can acquire any continuous value of these attributes. The introduction of waves and wave behavior is sometimes included in instruction at the secondary level, but is not a prerequisite before entering college chemistry. As a result, when presented with the quantum model, the classical ideas of position and energy are the dominant ones in students' minds, and shape their view on the nature of the world.

1.2.1 The Strength of Classical Thinking

Research has found that students often cling to thinking classically about atomic systems (Asikainena, 2009; Budde, 2002; Cervellati, 1981; Ke, 2005; Mannila, 2002; Mashhadi, 1999; Papaphotis, 2008; Petri, 1998; Taber, 2002), and envision the electron moving in a distinct trajectory or orbit. Students in many of these studies (Ke, 2005; McKagan, 2008; Nakiboglu, 2003; Olsen, 2002; Petri, 1998; Tsaparlis, 2009) show a reluctance to abandon a solar system model of electrons orbiting the nucleus in an atom, and show a great commitment to the Bohr model of the atom with electrons moving in distinct rings around the nucleus with fixed radii. Students frequently develop a "hybrid" model incorporating elements from both a solar system type model and a probabilistic model in their learning (Mannila, 2002; Olsen, 2002; Papaphotis, 2008; Petri, 1998; Taber, 2002).

Students have great difficulty with the probabilistic interpretation of electrons in atoms (Bao, 2002; Mannila, 2002; Papaphotis, 2008). Bao (2002) remarks, "In quantum mechanics, students have to use and interpret probabilistic representations that are very different from the deterministic ones they have become accustomed to thinking." Students also often struggle with the ideas of wave-particle duality (Ireson, 2001; Johnston, 1998; Mashhadi, 1999; Olsen, 2002), again clinging to more classical or particle-like views.

Mashhadi and Woolnough (1999) found that students in secondary school physics overwhelmingly visualize the electron in the atoms as some sort of particle when probed for their ideas by a written questionnaire. The dominant view in students' minds was a “particle-like” perspective, with only 2% of the sample (N=83) remarking that the electron has wave-properties. Likewise, Petri and Niedderer (1998) discuss an in-depth case study of an 18-year old physics student’s conception of the atom. Through observations and interviews, it was found that “Carl” held deeply to a planetary model of the atom with the electron moving in an orbit around the nucleus and “in many new contexts it is the first to be used.” During the course of the 16-week Physics class, “Carl” was introduced to new quantum models such as the electron-cloud model and partially integrated this into his strongly held planetary model conception, eventually expressing several distinct models at the same time.

Taber (2002) in a small-scale interview study (N=15) of UK college students found that students clung to more familiar ideas of electron shells and planetary-like orbits when presented with the ideas of probability distribution in orbitals. Learners often confused the idea of atomic orbitals with the diagrams that reflect the “envelope” or boundary of the orbital. As Taber (2002) remarks, “An electron occupying an orbital will always be ‘in’ that orbital, but will only be ‘probably found’ within the area represented by diagrams of orbitals. This is an inevitable consequence of drawing a meaningful representation of a technically infinite orbital!” Students do not fully comprehend the wave-character of the electron and the probabilistic nature of the orbital depiction, relying instead on classical notions of position.

In a study by Ireson (2002), responses were analyzed from a 40-item questionnaire given to a sample across six institutions (N=342) and it was found that students often exhibited conflicts between classical and quantum thinking. Again, evidence of a strong deterministic or classical viewpoint was observed in these student responses. Nakiboglu (2003) found that the planetary model was commonly used in a group of Turkish chemistry undergraduates who were studying to be prospective teachers. Responses were gathered using written short answer and multiple-choice questions.

Mannila, Koponen, and Niskanen (2002) specifically investigated student understanding of wave-particle duality. Undergraduates (N=29) who were physics majors or studying to be physics teachers were asked to provide written answers to eight open-ended questions on a problem about an interference pattern. Responses were categorized into four cases, from a trajectory-based description where classical particles follow certain trajectories - “the wavefunction is considered to be a guiding wave or ‘ghost-wave’ governing the trajectory of the particle”, to a quasi-classical description - “Quantum entities are seen as objects simultaneously having properties of classical particles and waves”, to a statistical or quasi-quantum description where quantum objects are seen as being non-localized or extended. It became evident that both classical ways of thinking and trajectory-like descriptions are dominant in student responses, and probability and indeterminacy were integrated into a trajectory description, again signaling the strength and deep-rootedness of classical ideas.

Confirming past results, Papaphotis and Tsaparlis (2008) found that students relied heavily on classical ideas, and confused “orbital” with the word “orbit, thought of orbitals as a bounded fixed space, and strongly preferred the planetary or Bohr model of atoms. The authors remark, “these preliminary models are very stable and difficult to replace with more advanced quantum mechanical models.” It was found that there was an overlapping of classical and quantum frameworks in students’ minds, along with low understanding of quantum concepts. A subset of these students (N=23) was then subsequently sampled in a semi-structured interview study done individually or in groups (Tsaparlis & Papaphotis, 2009). Students held dominantly on to the planetary Bohr model in their minds, and some constructed a hybrid model with the inclusion of a small electron cloud that also moves in specific orbits. Students found it difficult to comprehend the probabilistic nature of electron position. In both of these studies (Papaphotis & Tsaparlis, 2008; Tsaparlis & Papaphotis, 2009), classical ideas were strongly influencing student conceptions.

Ke, Monk, and Duschl (2005) studied a cross-section of Taiwanese physics students (N=140) from college to graduate school using both a written survey and a subsequent interview of a subset of the sample. Researchers found that the less experienced students used both classical and quantum concepts without being aware of the conflicts, while the more experienced students demonstrated “an ability to switch between classical mechanics and quantum mechanical models in different contexts.” The more advanced students understood the intricacies of both models and when each was applicable.

Although authors frequently highlighted the shortcomings or limitations of student understanding of the quantum model, the data also shows that students are integrating new quantum ideas into their existing classical conceptual framework in interesting ways. The behavior that is observed demonstrates how students are traveling from a classical way of thinking to a quantum way, proving that the transition not an easy one with classical ideas being strongly held and hybrid models frequently being formed.

1.2.2 Highlighting students’ lack of conceptual understanding

Researchers have found that with this subject matter, students are frequently falling back to a procedural type of thinking. Currently, quantum chemistry is often taught with a large emphasis on memorizing quantum numbers and orbital designations, and this leads to algorithmic thinking on the students’ part. Papaphotis and Tsaparlis (2008) administered both algorithmic and conceptual questions to a group of Greek 12th graders (N=125) and found much poorer performance on the conceptual questions, indicating a reliance on memorizing algorithms without developing an understanding of the concepts.

Students exhibited high algorithmic competence, but had very poor understanding of quantum concepts.

Third-year undergraduate physics students' (N=33) ideas about wave-particle duality were probed with a written set of short-response questions in Johnston, Crawford and Fletcher's (1998) work. The authors noted the fragmented nature of student responses and observed that these students used terminology in their answers that was not quite relevant or appropriate, indicating a lack of comprehension.

Olsen (2002) gathered data from a written questionnaire given to 236 students from different schools. Olsen's (2002) results suggest that students are merely applying algorithms and calculations, and have little understanding about what they are calculating. For example, they were given deBroglie's relation for calculating the wavelength of an electron, and although students mastered the formula, they had little to no understanding of what it meant, making it a "meaningless activity of calculation."

1.2.3 Curriculum interventions in teaching quantum concepts

An interesting study by Bao and Redish (2002) detailed the development of a curriculum designed to help teach probability by using classical mental "bridges." They used a "random picture" metaphor where students were asked to imagine taking a series of photographs of a moving classical object and used this to build the idea of a probability density function. This was an example where curriculum in quantum mechanics specifically looked to build upon students' classical ideas and leverage that in understanding quantum principles. The tutorials developed showed promising results in increasing student understanding of probabilistic concepts.

In McKagan, Perkins, and Wieman (2008), a college modern physics course for engineering majors was transformed with the implementation of a chemistry visualization that included explicit comparison and contrasting of the Bohr and Schrodinger Model. They found when students had the opportunity to reason directly with both models, their conceptual understanding increased. Through a curriculum that explicitly compared models, students did show learning gains.

From the results that Ke, Monk, and Duschl (2005) obtained, the authors advocate that teachers include practical activities and sensory-motor experiences such as examples of standing waves on a line or diffraction patterns to solidify quantum understanding.

Harrison and Treagust (2000) argue for the explicit teaching of the nature and limitations of models as a curricular strategy. Through a case study with one eleventh grade chemistry student, the researchers were able to document "Alex's" progression throughout the year of his conception of an atom. By the end of the yearlong course, "Alex used six different analogical models to describe the attributes of covalent organic molecules. More importantly, the way he used the ball-and-stick, space-filling, electron-dot, electron cloud/shell overlaps, two-dimensional structural diagrams, and the balloons model revealed that Alex viewed each representation as a model to be used for a specific purpose or in a particular context. He appeared to believe that each model described a few of the many attributes of covalent molecules and that, collectively, these model adequately described a molecule." This progression of understanding showed that Alex was able to perceive models as tools, each with descriptive and predictive ability, and that multiple models can be used to describe the same phenomenon in different ways.

The studies cited above show that it is possible to leverage classical ideas effectively to help students on their path from the quantum to classical world. Understanding how classical ideas are influencing learning of atomic spectra can be beneficial in developing curriculum and instructional strategies to assist students. As the results from Harrison and Treagust (2000) show, as students hold both classical and quantum models, it is important to understand how students may be applying and integrating these different models. In this dissertation, the impact of classical ideas on student understanding of atomic spectra will be discussed.

1.3 Rationale of current research:

Previous research has shown that students cling strongly to classical ideas and these ideas remain deeply rooted when learning about the probabilistic model of particle location, wave-particle duality, and orbitals. Students very often hold incomplete or fragmented ideas about electrons in atoms. To address these issues, curricular interventions that explicitly contrast models or that use classical thinking as a foothold when learning quantum concepts have potential to help students. The current study aims to understand how students make sense of atomic spectra and the existence of discrete energy levels by seeing how classical ideas impact their learning. This is important to 1) extend the current knowledge on student thinking of quantum chemistry into a little-researched but central part of the chemistry curriculum, and 2) understand how to use atomic spectra to offer richer instruction and assessment in quantum chemistry.

1. Extend the current knowledge on student thinking of quantum chemistry by determining the dependence of classical ideas on student understanding of energy absorption and atomic spectra

Spectra offer students a way to directly grapple directly with ideas of discrete energy states and discrete energy absorption.

This work aims to extend the current research to understand the influence of *classical* understanding on student learning of discrete energy absorption in the context of atomic spectra. Since research has shown students hold on to a classical type of thinking, how do these classical ideas impact their understanding of spectra? What classical concepts might be hindering their understanding of discrete energy absorption? Alternatively, what classical concepts may be productive or useful footholds to assist them in understanding atomic energy absorption?

2. Understand how to use atomic spectra to offer richer instruction and assessment in quantum chemistry

Atomic spectra and discrete energy absorption is a topic that has not been well researched, yet is an integral part of current quantum chemistry instruction. It is important to study types of student thinking in order to realize the subject's potential as a vehicle to teach and assess quantum chemistry at a higher level than memorization. Through this work, one can learn about possible ways students think about discrete energy and can begin to develop scaffolds to assist students in thinking about discrete energy absorption.

There is an opportunity to move chemistry instruction away from memorization of quantum numbers and move towards having students develop more in-depth understanding of main ideas in quantum chemistry. Since research has shown that students are falling back to algorithmic thinking (Olsen, 2002; Papaphotis & Tsaparlis, 2008), learning about a rich quantum context such as atomic spectra provides an opportunity to develop an avenue to teach this content in a more meaningful way.

1.3.1 Research Questions and Overview

<u>The questions this study aims to answer are:</u>

- **Q#1: How can student thinking about concepts related to atomic spectra be characterized?**
- **Q#2a: How do students interpret and connect representations of the energy level diagram and the line spectrum?**
- **Q#2b: How does classical thinking impact understanding of atomic spectra?**
- **Q#3: What are possible challenges in guiding students to a normative understanding of atomic spectra?**

In this dissertation, interview data was videotaped and transcribed from a sample of introductory college chemistry students (N=65) answering questions about atomic absorption and emission of light. Using grounded methods in Chapter 3, categories of student ways of thinking about quantum ideas, or dimensions of competence, were determined. These dimensions consisted of a subscale or code from one to three or four detailing a type of thinking within that dimension. Four dimensions were studied to determine if any correlations existed between them. In Chapter 4, ten student transcripts are analyzed using grounded methods to gain insight on student representational and conceptual understanding. In Chapter 5, an exploratory study was undertaken and data from two student interviews is studied using a qualitative protocol analysis to examine student successes and struggles as they interact with a visual on atomic spectra aimed to guide them to a normative understanding.

1.4 Theoretical Framework

1.4.1 Fragmented View of Knowledge

In the current study, knowledge is viewed as having a fragmentary nature, and this work is informed and guided by a view of learning as diSessa and Sherin's (1998) Knowledge in Pieces perspective. They view student knowledge as being less systematic and organized and view understanding of an idea or "coordination class" as a relation of these elements and others to form a knowledge system. They stress the importance of being explicit and clear about the types of knowledge elements that are undergoing reorganization in conceptual change. This view highlights the dependence on the context in activating these knowledge elements and the importance in looking at the relation between these elements in defining the knowledge system. In a similar vein, Hunt and Minstrell (1994) frame the fragmentary nature of knowledge in the language of facets, "a convenient unit of thought, an understanding or reasoning, a piece of content knowledge or a strategy seemingly used by the student in making sense of a particular situation".

The current study aligns with these ideas (diSessa & Sherin, 1998; Hunt & Minstrell, 1994), and acknowledges that student knowledge is fragmented and may be context-sensitive. For example, during the interview process, some students did bring up different ideas depending on the given prompt in the same interview, bolstering the idea that student ideas are not robust or theory-like. Students also sometimes expressed two contradictory ideas, a feature that is captured in the coding of the data. In this study, student ideas are not presumed to be robust or theory-like, as some researchers claim (Carey, 1999; McCloskey, 1983; Vosniadou, 1994).

Linn, Clark and Slotta (2003) and Hunt and Minstrell (1994) also stress the importance of looking at the connections between these pieces and studying their integration into existing knowledge systems. Linn, Clark and Slotta's (2003) Knowledge Integration Scale highlights the importance of making connections between models and ideas and Hunt and Minstrell (1994) stress the importance of looking at the relations between facets in building understanding.

Although this work does not explicitly undertake a knowledge analysis or facet analysis perspective, these theories guide and inform the current study.

Influence of Prior Knowledge:

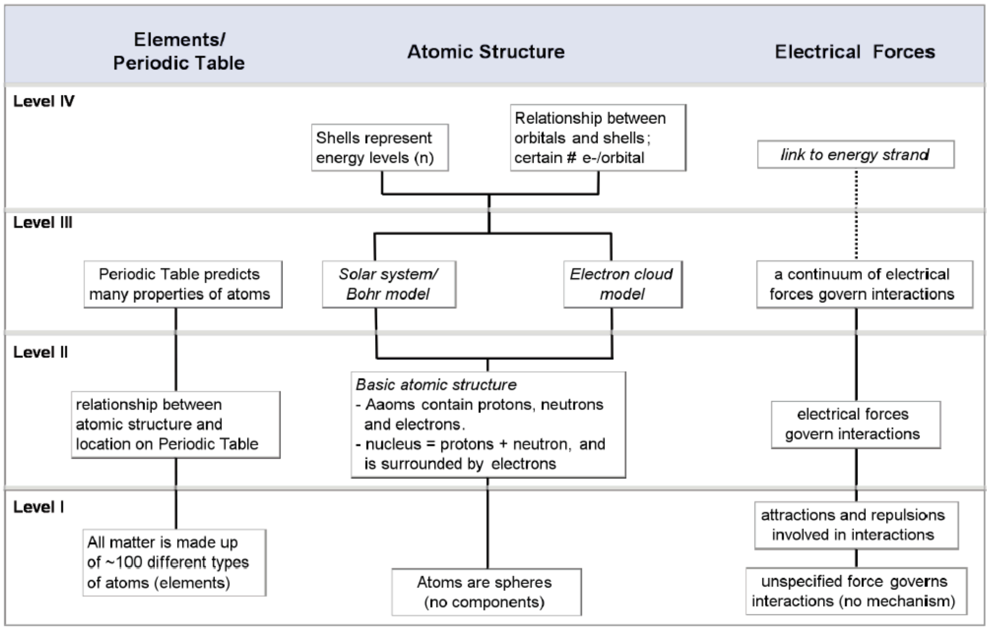
In this research, student prior knowledge is viewed as a resource that students bring to the table. Students build on the ways of thinking they have and their learning pathway is most certainly influenced by their previous ways of thinking. The role of prior knowledge and previous ways of thinking is significant as students struggle with moving from a more classical way of thinking to a more quantum way. Their prior ways of thinking classically can help or hinder them as they move to understand the quantum regime. Researchers (Clement, 1993; Hunt & Minstrell, 1994; Hammer, 2000; Teichert & Stacy, 2002; Carpenter, Fennema & Franke, 1996; Nakhleh, Lowrey & Mitchell, 1996; van Zee & Minstrell, 1997) have described instructional strategies that explicitly build on student intuitions and ways of thinking to improve performance, viewing student naïve knowledge as a resource. In the field of college chemistry, Teichert and Stacy's (2002) results indicated that instruction that identifies students' initial conceptions and integrates those ideas into class discussion led to enhanced conceptual understanding in the area of bond energy and spontaneity.

In the analysis in this study, attempts are made to look at how students are connecting and integrating various pieces of knowledge, both prior and newly learned, together in their learning of atomic absorption and emission of light.

Charting an Empirical Learning Progression

Building off of these ideas, how can we think of and describe the development of understanding of a particular topic, for example atomic spectra? The analysis in this study closely matches what Stevens, Shin and Krajcik (2009) term an empirical progression. In the field of chemistry education, the authors discuss how student ideas about the nature of matter and atomic structure evolve with instruction. Learning and developing understanding is viewed as a "progression of *sets* of ideas instead of isolated strands of knowledge." Learning is not a linear step-by-step path, but instead is a change in the connections between ideas as students move to a normative understanding. Understanding in one strand may also be connected to learning in other strand. A conceptual strand, for example is atomic structure, electrical forces or the periodic table, as is shown in Figure 1.1. Conceptual understanding is viewed as connections between strands as well as connections between ideas in one strand. Whereas a hypothetical learning progression is based on learning theories or input from experts in the field, an empirical progression is based on actual data from student observations, providing insight on which connections students make easily and which they struggle with. This can also identify which ideas are “threshold” concepts, those that allow students to understand a wide range of phenomena.

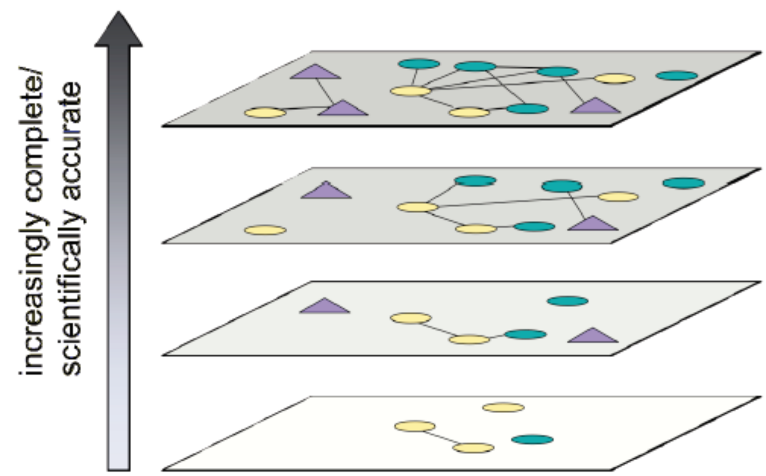
Figure 1.1. Representation of a portion of the hypothetical learning progression for the nature of matter (Stevens, Shin & Krajcik, 2009)



Learning is viewed as a progression to more integrated set of ideas, as connections between appropriate ideas are strengthened both in the topic strand and to other related strands.

For example, the authors (Stevens, Shin & Krajcik, 2009) develop an empirically derived progression of student understanding of atomic structure by looking at a range of student responses. They visualize this progression as a journey where the learner is creating a more expert-like set of connections between ideas, but this process can also extend “horizontally” as connections are being made to related content strands.

Figure 1.2. Representation of a multi-dimensional learning progression. The different shapes and colors represent ideas from different strands within the learning progression. The black lines represent connections among ideas in different constructs to build integrated knowledge. (Stevens, Shin & Krajcik, 2009)



In this manner, the connections being made between ideas as students grapple with atomic spectra can be visualized as an empirical progression. The goal of this work is to characterize student understanding and determine which connections between ideas are made by the more successful students through the analysis in Chapter 3 and 4, and to start to develop an empirical progression based on the observed data. In Chapter 5, ideas on how to guide students to higher levels of comprehension and associated struggles are discussed.

1.4.2 Use of Representations in Chemistry

Palmer (1978) forms a descriptive theory of what a representation is, and his framework is a useful one to guide an analysis of student representation use. He states that: **"**In order to specify a representation completely, then, one must state: (1) what the represented world is; (2) what the representing world is; (3) what aspects of the represented world are being modeled; (4) what aspects of the representing world are doing the modeling; and (5) what are the correspondences between the two worlds. A representation is really a representational system that includes all five aspects."

Particularly in chemistry, molecules and chemical properties cannot be perceived directly, thus chemists use a rich array representations as tools in explaining these microscopic entities. In this dissertation, student interpretation of representations will be one lens through which the data will be analyzed, and more details are provided in Chapter 4.

In the field of chemistry, Kozma and Russell (1997) discuss how “chemistry as a field of study is inherently representational or symbolic. Chemists have invented specialized symbol systems—such as reaction equations, molecular structure diagrams, concentration graphs, and three-dimensional (3D) computer models—to represent the molecular phenomena that they study in their laboratories.” In addition, chemical representations can be viewed as metaphors, models, and theoretical constructs of chemists' interpretation of nature and reality (Hoffman & Laszlo, 1991).

Through an analysis of expert and novice chemists’ reasoning with representations, Kozma (2003) highlights that experts are more likely to use representations reflectively and link them together in explanations or predictions. Experts often see the limitations and affordances of each representation and use them in an integrated manner to deal with the problem at hand.

Similar to Chi, Feltovich and Glaser’s (1981) work, Kozma (2003) also found that novices often focus on surface features while having difficulty connecting or translating between representations, and they often resort to algorithmic or rote application of rules with little understanding. Experts, on the other hand, "coordinate features within and across multiple representations to reason about their research and negotiate shared understanding based on underlying entities and processes” (Kozma, 2003). In addition, as Krajcik (1991) points out, although students can become proficient at manipulating chemical symbols, they often treat them as mathematical puzzles without any sort of deeper conceptual understanding.

It is important to note that while studying individuals reasoning with representations, there is a confounding of issues of representational competence and conceptual competence. It is reasonable to assume that a stronger conceptual understanding in students will demonstrate itself as higher representational competence, and it is hypothesized that as representational competence becomes stronger, the conceptual underpinnings also grow stronger in a parallel fashion. These skill sets are intertwined and evolve together, as the meaning derived from the interpretation of the representations grows with the skill of using representations in a more expert-like manner. As Michalchik et al (2008) states, “One can neither understand chemistry without using representations nor use representations of the domain without some understanding of chemistry.”

Different terms have been given to the ability to reason with models and representations reflectively and flexibly. Kozma and Russell (1997) use the term “Representational Competence”, while “Meta-Representational Competence” (diSessa & Sherin, 2000), “meta-modeling knowledge” (Shwarz & White, 2005), and “Metavisual capability” (Gilbert, 2005) have also been used. Kozma and Russell (1997) provide a description of “Representational competence” as the “set of skills and practices that allow a person to reflectively use a variety of representations, singly and together, to think about, communicate, and act on aperceptual physical entities and processes."

These guiding theories will inform the in-depth analysis of student interpretation and use of representations dealing with atomic spectra in Chapter 4.

1.4.3 Methodological Approach - Grounded Theory

Chapter 3 of this study examines a large number (N=65) of student interview responses, and aims to characterize student thinking in the general chemistry population. The analysis in this study is built on principles related to Grounded Theory (Glaser and Strauss, 1967), a methodology used in the social sciences for analysis of qualitative data. A good explanation is offered in Taber (2000) for application of grounded theory specifically in chemistry education. In this approach, the researcher looks at the data collected without applying preconceived notions, and assigns codes based on what emerges from the data. Categories are developed and refined based on these codes, and there is a cycle of revision and elaboration to develop an emerging model or theory.

In this method, the researcher examines the data and attempts to iteratively determine the best fit with the categories in an emergent process. The categories are successively modified to fit what the researcher "sees" in the data. This methodology is based in steeping oneself in the dataset to determine what patterns of thinking exist, and not clouding the analysis with preconceived ideas. For example, even though in this study the influence of classical thinking was probed, theories on how classical thinking affects understanding of spectra were not assumed before the data was examined. The meanings in the in the data were exposed upon study, and not initially assumed. Taber (2000) also discusses an example of using grounded theory to study student conceptions of the ionization energy, and offered an argument to the validity in using this type of methodology in chemistry education research, offering a middle ground or "bridge" between case studies and larger curriculum reform projects. By examining a large set of student responses and observing the patterns of thinking that emerge from the data, student understanding of this topic can be characterized and generalized to the larger college population.

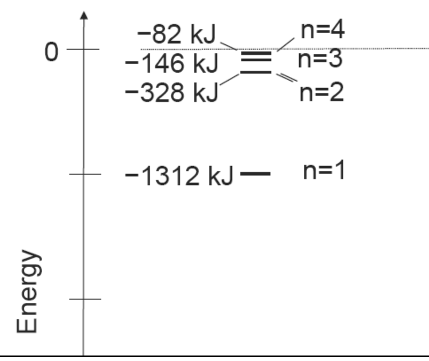
1.5 Atomic Spectra Conceptual Issues

The goal of this study is to determine how students understand the idea of discrete energy levels and light absorption through the interpretation of atomic spectra, along with seeing how their classical ideas influence understanding. A discussion is provided here of the main conceptual struggles related to atomic spectra.

1. Understanding quantized energy vs. classical notions of energy

In a quantum mechanical system, bound electrons can only take on certain specific levels of energy, in contrast with classical particles that can possess any amount of energy. These specific discrete states are called energy levels of the electron, and these energy states are said to be "quantized." The Schrodinger equation is a way to describe the observation of discrete energy levels, with solutions to the equation, wave functions, having specific associated energy values. Students have a difficult time understanding the notion of discrete energy states, and how these are different from classical continuous energy states.

Figure 1.3. Representation of an Energy Level Diagram of Hydrogen



2. Understanding discrete energy absorption as an "all-or-nothing" process

When photons hit the electron with energies that exactly match a difference between these energy states, the light energy is absorbed and the electron is excited or promoted to a higher energy level. Again, the photon energy must be a certain discrete value; any energy amount lower or higher than this value does not become absorbed and the electron does not transition to another state. This idea of an all-or-nothing absorption contrasts with the classical idea of energy absorption where any value of energy can be absorbed by an object. For example, a baseball can be thrown slowly with low energy or quickly with high energy or with any energy in between. The quantum particle can only exist in certain energy levels and cannot exist in between these levels.

Shakhashiri (2011) provides a concise but detailed explanation on the process of atomic absorption of light, suitable for a general chemistry level of understanding. This gives a normative understanding that is sought after for the introductory level in interpreting and understanding atomic spectra:

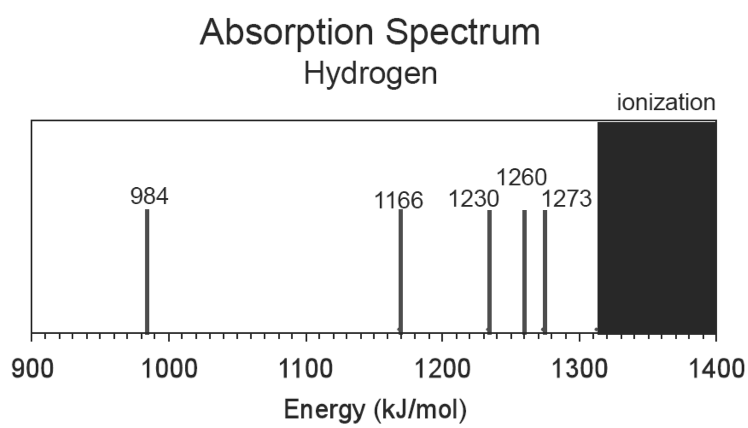
> (p. 35) "When a broad range of light frequencies shines through a sample of atoms, a few frequencies of the electromagnetic waves have exactly the correct energies to match the differences in energies between the electron energy levels in the atoms. Consider one

such energy-level difference and assume there is an electron at the lower energy level. The electric field of a wave that matches the energy-level difference can interact strongly with the electron and provide exactly the energy required for the transition from the lower to the higher energy level. This is an all-or-nothing process.

We have to account for the conservation of energy and the photonic nature of light and realize that the entire photon of this energy is used up in changing the energy of the electron. Thus, the electromagnetic wave corresponding to this photon disappears (is absorbed) from the spectrum of light and a gap appears in the spectrum of the transmitted light. Because only photons corresponding to energies that exactly match possible electronic transitions in the atom are absorbed, these gaps are very narrow. Photons (waves) with energies only slightly above or below the match cannot interact with the atom and are not absorbed."

The atomic absorption spectrum is a record of all energies of photons that become absorbed, causing an electron to transition to a higher energy level in the process. This is another topic where students struggle. They are unable to reconcile their classical ideas of energy absorption with corresponding quantum ideas in a normative fashion.

Figure 1.4. Representation of the Absorption Spectrum of Hydrogen (From Chemistry course lecture slides: Fall 2009)



3. Complicating representational factors - Lines and Scales – what do they mean?

Adding to this, an existing representational feature that adds to student confusion is that the absorption spectra (Figure 1.4) consists of a series of vertical lines, although there is no scale on the y-axis. The height of the line in this case has no significance and simply notes where the absorption took place, for example photons of energy 984 kJ/mol were absorbed. Students are familiar with working with plots which contain both a x and y axis label, so these one-axis plots can confuse them.

Likewise, the energy level diagram (Figure 1.3) consists of a series of horizontal lines, and there is no scale on the x-axis. The width of the line in this case has no significance and simply notes the energy level. For example, the n=1 level has an energy of -1312 kJ. These features commonly contribute to student misinterpretations of the representations.

1.6 Formative Work and Development of Current Study

The data collection in this dissertation involves a stratified random sample design, with approximately twenty each low, medium and high performing students, as determined from their scores on the first midterm exam, being interviewed during an introductory chemistry course. Questions related to atomic spectra and the absorption of light were asked in a semi-structured interview format. Data for this study comes from interviews at the end of the semester-long course after students had been exposed to instruction on the material.

Preliminary work was undertaken to inform the design and execution of the current study. Generally, three areas of development occurred: quantum Item development, curriculum design of the quantum course related to atomic spectroscopy, and refinement of interview style of quantum questions.

First, three main sources of student data were examined:

1) Whole-class online homework data from Fall 2007 from an introductory chemistry college course
2) Written responses to short answer questions dealing with absorption and emission of light from three discussion sections in Fall 2008 in an introductory chemistry college course
3) Observations of small group interactions in an Academic Talent Development Program (ATDP) Advanced Chemistry Summer Course for high school students in Summer 2009.

Data from Fall 2007's Introductory Chemistry class (N=1300) was collected and analyzed to gather some broad information on student difficulties with the quantum material. In particular, a total of 58 online homework questions (Online Web-based Learning (OWL), http://owl.cengage.com) were studied.

The online homework system contained weekly assignments that students completed and submitted online. The questions were mainly multiple choice, fill-in-the-blank, matching or ranking questions, and problems that required students to compute numerical answers. These covered a range of topics that were addressed during instruction the week prior to the due date. The data was analyzed to determine which quantum concepts a majority of students struggled with. The data was sorted by selecting only the problems dealing with quantum mechanics, and then statistics were calculated for each problem. For example, statistics were compiled for number of students who attempted, average number of attempts, percent of students who mastered or got the question right on the first try, and average time spent per attempt. From these overall statistics, certain trends were observed in particular problems or concepts that signaled specific learning difficulties or challenges.

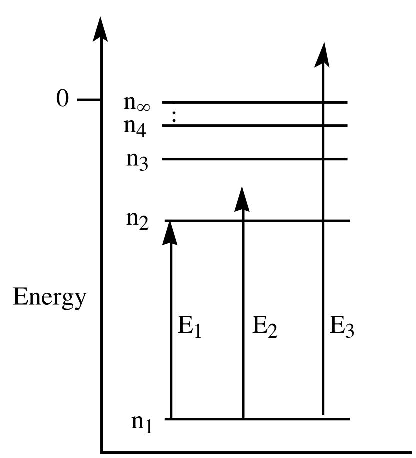
It was found that students had difficulty with calculations involving conversions between energy, wavelength, and frequency. Students also lacked the ability to transfer ideas related to hybridization to specific molecular examples. These results signaled that students were exhibiting a high dependence on memorization and rote application of algorithms to solve problems, recognizing formulas but being unable to apply these in new contexts. This data provided a first glimpse into the challenges students were facing. In future work, it was decided to abandon the use of the online homework system for data analysis. Because of the potential for students to copy from each other, and it was decided that written exam questions were a more reliable indicator of student knowledge.

Two final exam questions, from a sample of 56 students, were examined from the Fall 2007 class. Both were open-ended questions related to absorption of light. Question #9 dealt with the absorption spectrum of Chlorophyll, and Question #10 dealt with energy absorption of the Hydrogen Atom.

Figure 1.5. Item from Fall 2007 Final Exam

10) Hydrogen Atom

Consider the following energy level diagram for a hydrogen atom.



Can an electron in state n = 1 absorb a photon of energy E_2?

Circle one: Yes No

If you answered yes, where does the excess energy go?

If you answered no, why not?

Can an electron in state n = 1 absorb a photon of energy E_3?

Circle one: Yes No

If you answered yes, where does the excess energy go?

If you answered no, why not?

Question 10 of the final exam dealt with electronic transitions and the absorption of light. Surprisingly, when students were asked if an electron could absorb an amount of energy that was in-between the energy levels of the hydrogen atom, 36% of students responded that the hydrogen atom could absorb a photon with this energy. Discrete energy absorption is a fundamental concept in understanding the interaction of light with matter, the basis for all spectroscopic techniques, and more than a third of the sample population answered this question incorrectly! Even after being exposed to these concepts during the semester, students still fell back to the classical view of thinking about absorption. The simplicity and power of this item to probe a fundamental understanding of discrete energy absorption was noted and it was used to inform the current study.

Using these results, in three discussion sections in Fall 2008 (N=90), written worksheets were given to students probing their understanding of quantum concepts in both multiple choice and short answer formats. Questions were asked about students' picture of the atom and description of orbitals, as well as energy absorption. The results corroborated that students had difficulty in navigating between representations of the atom, and they held on strongly to a classical model of the atom with electrons in a "Bohr-like" orbit around the nucleus. From these results, items were refined and more effective questions were developed.

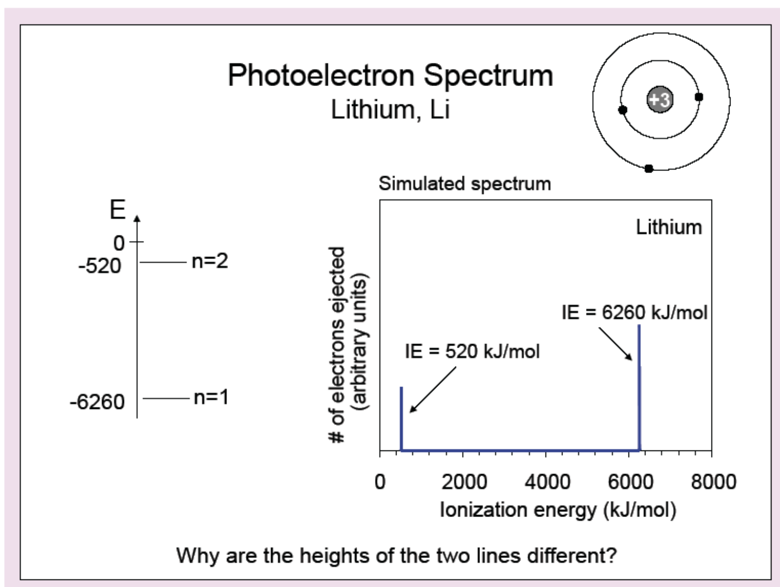
In the summer of 2009, a class of advanced high school students taking Advanced Chemistry at UC Berkeley in the Academic Talent Development Program (ATDP), a summer enrichment program held by the university for high school students, was used as an arena to gather more data on student thinking of atomic structure and light, and was mainly used for item refinement. Small groups of students were videotaped working in groups on written questions in a 1-hr session in a laboratory classroom on campus. In particular, items were tested dealing with atomic absorption and emission of light. Student responses were used to inform the final set of interview questions, and based on student feedback the wording of the questions was modified.

Insight was gleaned from this work on types of effective questions, wording of questions and delivery of questions. It was found that open-ended questions were more effective at probing student ideas and students were less likely to try and spit out the "textbook" answer or memorized definitions. It was also found that students brought up different ideas depending on the context of the question, signaling that multiple ways of probing the same concept was important. The ordering of the questions was also crucial as some ideas served to prime students as to what the "right" answer should be in future questions, so care was taken in the current study to organize the questions such that earlier questions did not clue the answers to the following questions.

Fall 2008 Curriculum Work:

Along with the data gathering effort of online homework responses, exam responses and small group problem solving, in Fall 2008, work was done to rethink the organization and delivery of the quantum chemistry section of the course. In particular, a concerted effort was made to shift the material to a focus on having students interact with observable data, *spectra*, and have them build a quantum understanding based on grappling with evidence in a structured inquiry manner.

Figure 1.6. Slide from Fall 2008 redesigned course



Work was done developing lecture slides where students would see examples of photoelectron spectra (PES) and use this evidence to justify the existence of shells and subshells in the atom, for example proving the existence of discrete energy states through spectral data. From interviews conducted at the end of the Fall 2009 course from a small sample of students, it was found that learners appreciated this approach to quantum, and frequently stated that the delivery was interesting and that they appreciated how the quantum concepts tied back to other aspects of the course as a whole.

This approach to quantum chemistry informed and motivated the current study. It was found that quantum instruction could be rethought to have students think about the fundamental concepts in a deeper way instead of with a purely algorithmic method. Thus, a focus on atomic spectra and student understanding was chosen for due to its potential and preliminary success as a curricular tool.

From this formative work, interview questions were narrowed down to three types for Chapter 3 and 4 of the dissertation:

1) Descriptive: First a descriptive question was included at the start of the interview to ensure that students didn't get intimidated by the math involved, and also to avoid prompting memorized or textbook descriptions. Students were asked about their conceptions of atoms and light, and this question was a good starter question to reduce anxiety.
2) Interpreting Spectra: Subsequently a quantitative question was included to see how students were matching up the two representations and using the numerical data provided. Numbers were included to gather specific information on how students were navigating between the two representations.
3) Applied Context: Finally, a question about gas discharge tubes was included as another context to probe for their understanding of concepts related to atomic spectra, and one that was directly linked to visual macroscopic evidence.

Care was taken that all of the material included in the interview was familiar to students from lecture material or exam content. Details are given in the next chapter on the questions asked, and the full interview protocols are provided in Appendix A.

1.7 Overview of Dissertation

The questions this dissertation aims to answer are:

- **Q#1: How can student thinking about concepts related to atomic spectra be characterized?**
- **Q#2a: How do students interpret and connect representations of the energy level diagram and the line spectrum?**
- **Q#2b: How does classical thinking impact understanding of atomic spectra?**
- **Q#3: What are possible challenges in guiding students to a normative understanding of atomic spectra?**

In Chapter 1, the research questions, purpose and importance of the study are described. A literature review related to student understanding of quantum chemistry is included. A short description of conceptual issues related to atomic spectra is presented along with information on pilot work conducted and the development of the interview protocols.

The data in this dissertation study comes from a set of semi-structured clinical interviews after the unit on quantum chemistry using a stratified random sample. Open-ended questions were asked on the topic of atomic spectra to a representative sample of students from a large introductory chemistry class (N=65). Further details on the sample population and the methods used are included in Chapter 2. Chapters 3 through 5 present analyses of the interviews and address one of the research questions listed above. Chapter 6 concludes this study by discussing future directions of the work.

In Chapter 3, using grounded methods, data was analyzed to determine student dimensions of competence on four quantum aspects of learning. Each dimension was subdivided into 3 or 4 codes or sub-categories, each which reflect a way of thinking about the quantum idea. The 4 dimensions were analyzed to determine which dimensions exhibit strong or weak correlations. The development of these dimensions and the correlations between dimensions serve to address research question #1: How can student thinking about concepts related to atomic spectra be characterized?

In Chapter 4, a subset of 10 interviews was chosen for analysis using grounded methods to look more closely at student conceptual and representational understanding, and to address research question #2a and #2b: How do students interpret and connect representations of the energy level diagram and the line spectrum? How does classical thinking impact understanding of atomic spectra?

In Chapter 5, an exploratory study was conducted to see possible challenges in leading students to a normative understanding of spectra. Data is analyzed from two students who were brought back and interviewed one year after the course was completed. They had initially struggled with interpreting spectra and were asked to interact with a representation designed to scaffold their understanding of spectra. The research question addressed in this chapter is: What are possible challenges in guiding students to a normative understanding of atomic spectra? Student successes and obstacles in their learning are explored in depth.

Figure 1.7. summarizes the research questions, sample population, tasks, methodologies and results for each chapter’s discussion.

Table 1.1 Overview of dissertation

	Chapter 3	Chapter4	Chapter 5
Research Questions	Q#1: How can student thinking about concepts related to atomic spectra be characterized?	Q#2a: How do students interpret and connect representations of the energy level diagram and the line spectrum? Q#2b: How does classical thinking impact understanding of atomic spectra?	Q#3: What are possible challenges in guiding students to a normative understanding of atomic spectra?
Sample Size	Interview data from 65 students, Fall 2009	Interview data from 10 students, Fall 2009	Interview Data from 2 students, Spring 2011
Tasks	• 3 types of quantum questions • Tasks given in Figure 2.2 through 2.4 and in App. B • 15-20 minute interview section analyzed	• 3 types of quantum questions • Tasks given in Figure 2.2 through 2.4 and in App. B • 15-20 minute interview section analyzed	• Interaction with visual from KSU • Construction of spectrum from energy level diagram and vice versa • Follow-up qualitative questions on spectra • Approx. 1 hr. interview
Methods	Grounded methods	Grounded methods	Exploratory Study – qualitative protocol analysis
Results	Four Dimensions of Competence are found. Each dimension is divided into 3 or 4 subscales or codes representing a way of thinking. Correlations between dimensions are analyzed.	Four types of behavior or representational and conceptual ways of thinking are found. Impact of classical thinking on representational and conceptual mastery is discussed.	Exploration of issues students may face as they move towards quantum understanding

Chapter 2: Methodology

The method of data collection for this dissertation was individual semi-structured clinical interviews of a population of introductory chemistry college students to probe their understanding of atomic absorption and emission of light. Data for Chapters 3 and 4 were collected using a stratified random sample design. The interview data for Chapter 3 and 4 came from the interviews (N=65) collected during the course, in the fall semester of 2009. The data for Chapter 5 (N=2) was collected at a later timepoint after the course was completed. In this chapter, the classroom context and class population is described. The methods for sample recruitment and a description of the interview tasks and procedure is provided. Finally, a discussion of the data analysis techniques used is briefly addressed for each of the research questions below:

<u>The questions this dissertation aims to answer are:</u>

- **Q#1: How can student thinking about concepts related to atomic spectra be characterized?**
- **Q#2a: How do students interpret and connect representations of the energy level diagram and the line spectrum?**
- **Q#2b: How does classical thinking impact understanding of atomic spectra?**
- **Q#3: What are possible challenges in guiding students to a normative understanding of atomic spectra?**

2.1 Classroom Context

Instruction in the general chemistry course took place in Fall 2009. Three different lectures with different professors, each of 400-500 students, were given on the same day, with content in lecture slides being synchronized so that all students received comparable instruction. The course was divided into 4 topical units: matter, change, energy, and light, with quantum chemistry material included in the last unit covered in the course before the final exam. After each unit, a midterm exam was administered consisting of both multiple choice and short answer questions that mainly assessed understanding of the content of the unit just completed. Midterm 4 consisted of all multiple choice questions. The final exam in the course was cumulative and assessed understanding in all four units.

In the last unit, students were exposed to instruction encompassing the nature of light and color, spectroscopy and the interaction of light and matter, atomic orbitals, periodic trends, and molecular orbitals and bonding. It was in this unit in which students were exposed to atomic absorption and emission of light.

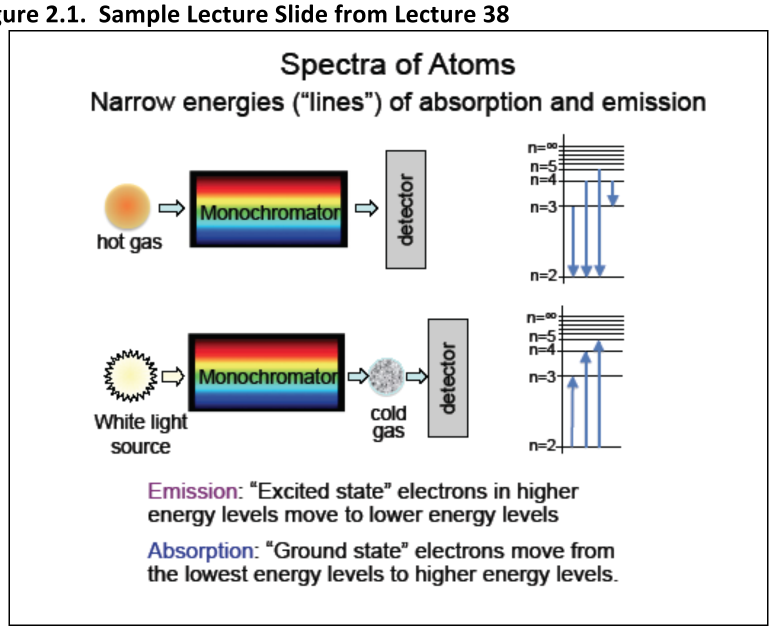
Unit 4 consisted of a series of 8 lectures of 50 minutes each, with lecture instruction being guided by PowerPoint slides, visual animations, and in-class demonstrations.

Table 2.1. Organization of Lectures for the Unit on Light and Quantum Chemistry

Lec. No.	Title	Key Idea	Summary Points
Lecture 34	**How Absorbing:** Light and Color	Colors of compounds are a result of absorption of a portion of the visible spectrum of light	- Matter can absorb, reflect, or transmit light. The light that you see consists of the wavelengths that do not interact with the molecules in an object. - Visible absorption spectroscopy can be used to measure the amount of light absorbed at different wavelengths. - The observation that matter interacts with only a certain portion of the visible spectrum indicates that only certain electronic transitions are possible.
Lecture 35	**Now you see:** Spectroscopy	Spectroscopy is a powerful tool for learning about atoms and molecules.	- Flame emission spectroscopy can be used to measure concentrations of metal ions in solutions. - IR absorption spectroscopy can be used to identify composition of complex mixtures of organic compounds. - Photoelectric effect: the energy of incident photons (if above a critical value) will cause electrons to be ejected from a metal surface with a specific kinetic energy: E(photon) = IE + KE(electron).
Lecture 36	**Photo Opportunity:** Subshell Model	High-energy photons can be used to eject electrons from atoms.	- Electrons are ejected by photons with energies exceeding certain minimum value, the ionization energy. - Photoelectron spectra suggest a shell and sub-shell model of the atom with discrete electron energy levels. - The principal quantum number, n, is assigned to energy levels. - The sub-shells are labeled s, p, d, and f. - Photoelectron spectra are used for chemical analyses.
Lecture 37	**Breaking the code:** Periodic Table	Periodic properties of atoms can be understood in terms of the locations of electrons in subshells.	- Electrons have both a particle and wave nature. - Increasing the energy of a standing wave leads to a greater number of nodes. - Quantum mechanics describes the locations of electrons in terms of probabilities. - Orbitals indicate where electrons are most likely to be found (1^{st}, 2^{nd}, 3^{rd}, 4^{th} quantum numbers) - Periodic trends can be understood in terms of electron configurations.
Lecture 38	**Technicolor Atoms:** Line Spectra	When electrons relocate from one orbital to another, they absorb or emit a specific amount of energy.	- Only discrete energies of light are emitted and absorbed by bound electrons. - Atomic line spectra confirm the shell model of the atom with discrete electron energies. - Atoms can be excited in high T media: flames and plasma - Measurements of intensities of emitted light can be used to identify elements and quantify their concentrations in a sample
Lecture 39	**Housing Co-op:** Molecular Orbitals	Colors of molecules reflect the transitions of electrons between molecular orbitals when light is absorbed.	- The energy levels in molecules are different from those of atoms that form those molecules. - Molecular orbitals describe the locations of electrons in molecules. - Molecular orbitals can be viewed as the result of overlap of atomic orbitals. - Absorption of light in the visible or UV range causes electrons to move from the highest occupied MO to the lowest unoccupied MO.
Lecture 40	**Dying to Know:** Colorful Molecules	Molecules with π bonds and transition metal ions are colorful because electrons absorb visible light to move between orbitals.	- Hybrid orbitals form when s and p orbitals of the same atom mix together. There are 2 sp, 3 sp^2, or 4 sp^3 hybrid orbitals. - Absorption of light in the visible or UV range causes an electron to move from the highest occupied MO to the lowest unoccupied MO. - Transition metals have partially filled d orbitals. The colors of transition metal compounds are due to promotion of electrons between d orbitals.

The quantum unit stressed the importance of data and evidence in justifying the quantum model. The connection to types of data and what that reveals about the nature of matter was repeatedly addressed and students were pushed to connect their observations with underlying models. The nature of light was introduced in Lecture 34, and the idea of interaction of light with matter to reveal properties about matter and spectroscopy was introduced in the following lecture. After discussion of the subshell model of atoms and relation to the periodic table, line spectra were introduced in Lecture 38. From here, molecular orbitals and hybridization were presented, with a focus on characterization of matter through data and evidence.

Figure 2.1. Sample Lecture Slide from Lecture 38



2.2 Population

The participants in this study were students in an introductory general chemistry course at a large public university. Approximately 1300 students were enrolled in the fall semester of 2009, and the course was generally intended for life science and non-chemistry majors, with a large number of students in the pre-medical track. A demographic survey was administered at the beginning of the semester, and students were asked to self-report gender, intended major, socio-economic status and ethnicity data, and the results are presented in Tables 2.2-2.5. Out of the entire class, 892 students consented to having their survey responses collected and reported, and from this data it was determined that in the class, approximately 51% were life science majors, 20% were engineering majors, 4% were humanities majors, 15% were undeclared, along with a few students from physical science, mathematics, and others. 41% of the students were male and 59% were female.

Table 2.2. Comparison of Interview Group with Whole-Class Survey Responders - Gender

Gender	No. of Students from Survey Responses	%	No. of Students from Interview Group	%
Female	526	59.0%	34	52.3%
Male	362	40.6%	31	47.7%
Decline to state	4	0.4%	0	0.0%
Total	892	100.0%	65	100.0%

Table 2.3. Comparison of Interview Group with Whole-Class Survey Responders – Intended Major

"What is your intended major?"	No. of Students from Survey Responses	%	No. of Students from Interview Group	%
Life Science/Biology	458	51.3%	30	46.2%
Engineering	180	20.2%	15	23.1%
Undeclared	134	15.0%	8	12.3%
Other	53	5.9%	4	6.2%
Humanities	33	3.7%	4	6.2%
Physical Science	25	2.8%	4	6.2%
Mathematics	8	0.9%	0	0.0%
No Response	1	0.1%	0	0.0%
Total	892	100.0%	65	100.0%

Table 2.4. Comparison of Interview Group with Whole-Class Survey Responders - Ethnicity

"Of the ethnic categories below, which do you self-identify with most? (pick one)"	No. of Students from Survey Responses	%	No. of Students from Interview Group	%
Chinese/Chinese American	254	28.5%	16	24.6%
White	227	25.4%	24	36.9%
Korean/Korean-American	73	8.2%	1	1.5%
East Indian/Pakistani	52	5.8%	3	4.6%
Mixed	49	5.5%	5	7.7%
Decline to State	43	4.8%	2	3.1%
Mexican/Mexican-American/Chicano	36	4.0%	3	4.6%
South East Asian	31	3.5%	1	1.5%
Other Asian	31	3.5%	4	6.2%
Filipino/Filipino-American	23	2.6%	1	1.5%
Middle Eastern	21	2.4%	2	3.1%
Japanese/Japanese-American	12	1.3%	0	0.0%
Spanish-American/Latino/Latina	8	0.9%	0	0.0%
African-American/Black	3	0.3%	1	1.5%
Pacific Islander	2	0.2%	0	0.0%
Did not answer	27	3.0%	2	3.1%
Total	892	100.0%	65	100.0%

Table 2.5. Comparison of Interview Group with Whole-Class Survey Responders – Socio-Economic Status

"Which of the following best describes your socio-economic class when you were growing up?"	No. of Students from Survey Responses	%	No. of Students from Interview Group	%
Low-income or poor	98	11.0%	3	4.6%
Working-class	112	12.6%	6	9.2%
Middle-class	309	34.6%	23	35.4%
Upper-middle/professional-middle	327	36.7%	32	49.2%
Wealthy	24	2.7%	1	1.5%
Decline to state	22	2.5%	0	0.0%
Total	892	100.0%	65	100.0%

Table 2.6. Comparison of Interview Group with Whole-Class Survey Responders – Midterm 1 Score

	No. of Students in whole class	Average (%)	No. of Students from Interview Group	Average (%)
Midterm 1 Score	1351	70.9%	65	72.5%

2.3 Recruitment

At the beginning of the course, in the Fall 2009 semester, students were asked their consent for the research through the use of an online survey. On the survey, students were asked for their agreement to participate in the research and asked permission to have access to their student work. Approximately 892 students participated in the survey and gave consent for their survey responses to be used in the study. At the same time, students were asked if they would be willing to be contacted to participate in interviews over the course of the semester.

From the population of students who consented to be contacted, a group was chosen which was representative of the class as a whole in terms of gender, ethnicity, intended major and socio-economic status. In addition, based on the students' first midterm scores, students were divided into performance groups of the highest third percentile of the class, medium third percentile and lowest third percentile and approximately one-third of the sample students were selected from each group. This was done to ensure that the sample was indicative of the larger population in terms of exam performance. Comparison of the sample population to the entire group of survey respondents is included in Tables 2.2 through 2.6. Student anonymity was protected throughout the study and the proper permissions from the Committee for the Protection of Human Subjects (CPHS) were obtained [CPHS 2009-07-28].

2.4 Interview Procedure and Protocols

All the interviews were conducted on the campus of the university, and were videotaped. Data was collected by two interviewers - one was the author of this dissertation study, and the other was a graduate student colleague involved in chemistry education research with the same set of students. The co-researcher was very familiar with the course, student population, and research details. Two interviewers interviewed approximately 65 students at three time points in the semester: some students did not attend all 3 interviews. Data for this dissertation came only from the last interview conducted. Each interview was organized with a protocol consisting of script fragments, and interviewers started by asking questions but followed up with clarifying questions as the subject explored different avenues in the interview. Then, the interviewer would return to the script to continue the protocols. Both of the interviewers participated in a norming process at the beginning of each set of interviews to ensure consistent procedures. In this process, each researcher sat in on one of the interviews held by the other researcher and any differences in style or format were addressed and modified. As the interviews progressed, each researcher also watched a few of the videos of the other researcher, again to ensure consistency and any deviations or changes to the protocol were subsequently made to ensure consistency.

The first interview was conducted after the first midterm, and here, students were able to familiarize themselves with the researcher and the research setting, with the aim of reducing anxiety or discomfort in future meetings. The second interview was conducted after Midterm 2, and the third interview was conducted after Midterm 4. A small group of approximately 30 students was asked back in Spring 2010 to gather some additional data on retention in the chemistry series, but this data was not analyzed for this dissertation. Two students who had originally struggled with interpreting atomic spectra were asked to come in for one more interview in Spring 2011 to study how they interacted with a representation designed to guide their learning, and their responses were analyzed in Chapter 5.

The data for Chapter 3 and 4 of this study comes from the interview conducted directly after Midterm 4, which probed student understanding of quantum ideas. A total of 66 students were interviewed at this time, with the author of this dissertation personally conducting 31 of those. One interview was omitted from the dataset because the student had personal issues and could not follow through with the interview. Each researcher interviewed the same group of students over the course of the semester to ensure consistency and to build familiarity and minimize student anxiety. Students were invited to meet with each researcher in a small office room in the chemistry building on campus, and one video camera was positioned so that the student and the desk area, including writing implement and paper, were visible on the recording. Written documents of all work were collected.

Midterm #4 was administered on December 4th, 2009, and the interviews were conducted in the week immediately following the exam, during December 7th-14th, 2009. By this time, students had been exposed to concepts of the quantum model, the sub-shell nature of energy levels, and orbital models of bonding, and spectra. They had recently taken Midterm 4, and the material was still fresh in their minds. In the interview, students were asked questions about the nature of atomic structure and interaction of light with matter.

Interview Protocols

As described in Chapter 1, based on preliminary work, a set of interview questions was developed probing student understanding of atomic spectra and the quantum model. Their development involved a series of pilot testing along with cycles of review from other researchers. The type of questions, style and format were influenced by preliminary work and were informed by previous interview studies on quantum chemistry (Tsaparlis & Papaphotis, 2009; Taber, 2002).

During the development of the protocols, preliminary data showed that questions that were too specific or narrow quickly prompted memorized "textbook" responses from students, while open-ended questions appeared to better capture students' raw thoughts on the material. In addition, it was found that asking about one idea (i.e., an orbital) in two different contexts often produced two different answers from students. Thus, in the current study, questions were asked in multiple ways to probe student conceptions under slightly different contexts. During the course of the interview, for example, students were pushed to explain their thinking fully for each question. For instance, if they talked about quantization for question #1, and brought it up again during question #3, they were asked to elaborate fully the second time as well.

During the semi-structured interviews, students were asked three different questions related to the quantized nature of matter and the interaction of light with matter. The first question asked them to provide a description of the nature of the interaction between light and the hydrogen atom. The second question gave the students some data and asked them to draw both the energy level diagram and absorption spectrum for hydrogen or at the very least talk through the construction of these if they were struggling. The third question applied these concepts in a problem involving gas discharge tubes. All of the questions dealt with topics students had been exposed to during class, and questions 2 and 3 were very similar to questions that had appeared on the midterm exam.

Students were pushed to be clear and explicit about their descriptions and asked to explain each part of their answer. Students were allowed to explain things at their own pace, and the researcher asked them to explain their reasoning and justifications with as much specification as possible. The interview followed a semi-structured format, with all the questions being asked of each student, but the order and types of the follow-up questions possibly being modified depending on the flow of conversation and the ideas being presented. Details on the protocols are given below. The full protocols are included in the Appendix A.

Question #1 – Descriptive Question on Interaction of Light with Atoms
In the beginning part of the interview, students were asked to describe the atomic structure of hydrogen and oxygen. Depending on what ideas subjects brought up, they were asked to elaborate on their description of orbitals, the role of energy, what quantized means, and what discrete means. Students were subsequently asked to offer a description of light, and elaborate on their ideas of models of light as they introduced them. Then, qualitatively, students were asked to describe what happens when light hits an atom.

These questions were designed to be an easy entry point for students in the interview, and allowed students to describe their ideas of the atom and light before any calculations or specific concepts were introduced. Frequently student ideas here conflicted with their answers in later parts, perhaps signaling a return to memorization or reliance on algorithms or rote learning. Students may have become fluent in memorizing "buzz words" or "lingo", which were activated when presented with more quantitative questions later in the interview.

Figure 2.2 Descriptive Question on Interaction of Light with Atoms

1. Describe how you visualize the atom. (ask about both hydrogen and oxygen)
(sample follow up questions)
   a. What is an orbital? Probability of what? why do electrons "live" in orbitals?
   b. Have them draw a picture of the 2p orbital for O– what does this represent?
   c. Why do electrons have discrete energies? What does this mean?
   d. Describe "quantized" as if you had to explain it to someone who hasn't taken chemistry.

2. Describe what happens when light hits a hydrogen atom.
   - with an energy greater than the Ionization Energy (IE)?
   - with an energy less than the IE?

Question #2 - Quantitative Question using Data to Calculate Spectral values
In the second portion of the interview, subjects were given a table listing the first 4 energy levels in hydrogen. They were asked to draw an energy level diagram or talk it out if they were struggling along with an absorption spectrum. Along with this, they were asked to reason with the numbers given and answer questions related to ionization, absorption and emission. The table of data was directly taken from a midterm exam

given in class about the material. Students were familiar with tables and values such as these from their class work and exams.

Figure 2.3. Quantitative Question using Data to Calculate Spectral values

Question: The first 4 electron energy levels in hydrogen, H are provided in the table below.

Energy level	Hydrogen, H
n=1	-1312 kJ/mol
n=2	-328 kJ/mol
n=3	-146 kJ/mol
n=4	-82 kJ/mol

- Can you draw an energy level diagram of Hydrogen? (talk through it) what does this represent?
- Can you draw the absorption spectrum of Hydrogen? (talk through it) How much energy is needed to ionize Hydrogen?
- What happens if you shine light on hydrogen with energy of 1512 kJ/mol? 500 kJ/mol? 984 kJ/mol? 985 kJ/mol? (or slight variations of these numbers)

Question #3 - Scenario involving Gas Discharge Tube

Students were presented with a scenario involving a gas discharge tube and were again probed about their ideas related to absorption, emission and atomic structure. Subjects were asked to explain why two different gas tubes, neon and helium, were different colors, and what the possible causes of the colors might be. Students had seen examples of gas tubes in lecture, and again, the prompt itself was very similar to a midterm question given in class just prior to when the interview was conducted. This was done to ensure that students were familiar with the content and concepts asked about.

Figure 2.4. Scenario involving Gas Discharge Tube

When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?
(follow up questions)

a. Why are Ne and He tubes different colors?
b. Over time, would the tubes change color?
c. If you change the energy transferred to the tube, do you see a color change?
d. Is there any amount of energy that wouldn't light the bulb?

2.5 Data Analysis

Video Data and Transcription

For the 65 videos included in this analysis, the section of the interview that specifically dealt with the questions described above was transcribed. Due to the free-form nature of the interviews, sometimes the order of these questions varied between students, but all of the questions were asked of the students at some point during the interview. This portion of interest for each video was generally a 15-20 minute section. The researcher transcribed verbatim the student's explanation. Two student interviews used for the analysis in Chapter 5 were videotaped and transcribed in the same manner. The transcripts are included in Appendix B and C.

General description of Data Analysis:

Chapter 3 and 4 of the dissertation utilize grounded methods to analyze student interview data to answer the research questions listed in the Table 1.1. Chapter 5 involves an exploratory study to gain insight on student struggles with the content. Refer to Table 1.1 for an overview of the methods and data used for the dissertation.

Chapter 3: Characterization of Student Thinking

The first analysis will appear in Chapter 3 to answer question #1: How can student thinking about concepts related to atomic spectra be characterized? This consists of identifying dimensions of competence of four ways of thinking about quantum ideas. For this analysis, data from all interviews (N=65) was assigned a code for each of four dimensions that emerged from the data. The four dimensions were divided into 3 or 4 codes that represented a particular way of thinking about the dimension. For example, one dimension is student understanding of the probabilistic nature of electron position in the atom. This dimension is divided into 3 codes, with a code of "1" representing a classical or trajectory-based description, a code of "2" matching a hybrid classical and quantum description of electron position, and a code of "3" matching a probabilistic description of electron position. Students fell into one of these three codes from an analysis of their responses. The four dimensions of thinking were coded in this manner for each student.

Subsequently, correlations between these dimensions were examined. An analysis was performed to see if ways of thinking along different dimensions existed independently or in tandem. The strength or weakness of the connections between dimensions was studied to determine what kinds of understanding successful students exhibit. This information is useful in developing curricular tools for less successful students.

Chapter 4: In-depth look at student understanding and representation use

Analysis in this chapter relates to research question #2a and #2b (Q#2a: How do students interpret and connect representations of the energy level diagram and the line spectrum? Q#2b: How does classical thinking impact understanding of atomic spectra?)

For this analysis, a subset of student interviews (N=10) representing high, low and medium levels of normative understanding of spectra was studied using grounded methods. These interview cases were analyzed to explore the how students are demonstrating representational and conceptual mastery of atomic spectra. In particular, four types of representational and conceptual competence were found that related to student interpretation of the energy level diagram and the atomic absorption spectrum. In addition, protocols were analyzed to gain insight on how classical ideas were impacting student understanding.

Chapter 5: Guiding Students to a Normative View

In Chapter 5, two additional interviews (N=2) were conducted and analyzed in an exploratory study to address the question: Q#3: What are possible challenges in guiding students to a normative understanding of atomic spectra? Through an analysis of student protocols, two struggling students were examined in an interview as they interacted with a representation designed to scaffold their comprehension of atomic spectra. Issues related to their successes and challenges are explored.

For each analysis, the data is the students' responses to the tasks presented based on transcriptions of a videotaped interview. More detail is provided in the corresponding chapters.

2.6 Summary

In this chapter, a description of the classroom context, course organization and sample population was presented for the introductory general chemistry class from which subjects were drawn. A discussion of the recruitment and interview methodology and procedure was discussed. A summary of the interview tasks was included along with a brief overview of the data analysis techniques utilized in the study.

Chapter 3: Characterization of Student Thinking

3.1 Introduction

In this dissertation, the challenge is to understand how students are making sense of spectra and the absorption of light and at the same time how they are navigating the transition from a classical to a quantum way of thinking. One question that arises is whether the known difficulties in visualizing atoms and electrons are impacting the learning of atomic spectra, and if so, how. Understanding the ways students are thinking about atomic spectra provides tools for improving teaching and curriculum with this content.

This Chapter aims to answer the following questions:

- **Q#1: How can student thinking about concepts related to atomic spectra be characterized?**
  - What types of thinking are the most successful students using when interpreting atomic spectra?
  - Does students' spatial or probabilistic view of the atom impact their understanding and interpretation of atomic spectra?

By understanding what dimensions of quantum thinking are important to build a successful understanding, teaching and learning can be enhanced. This chapter aims to determine the types of connections between quantum ideas that are essential for student learning. The first part of the analysis is the finding and development of the dimensions of quantum thinking. Then, by looking at students who successfully interpret spectra, the strength of these connections between dimensions is ascertained. From this, it can be determined which aspects seem to be linked or necessary to be learned at the same time to understand atomic spectra. Finally, a discussion is presented of how successful students are building understanding with atomic spectra.

3.2 Data

Details on the sample population, interview protocols, and data collection techniques are provided in Chapter 2. Interview data from a sample of 65 Introductory General Chemistry students was used for the analysis in this chapter.

3.3 Analysis

The analysis in this chapter is built on principles related to grounded theory (Glaser and Strauss, 1967), a methodology used in the social sciences for analysis of qualitative data. Categories are developed and refined based on assigned codes, and there is a cycle of revision and elaboration to develop the emerging model or theory. Refer to the discussion in Section 1.4.3 for more details on this method.

Refinement and Development of Coding Scheme:

As the videos were transcribed and examined, a coding scheme was developed and refined such that:

1) the student utterances could be categorized with the dimensions;
2) different researchers were able to use the coding scheme and achieve agreement;
3) and the researcher felt the analysis captured the data effectively and had the proper levels of specificity and grain-size.

After the video segments were transcribed, a subset of 15 videos that included varying levels of student performance was chosen as a sample. As these video transcripts were examined, dimensions were developed which reflected main differences in thinking between students. The unit of analysis for this study was the approximately 15 minute section of the video that consisted of student answers to questions outlined in Figures 2.2 through 2.4. These questions were a subset of the entire interview, and occurred in one continuous section during the first part of the interview. The subsequent questions for the interview were not transcribed and used for analysis. As any new pattern of thinking or observable trend became apparent, another dimension was noted. A preliminary group of 7 dimensions was developed using exemplars from this subset. After reflection and consultation with co-researchers, specifications of these categories were further refined and elaborated, and the remaining videos were analyzed using this scheme. Full details on the dimensions are provided in the next section.

1. Deterministic to Probabilistic
2. Continuous to Discrete View of Energy Absorption
3. Unitary to Dualistic View of Light
4. Energy Conservation ideas vs. Non-energy conservation ideas
5. Inclusion of Forces vs. Non-inclusion of forces
6. Difficulties with Absorption vs. Emission vs. Transmission
7. Interpreting Spectra as differences between Energy Levels

At this point, the list was again refined and dimensions #4 and #5 were integrated into a single group. Initially both of these foundational ideas were analyzed separately. However, upon analysis and review, these two ideas were combined into one dimension that measured subjects' integration of Energy/Force concepts into their explanations. Students' inclusion of ideas related to the Coulomb attraction of the electron to the nucleus and energy conservation ideas often occurred in tandem, and one combined dimension was devised to capture that aspect of their thinking.

Because students had varying levels of exposure to instruction on the nature of light from previous science courses, it was unclear how the chemistry course had shaped their view of the nature of light (Dimension #3). This dimension was not included in the present analysis. Dimension #6 dealt with confusion between absorption, emission and transmission of light and it was unclear if this was a vocabulary/language issue or a conceptual issue from the items used in the interview. Due to the nature of the interview, there was not enough data from some students to determine their conceptual difficulties with this subject. Because of this lack of data, this dimension was not included in the analysis.

Summary of Coding Scheme:

For the student responses to the quantum questions in the interviews, four dimensions were used for the analysis in this study. Each dimensional code was assigned independently of the others, and all 4 dimensions were coded by looking at the entire transcript for the quantum portion of the interview. Two dimensional codes were assigned that measured student thinking as being on various points in a continuum from a classical to quantum understanding.

- Deterministic to Probabilistic (1→3)
- Continuous to Discrete (1→3)

For these codes, a score of 1 designated a view closer to the classical viewpoint, and a score of 3 was closer to the quantum viewpoint.

One dimensional code was assigned to gauge how subjects were interpreting atomic spectra.

- Interpreting Spectra (1→3)

This code was included because it highlighted a slightly different skill involved in understanding the material, and varying levels of competence were observed. For this dimension, students were assessed on their ability to relate two pictures to each other – the energy level diagram and the absorption spectra.

During the review of the data, another trend became apparent - the degree to which students were incorporating basic ideas about force and energy into their explanations.

- Energy/Force (1→4)

Thus, one code was assigned to this dimension to mark how subjects were integrating foundational concepts such as energy conservation and Coulombic forces into their explanations.

The process of examining the data and identifying student patterns of thinking directly spoke to the first research question – "How can student thinking about concepts related to atomic spectra be characterized?. The groupings that emerged, at least at a broad scale, provided a means to classify and characterize student thinking about atomic spectra in this chapter's research.

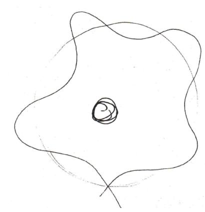
Deterministic to Probabilistic Dimension:
In the analysis of this dimension, subjects were coded on a scale from 1 to 3 based on their drawings and utterances regarding the nature of electronic position in the atom.

Students were coded a "1" if they clung to a classical or trajectory type of thinking and mentioned some sort of definite "path" or "orbit" that the electron exhibits. As was found by previous researchers, this code highlights the fact that students have a very difficult time giving up a classical deterministic viewpoint (Taber, 2002; Petri & Niedderer, 1998; Harrison & Treagust, 2000; Tsaparlis & Papaphotis, 2009).

A code of "2" was assigned to students who simultaneously expressed aspects of both deterministic and probabilistic viewpoints. Often these manifested in a picture of a "fuzzy ring" where electrons had some uncertainty in their position but still traveled in a circular orbit. This type of hybrid thinking has also been reported in the literature (Mannila, Koponen & Niskanen, 2002; Olsen, 2002; Papaphotis & Tsaparlis, 2008; Petri & Niedderer, 1998; Taber, 2002).

A code of "3" was assigned to subjects who spoke in terms of probability and acknowledged that the electron cloud model attempted to capture that the electrons were more likely to be in certain areas. The language the subjects used for this type of reasoning was less deterministic and included utterances such as "most of the time", "more likely", etc., without mentioning an orbit or specific circular path the electron takes.

Table 3.1. Deterministic to Probabilistic

Deterministic (1) • mentions some kind of "orbit"; "circle", "track", "circular path" "pathway" • describes classical circular trajectory or deterministic path -- (12) "So the orbital looks like a sphere. It's most likely for the e- to be orbiting. (is it moving in a circle?) the electron? Yes." (13) "electron floating around it in orbital 1s. Orbital is pathway where the e- is gonna be. 1s is a circle."	
Hybrid/Semi-Probabilistic (2) • limits position of electron in some way • Electron "close to or near circle" "on edge of orbital" • However, acknowledges some uncertainty in location of e- • unable to resolve the two types of thinking and expresses contradictory ideas -- (38) "The electrons are distributed mainly around the edge in an orbital. Found there most of the time." (65) "orbital... I still think of it as like a solar system except that instead of being on a defined track it can just be like anywhere roughly near the track and the density is like closer to the middle of the track I would assume would be more electrons, higher probability of it existing there"	
Probabilistic (3) • Electron has a probability to be found in orbital (not 100%) • recognizes uncertainty in position of electron, uses words like "most of the time" "95%" "don't know where it is" "mostly here", "electron cloud", "probability cloud" -- (17) "so you can't say where the electron is at any given time cause then it could be somewhere else, so the cloud is just like an area of probability of where the e- will be like some % of the time like 99% of the time , it would be in that cloud, one of the points" (27) "I guess they move around a lot but I guess if you think if you account for where each electron was over a long period of time then most of the time they will be within those shapes, I think it's like 90% of the time"	

Continuous to Discrete Dimension:
This dimension also measured students' progression from a classical to quantum regime, this time regarding absorption of energy. Up to this point in their chemistry learning, students have had very little exposure to non-continuous energy absorption, so many fall back to a classical way of thinking about energy absorption, for example that any energy can be absorbed and incorporated into the system.

Students were coded on a scale from 1 to 3 on their understanding of discreteness of energy absorption.

Subjects were coded a “1” for thinking about energy absorption as a continuous process. Subjects in this group demonstrated a threshold argument, meaning that if the energy of the photon is slightly greater than the energy difference between two levels, students said the photon energy would be absorbed and the excess would go into some other aspect of the atom. As an example, students state that the system could absorb any energy greater than the n=1 to n=2 energy level difference, and the extra energy would do something different to the electron, for example heat it up or vibrate it.

Subjects were coded a “3” in this dimension if they explained that only energies matching a difference between energy levels would be absorbed. They demonstrated an all-or-nothing thinking that is appropriate for the quantum regime. Additionally this code applied only to students who did not contradict themselves.

Students were coded a “2” if they expressed contradictory ideas of energy absorption during the interview, stating it both as a discrete or continuous process as various points during questioning. For example, students assert that “only discrete energies get absorbed” but then claim that energy of 990 kJ/mol, slightly more than the energy level difference between n=1 and n=2, would indeed get absorbed. Subjects coded in this group might also claim that both types of thinking are reasonable and express confusion or frustration at having to reconcile these two ideas.

Table 3.2. Continuous to Discrete

Continuous (1)

- admits that energy a little greater than the n_2-n_1 difference would get absorbed
- electron would then fall back to the closest lower level
- intermediate energies can be absorbed and give electron "a little more KE" "make it wiggle more" "give it heat" "extra energy doesn't do anything" "vibrate"
- ideas like "falls back to last energy level" "threshold it needs to cross before getting to next level"

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(09) "(absorb 985?) then there would be some KE associated with the electron and it would start moving (still move to n=2?) yes. (and what would the 1kJ of KE do?) I don't really know what it would do representatively. The way that I see it, it moves up and then it can start moving around and like jiggling around in it's little subshell."

(43) "I guess you could excite it to somewhere in between but it's always gonna fall back to the last energy level that it crossed. because the e- can't exist in between levels so it either has to be in one or another"

(46) "discrete means there is a certain... it's kinda like... I know neurons have a threshold kinda thing like you need that certain amount of energy before you can actually trigger a response, so it's kinda like you need a certain amount of energy it's kinda like stairs, like you need a certain amount of energy to go to the next level you can't go halfway to the stair otherwise it just goes back down again"

Discrete (3)

- Explains that 985 kJ (a little larger than the n_2-n_1 difference in H) will not be absorbed
- Clearly explains an "all-or-nothing" type of reasoning regarding absorption
- Demonstrates consistent reasoning (not contradictory)

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(41) "(985?) no it's not going to do anything, it has to be exactly right, it can't be like a little bit over the second subshell it has to be exactly on the second subshell, the light has to match up with the difference exactly, the electron can't really have Kinetic Energy in the shell because it's already there it can't really move"

(45) "(985?) I don't think in moves in that case… cause it can't go into making… I need to read up and verify this but I think it had to exactly that energy or nothing would happen... cause for IE the rest can go into KE but the electrons are always moving the same so you can't make them move faster in their little... they are just somewhere"

(11) "(985?) it wouldn't do anything. (why?) I guess it's this whole thing of quantum, like it has to be exact, it's just how it is"

Hybrid/Semi-Discrete (2)

- expresses plausibility for both discrete absorption and continuous absorption
- unable to resolve the two types of thinking, or expresses contradictions
- In course of interview, both continuous ("threshold") thinking and "discrete" absorption ideas are simultaneously used

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(15) "(990 kJ) um, I'm tempted to say one of 2 things. (laughs) the first thing I was going to say was that it will still go from 1 to 2 except it would only be up to 984 and the remaining energy would just be absorbed. I'm also tempted to say nothing will happen cause it's not at a specific energy"

(20) "Either, yes, it does affect the electron and pushes it up and then there is extra energy that could increase the temperature or could increase some movement around and not actually fully excite an e- or that e- into the next orbital. Or it could just pass through because it doesn't properly fit the wavelength it doesn't properly fit the electron and it doesn't hit it."

(54) "It depends. I struggled with this for 10 minutes on the midterm. Either, yes, it does affect the electron and pushes it up and then there is extra energy that could increase the temperature or could increase some movement around and not actually fully excite an electron or that electron into the next orbital. Or it could just pass through because it doesn't properly fit the wavelength it doesn't properly fit the electron and it doesn't hit it. On the Midterm, I decided 50/50!"

Interpreting Spectra Dimension

In addition to shifting toward a quantum type of thinking, students are faced with a multitude of representations related to energy absorption. Students are asked to interpret and understand the energy level diagram, absorption and emission spectra.

The "Interpreting Spectra" dimension was developed in order to gauge student fluency in translating and relating two representations that are so central in understanding how absorption of light occurs – the energy level diagram and the atomic line spectrum. This data mainly comes from the quantitative question in the interview protocols where students are asked to use the data provided to construct both an energy level diagram and spectrum.

The full description of how to normatively relate these two representations will be discussed in Chapter 4. Subjects were coded a "1" if they did not exhibit any type of "difference" thinking and instead claimed, for example, that the exact numbers corresponding to the energy levels matched the energies of absorption that occurred, literally matching the numbers in the table to the spectral lines. This group was marked by a lack of "difference" thinking – they did not acknowledge that a difference in the energy levels was somehow correlated to the lines in the spectra.

Students were coded a "3" in this category if they correctly interpreted the energies of the spectral lines as matching differences of energies in the energy level diagram.

Students were coded as a "2" if they expressed contradictory ideas during the interview, stating that the energies of spectral lines both match the energy level values, as well as match the differences between energy levels. Students were coded a "2" if they verbalized their inability to decide between the two types of thinking. These students were deemed to be at an intermediate state of understanding because they acknowledged the two different ways of thinking but were unable to come to a decision. This showed that they were making an effort to grapple with both classical and quantum ways of thinking. Their acknowledgement of quantum behavior and attempted integration, although sometimes faulty or inconsistent, at least showed an appreciation for a quantum way of thinking, in contrast to the coding group "1".

Table 3.3. Interpreting Spectra

"Difference" Reasoning		
(Score 1) • no correlation between absorption peaks to differences in values of energy levels • may claim absorption happens exactly at the energy levels listed in table – no differences calculated • or may express confusion or inability to calculate absorption values (10) "(which energies of light are absorbed?) so you've got 1312, and then like crap, is this the absorption spectrum? you have like 1312 and 328 - am I drawing that right? (what do you think? why 328?) because that's where the second energy level is. I don't know if I'm doing this right, hmmm I'm mixed up for some reason" (39) "so if you're dealing with, so these would be the diff wavelengths the energy like you would be able to well if I do that so pretend it would be this, so it would adjust according to these peaks so 1312, so it would peaking there and at 82, 83 so they absorb at these energies"	(Score 2) • presents contradictory arguments • verbalized inability to decide between two ideas (26) "not sure how much energy it takes to excite it... the difference between n=1 and n=2, but I'm not really sure... I see these numbers as the energy it takes to remove the e- if it was in these levels, but I am not sure if the difference in these numbers is what it takes to excite the electron (03) "you can subtract the 2 energies, but I don't really know how to translate it to... (possible jumps?) well, n_2 to n_1 or 3 to 1 or so on (go up?) I was thinking that but it can move from there but I'm confused... I've always associated this with the light that it releases, so it would have to jump down levels to release light and so I just remember during lecture I write 1 to 2 and 1 to 3, and so now I'm confused..."	(Score 3) • correctly interprets spectral lines as corresponding to differences in values of energy levels (07) "oh ok, um, so yeah I guess you would have to find the differences between each of these, like photons of varying wavelength would hit the electron. And if you had one that was the proper energy that equaled the distance between that and that or that and that, it would be promoted to that level, and so that amount of energy would be absorbed, and so those photons wouldn't be transmitted through, and that's how you would know that they'd been absorbed" (53) "and the next one should be around 900, the difference between these two, and that's the energy required for it to go from n=1 to n=2, that's specific, so if it's like 1000 kJ/mol, nothing would happen, it would just be transmitted (*the photon would be transmitted through the gas*)"

Energy/Force Dimension

In their explanations of spectra, two additional foundational concepts were observed in the data: 1) energy conservation ideas and 2) Coulombic attraction of the electron to the nucleus. Both of these ideas had been covered in previous sections of the course, but students' utilization of these ideas while explaining atomic spectra offered them a way to make sense of the topic. These ideas are discussed further below:

1) Energy Conservation

Students were found to bring in energy conservation when discussing absorption and emission of light. For example, students recognized that as an electron transitions from a lower energy level to a higher energy level, light energy is absorbed or put into the process. Conversely, when an electron transitions from a higher energy level to a lower one, the corresponding amount of energy is released or emitted as light.

2) Coulombic attraction of electron to nucleus

Students were found to relate the various energy levels of the electron to the nuclear attraction it experiences. They rationalized that the electrons that are closer to the nucleus will also have a lower energy level, and to "pull" or move the electron to a higher energy level required an energy input because the electron was moving farther away from the nucleus that it was attracted to.

Interestingly, students who talked about the Coulombic attraction of the electron to the nucleus during the course of the interview and did not talk about energy conservation did not exist in the interview sample, and so a code was not assigned to this category.

Students were coded as a "1" in the Energy/Force dimension if they did not introduce any ideas related to energy conservation or Coulombic forces.

Students were coded as a "2" if they only brought up ideas related to conservation of energy in their interview responses. Here, students were thinking about energy ideas as a type of conversion process or algebraic sum or difference problem. Little connection to the spatial or mental picture of the atom was included in their descriptions. For example, students in this group did not mention the attractive force of the nucleus.

Students were coded as a "3" if they included both Coulombic force and energy conservation principles, but mentioned them both as distinct conceptual entities. The concepts were not interconnected and only came up separately as answers to different items. Students did not combine both force and energy into their answer for one question during the interview.

Students were coded as a "4" if they included both energy conservation and the attractive force of the nucleus in the answer to one question during the interview. This group, as is explained by the exemplars in the table below, were able to relate energy levels to a physical picture of the electron in the atom, and note that to move an electron from a lower to higher energy level, energy must be put into the system. The electron is moved further away from the nucleus in this case and an energy input is required to overcome the attractive force of the nucleus and move the electron away from the positive center.

Table 3.4. Energy/Force

➢ **Energy Conservation:** Use terms like: "releases same amount" "transferred" "conserved" "not wasted" "has to go somewhere" "losing energy as light" "releasing that energy" "that amount that matches the difference would be absorbed" "translates into" "add energy the e- move faster" "enough to overcome energy barrier" "energy put in and e- is pulled outwards" "electron loses energy" "electron gains energy" "more energy to work with"
➢ **Coulombic Forces:** Uses terms like: “Coulombic force” “nuclear attraction or force” "hard to remove" "easy to remove" "forces" "pull" "attraction"
1 – No mention: No mention of energy conservation or Coulombic forces (15) with an absorption spectra, an e- is moving up to a different orbital, as opposed to an emission spectra where it's going down, I guess when I illustrate it the arrows going down are the emission spectra, absorption is going up **2 – Energy Only:** Student mentions energy conservation, but does not mention attractive force of nucleus. They visualize it as a sum or difference type of energy problem, and make no connection to the physical picture of atom. (08) “Emits light because the energy has to be conserved it can't just disappear” (10) “when it moves down, because it's at a lower PE level and when you do that energy is released.” **3 – Distinct Forces and Energy:** Student brings up ideas of energy conservation and Coulombic forces, but never uses both concepts to answer the same item. Student has distinct conceptual applications for each. **4 – Integrated Force and Energy:** Student is able to explain absorption in terms of both energy and Coulombic forces, and integrates both concepts in explaining answers to items. (45) “it relates to how closely the electron is attached to the atom, so if the atom is a really high energy it's really easy to remove and if it's a really low energy it's really hard to remove so you can like look at the electronegativity and how big the atom will be you predict that as you go across the periodic table, the energy gets smaller because it's harder to remove e-“

Inter-rater reliability

Of the sample of interviews, the primary researcher coded all 65 videos. Then, 22 transcripts were double coded by 2 different chemistry education co-researchers. One researcher coded 10 transcripts, and another researcher coded 12 different transcripts. This subset of 22 videos was chosen to include a variety of coding levels for each category. The co-researchers were given detailed written coding schemes as well as verbal instructions describing the coding process. They were given the transcripts of the students and asked to assign four codes based on the written data.

The Cronbach’s Alpha value for the inter-rater reliability for each code is listed below. This is based on a sample of 22 interviews that were double coded:

Table 3.5. Inter-rater reliability

Based on N=22	Cronbach's Alpha	% Agreement
Deterministic to Probabilistic	0.889	86% (19/22)
Continuous to Discrete	0.969	91% (20/22)
Interpreting Spectra	0.950	86% (19/22)
Energy/Force	0.989	95% (21/22)

An alpha value over 0.8 signals good internal consistency, so these results show that the coding was overall reliable. When the codes were not in agreement, 9 instances out of 88, the codes from the primary researcher were used for the analysis.

3.4 Results and Discussion

The questions guiding the analysis in this chapter are:

- Q1: How can student thinking about concepts related to atomic spectra be characterized?
  - What types of thinking are the most successful students using when interpreting atomic spectra?
  - Does students' spatial or probabilistic view of the atom impact their understanding and interpretation of atomic spectra?

1. How can student thinking about concepts related to atomic spectra be characterized?

From the data and analysis, student thinking about atomic spectra was characterized in three ways:

1. Reasoning about energy absorption in a discrete vs. a continuous way
2. Interpreting atomic spectra in a literal way by matching spectral line values exactly to energy-level values or using a "difference" reasoning by matching spectral lines to differences in energy levels
3. Reasoning about energy level transitions by tying back ideas to the physical model of the atom and nuclear attractive forces, or in terms of energy conservation, or both.

Three dimensions developed, Continuous to Discrete, Interpreting Spectra, and Energy/Force, explain how student thinking about atomic spectra can be characterized. The transition from a deterministic to a probabilistic viewpoint has been discussed in the research before, but the newly observed dimension of a continuous to discrete way of thinking about energy absorption emerged as another aspect of student understanding. Just as students hold onto classical trajectory-like arguments about electron position, they also hold onto classical views of energy absorption – i.e., the extra energy will "heat" up the atom or cause "it to vibrate". Thus, when presented with discrete absorption and quantized energy levels, the students cling to classical ideas along their path to understanding.

Table 3.6. Overall Results (4 Dimensions)

	Deterministic (1) to Probabilistic (3)		**Continuous (1) to Discrete (3)**		**Interpreting Spectra (3 = correct Difference reasoning)**		**Energy/Force**	
Code	No. of Subjects	%	No. of Subjects	%	No. of Subjects	%	No. of Subjects	%
4	-	-	-	-	-	-	39	60%
3	44	68%	38	58%	41	63%	5	8%
2	17	26%	10	15%	12	18%	18	28%
1	4	6%	17	26%	12	18%	3	5%
Total	65		65		65		65	

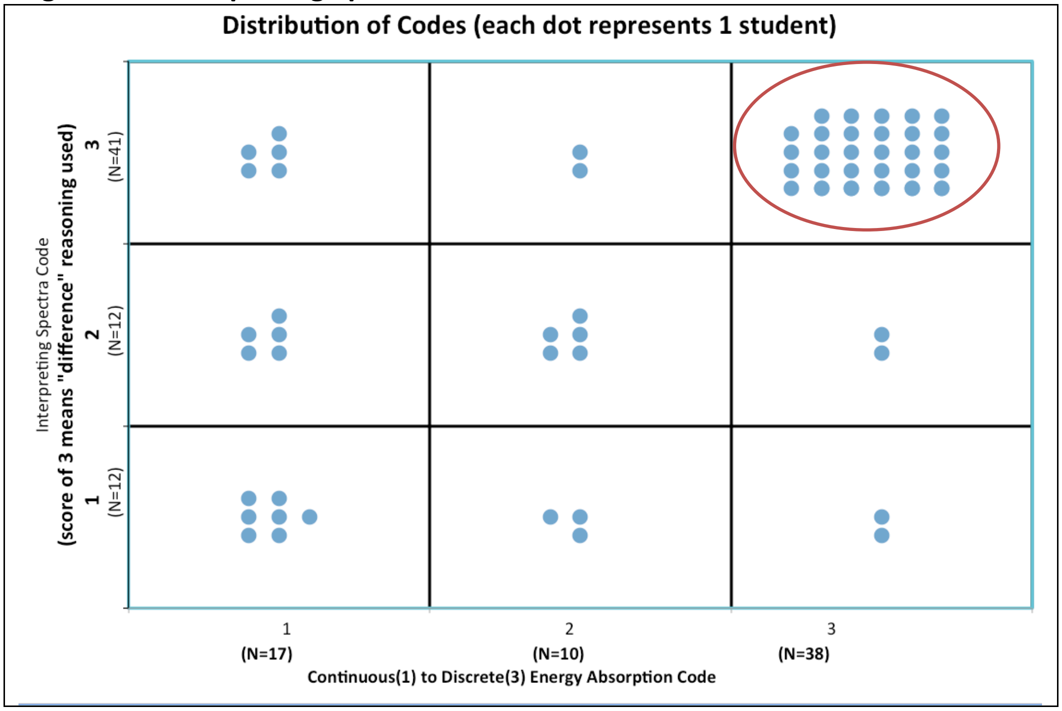
It is apparent from the data that there are significant numbers of students at each coding level. While in this sample, a majority of students, 68%, scored a 2 or a 3 in their probabilistic interpretation of the electron, only 58% of the sample correctly describes discrete energy absorption with a code of "3", and only 63% correctly match the spectra to differences in energy levels. These two dimensions of student understanding, a discrete energy reasoning and a difference reasoning, reflect a prevalent struggle that students in this sample group deal with. By extension, these struggles also very likely manifest in the general chemistry student population to a similar degree.

2. What types of thinking are the most successful students using when interpreting atomic spectra?

2.a. Students who grasp the concept of discrete energy absorption also correctly interpret energies of spectral lines as matching energy level differences.

In Figure 3.1 below, each dot represents an individual student. It is remarkable that out of the 38 students who scored a 3 on the "Continuous to Discrete" dimension, 34 of these students also interpreted the spectra correctly. This is strong evidence that the skills involved in interpreting spectra (i.e., realizing that the spectral lines correspond to a difference in energy levels) are strongly associated with an ability to describe energy absorption in a discrete fashion. These two slightly different skills are both important components of understanding spectral lines. A Chi-squared analysis on these results yields a Chi-squared value of 29.3295, p-value = 6.7E-06 (<0.05) which shows that the two dimensions show a significant association.

Figure 3.1. Interpreting Spectra and Continuous to Discrete Dimension



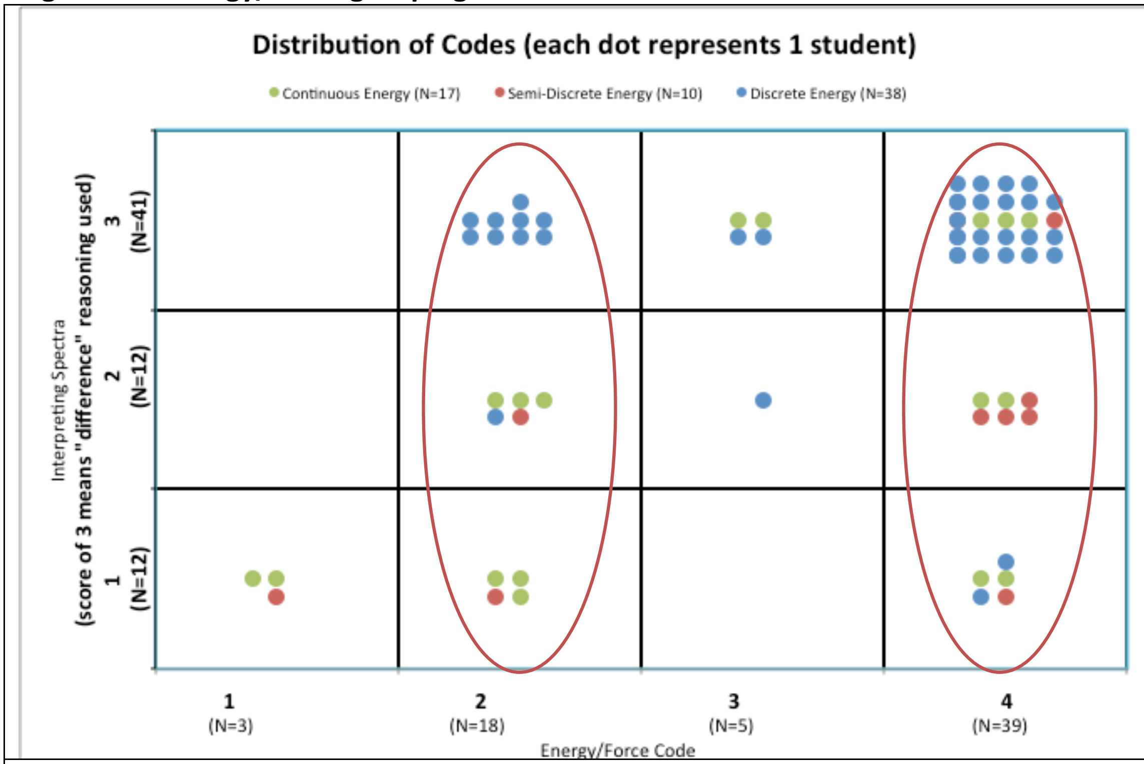
These two concepts have a strong relationship with each other, and 34 of the 38 students who scored a "3" in the Interpreting Spectra dimension, are able to grasp both these ideas in tandem to explain atomic absorption of light. Thus, students in the sample population mastered two separate but related ideas in order to understand spectra – 1) that energy will only be absorbed that matches a difference between energy levels, not any continuous amount higher than some threshold value and 2) the lines in the spectra correspond to this exact energy level difference.

These two dimensions of understanding are learned at the same time when making sense of atomic spectra. A code of "3" in the interpreting spectra dimension indicates a representational competence of the translation between the two diagrams, and a code of "3" in the discrete to continuous dimension demonstrates an understanding of what the discrete line means in the spectra. Successful students are able to grasp these two dimensions in conjunction to gain a full understanding of atomic absorption of light.

2.b. Two groups emerged – those who used only Energy conservation arguments, and those who used Energy and Force arguments in an integrated fashion. However, both groups successfully interpreted spectra.

Along with the difference reasoning and discrete absorption reasoning, Figure 3.2 below shows how the Energy/Force dimension interacted with these other two dimensions. Again, each dot represents one student, and here the colors of the dots signify the Continuous to Discrete code.

Figure 3.2. Energy/Force groupings

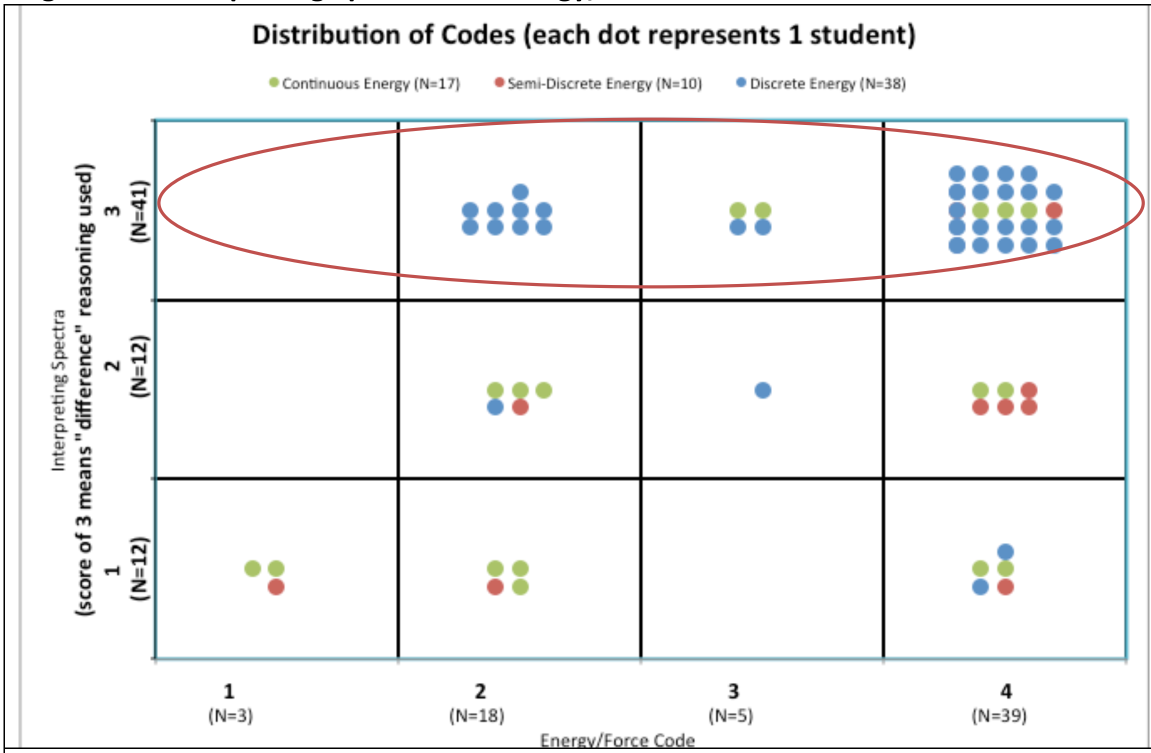


Interpreting Spectra Code and Energy/Force Code (colored by Continuous to Discrete Code) –Students split into 2 groups – those using only energy arguments (N=18) and those using Energy and Force arguments in an integrated fashion (N=39)

Students split into two major groups based on the Energy/Force dimension– those using Energy Conservation ideas (N=18), and those using Energy conservation AND force ideas (N=39).

Although the two groups differ in how they integrated foundational concepts, they both include students who correctly applied a difference type reasoning to understand spectra, as is shown in Figure 3.3.

Figure 3.3. Interpreting Spectra and Energy/Force Dimension



Interpreting Spectra Code and Continuous to Discrete Code (colored by Energy/Force Code). Both Energy/Force groupings are able to demonstrate "difference" reasoning. Students in the red circle above include Energy/Force code of "2" as well as "4".

The group incorporating Coulombic force arguments along with energy conservation arguments has a much more detailed and articulated understanding of the energetics of the transitions between energy levels. These students are using the concept of force as a mediating factor to make sense of atomic spectra, and are connecting ideas of atomic structure and the spatial model of the atom to the process of absorption. The interpreting spectra code has a limitation in that it is not assessing students' appreciation for the physical model of the atom, only the facilitation in translating between two representations. Thus, the group using only energy arguments is also able to correctly interpret spectra, however at a less detailed level.

It seems that for a large number of students (N=39), bringing in force arguments is a way to think about atomic spectra. Students were not prompted about Coulombic attraction in the interview, they brought in these arguments themselves. This is an interesting finding because in most textbooks and presentation of this material, force is rarely mentioned while describing the creation of atomic line spectra, and 60% of the sample population is including both energy conservation and the Coulomb attractive force in their answers. This perhaps signals that it is a valuable scaffold for students to make sense of atomic spectra. In addition, this may indicate a need for assessment items that probe for student integration of force ideas with interpretation of atomic spectra, which is also currently not a common occurrence in instruction.

The use of force seems to act as a foothold for students as they are traveling from the classical to the quantum regime. This will be discussed more in-depth in the next chapter where a closer look is taken at the interview responses.

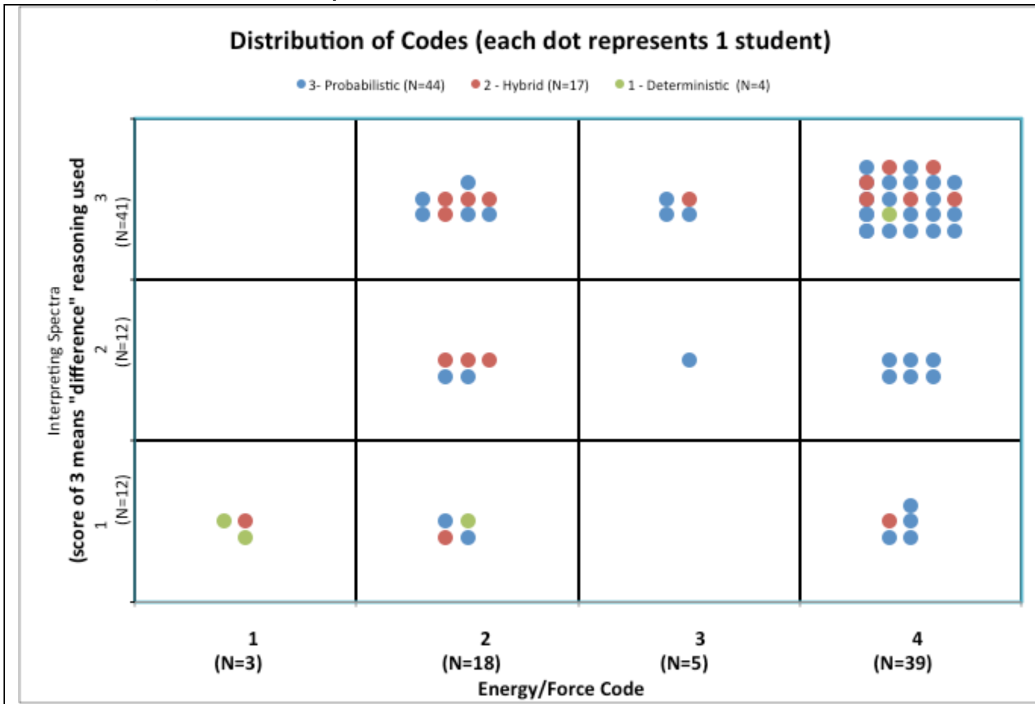
3. Does students' spatial or probabilistic view of electron position in the atom impact their understanding and interpretation of atomic spectra?

3.a. Mastering the Probabilistic Nature of electron position has little impact on students' ability to interpret spectral lines.

In the chart below, the interplay of the Probabilistic to Deterministic dimension is displayed along with two other dimensions. A majority of students (N= 44 or 68%) described the atom in some way in terms of a probability. Of the remaining students who expressed a deterministic or hybrid model (N = 21), there seems to be no pattern that emerges linking this to their understanding of discrete energy absorption or the interpretation of spectral lines. A Chi-squared analysis on these results yields a Chi-squared value of 9.3087 with a p-value = 0.05383 (> 0.05) which shows that the two dimensions do not show a significant association. The spatial understanding of electron position in the atom, as an orbit-like trajectory vs. an electron cloud, seems to have no significant impact on their interpretation of spectra, at least in this current assessment.

These two concepts, a probability view of the electron position and interpretation of spectra are independent concepts in students' minds. One reason for the original research question was to determine whether a deterministic viewpoint hinders interpretation of spectra, but the data shows that it does not. Students can still hold a semi-classical picture of the electron orbiting the nucleus and still successfully interpret atomic spectra. For example, the Bohr model consists of an orbit-like trajectory and absorption and emission is commonly described as the electron jumping from one ring to another. This model still works for interpreting spectral lines, and thus these two ideas do not conflict with one another, which the data supports. These two ideas are logically distinct and they can be understood independently from one another. A richer assessment concerning atomic spectra might ask students to combine the orbital picture with the spectral diagram to push students to connect ideas about orbitals and energy level transitions.

Figure 3.4. Interpreting Spectra and Energy/Force Dimension (colored by Probabilistic/Deterministic)



No correlation between probabilistic thinking and interpretation of atomic spectra. The colored dots are distributed throughout the interpreting spectra coding categories.

3.5 Summary

In this chapter, various dimensions of student thinking about concepts related to atomic spectra were identified and elaborated. Gauging student understanding on a scale from discrete to continuous, and judging their proficiency of difference type thinking are both ways to understand student comprehension of the material.

Sixty percent of the sample population, 39 out of 65 students interviewed, were found to incorporate Coulombic force and energy conservation arguments when explaining and describing spectra signaling a possible foothold for students to depend on as they are moving from the classical to quantum regime. Students were also found to master the idea of discrete absorption and difference thinking when interpreting spectra in tandem. A successful understanding of atomic spectra for most students includes both a mastery of discrete (not continuous) energy absorption and the understanding that the energies of spectral lines correlate to differences of energy levels.

Finally, students who successfully interpreted spectra did not necessarily have a probability view of electron position, signaling that these concepts, as they were instructed, do not strongly affect each other, at least as they were assessed.

Chapter 4: In-depth look at student understanding and representation use

4.1 Introduction

The analysis in this chapter aims to answer the following questions:

- **Q#2a: How do students interpret and connect representations of the energy level diagram and the line spectrum?**
- **Q#2b: How does classical thinking impact understanding of atomic spectra?**
  - What classical concepts may be hindering understanding of atomic spectra?
  - What classical concepts may be productive or useful footholds in understanding atomic spectra?

Part 1 of Chapter 4 specifically addresses question #2a above: How are students interpreting and connecting representations of the energy level diagram and the line spectrum? A detailed discussion of the relevant representations is presented with excerpts of data from 8 interview cases to analyze student representation use along with conceptual understanding. An empirical trajectory is developed that maps out student learning patterns.

Part 2 of Chapter 4 addresses question #2b above: How does classical thinking impact understanding of spectra?. Based on literature to date, it is evident that students incorporate their classical ideas into learning of quantum chemistry. The analysis in this part aims to discover what types of classical thinking are present in the sample population as they interpret spectra. Data from student interviews is examined to explore in-depth how students' classical ideas are hindering or helping their understanding of atomic spectra.

4.2 Data

Details on the interview protocols and procedure are given in Chapter 2. Responses to the same tasks from Chapter 3 are analyzed in this chapter, and detailed description of the task is given in Figures 2.2 through 2.4. In particular, the questions in Figure 2.3 are a focus of this analysis, although responses to all three types of questions are considered.

Figure 2.3. Quantitative Question using Data to Calculate Spectral values

Question: The first 4 electron energy levels in hydrogen, H are provided in the table below.

Energy level	Hydrogen, H
n=1	-1312 kJ/mol
n=2	-328 kJ/mol
n=3	-146 kJ/mol
n=4	-82 kJ/mol

- Can you draw an energy level diagram of Hydrogen? (talk through it) what does this represent?
- Can you draw the absorption spectrum of Hydrogen? (talk through it) How much energy is needed to ionize Hydrogen?
- What happens if you shine light on hydrogen with energy of 1512 kJ/mol? 500 kJ/mol? 984 kJ/mol? 985 kJ/mol? (or slight variations of these numbers)

In this Chapter, excerpts from transcripts of ten students are analyzed more closely. These ten students were chosen from the overall sample group such that their responses represented a range of ideas. Two students were chosen who scored a “1” on the interpreting spectra dimension as is described in Chapter 3; four were chosen who scored a “2”, and four who scored a “3”. This was done to more closely examine how different types of students were making meaning of representations. The students’ full transcripts are presented in Appendix C. In the transcripts below, an “I” designates the interviewer. Notation in square brackets indicates non-verbal actions or communications such as gestures. In the transcripts, ellipses indicate a pause in the conversation. All student utterances were transcribed verbatim. Students are referred to by their code number (i.e., Student #7) in the transcripts and analysis below.

Table 4.1. Assigned Codes from Chapter 3 of selected interview cases

Student Number	9	10	18	26	28	52	40	65	23	66
Deterministic (1)/ Probabilistic (3)	3	2	3	3	2	2	3	2	3	3
Continuous (1)/ Discrete (3)	1	1	2	1	1	1	3	3	3	3
Interpreting Spectra Code	1	1	2	2	2	2	3	3	3	3
Energy/Force Code	4	2	4	4	2	2	4	4	4	4

4.3 PART I: How are students interpreting and connecting representations?

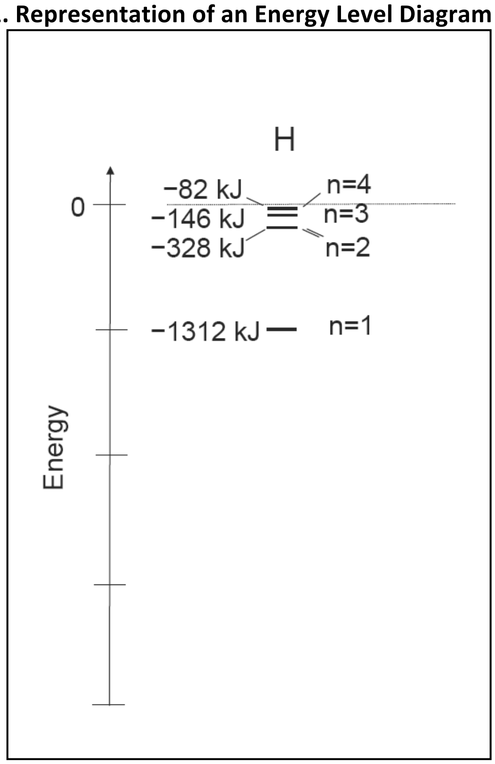
4.3.1 Description of Representations

When learning about the absorption and emission of light, students are asked to bring together models and representations dealing with atoms, light, energy levels, and spectra. A review of the representations referenced during the study is presented.

As mentioned in Chapter 1, two main representations used during instruction of atomic spectra are: 1) the energy level diagram and 2) the absorption spectrum. Students are exposed to both these representations in lecture, in online homework assignments and in their textbook.

First, the representation of the energy level diagram as shown in Figure 4.1 symbolizes how the different energy states of the electron in the hydrogen atom relate to one another. This is depicted as a vertical arrow like a "number line" with energy becoming more positive the higher up you are on the arrow. The units for this scale can be J/mol, kJ/mol, eV, etc. The energy states of the electron are depicted as short horizontal line segments, and a designation as "n=1" is listed adjacent to the line segment to denote that this is the quantum level with the primary quantum number of "1".

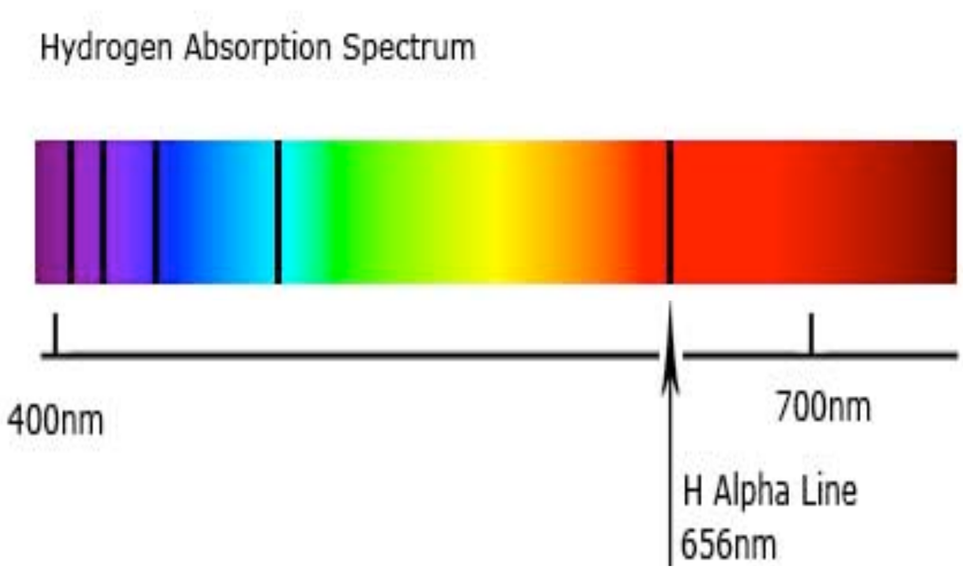
Figure 4.1. Representation of an Energy Level Diagram of Hydrogen



To explain this representation using Palmer's (1978) framework, the represented world is the possible energetic states of the electron, and the representing world is a series of horizontal lines (and numbers and labels). The correspondences or operational relations which connect the two worlds are an understanding that if an electron is at the "n=1" level, or has an energy of -1312 kJ/mol, it is one possible state the system can be in. The only other possible states are represented by the other horizontal dashes (i.e., n=2, n=3, n=4), and the electron is not allowed to exist in a place on the paper or an energy state that is not designated by a horizontal line. This is the gist of what a professional chemist means to convey in this diagram.

The second representation is a diagram representing the atomic absorption spectrum of hydrogen. When light shines on a sample of hydrogen atoms, the atoms absorb very specific wavelengths of light. The electrons absorb the energy and as a result have higher potential energy, which means they must exist in a higher energy level. Figure 4.2, shows what actual experimental output looks like observing light that is transmitted from a sample of hydrogen that is bombarded with light. When light shines on a sample of hydrogen, the wavelengths of light that are absorbed are plotted on an absorption spectrum. The black lines signify that no light of that color was detected which thus indicates which wavelengths of light were absorbed by the sample.

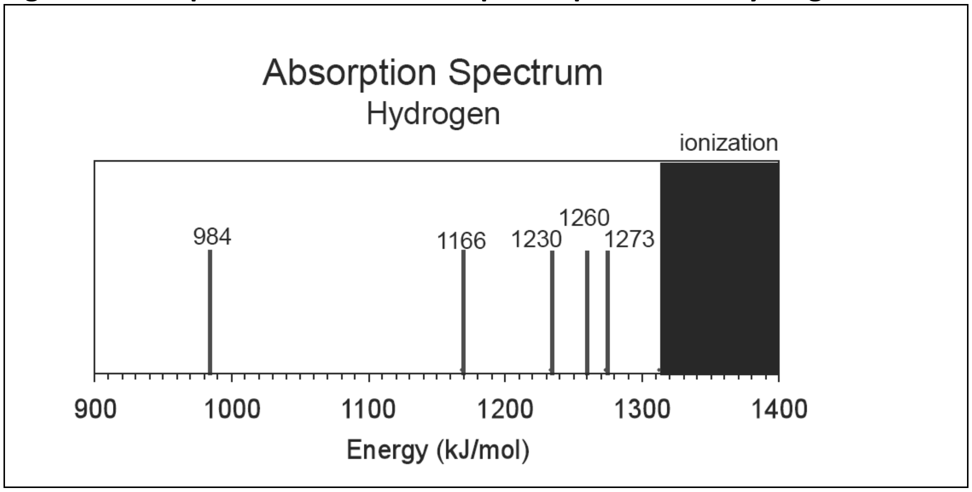
Figure 4.2. Hydrogen Absorption Spectrum – simulation of experimental output



(taken from http://www.astronomyknowhow.com/hydrogen-alpha.htm)

Because it is more difficult to work with colored representations while solving problems with pencil and paper, students require a more simplified version of this output. Thus, they deal with the following representation of the spectrum as shown in Figure 4.3. Note the energy scale here is represented in units of energy, not wavelength, so the lines appear to be reversed from the picture above.

Figure 4.3. Representation of Absorption Spectrum of Hydrogen



In this representation, the energy is plotted on the x-axis. If absorption occurs at a particular energy, this is represented by a short vertical line on the plot. The y-direction does not have a stated axis and all the lines are drawn to be the same height, highlighting points on the linear scale. In this figure, the value of the energy depicted by each line is written directly above the line. When the ionization energy of the atom is met or exceeded, in this case any energy greater than or equal to 1312 kJ/mol, the electron is separated from the nucleus, and any amount of energy can be absorbed in this state. Here, any excess energy beyond what is needed for ionization is transferred into the kinetic energy of the electron. Because the electron is no longer in a bound state, its energy levels are not quantized, shown by the solid black region.

Using Palmer's framework (1978), the represented world is the experimental output that the spectrum corresponds to, the energies of light that are absorbed and transmitted. The representing world is the series of vertical lines and the empty spaces between them. The set of rules required for the translation is what is described in the previous paragraph that explains how the representation is produced from the actual experimental output.

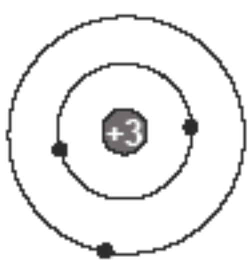
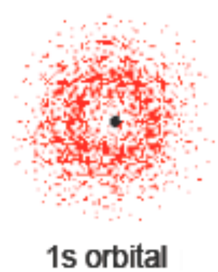
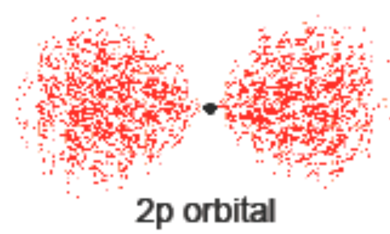
In some sense, both the energy level diagram and the absorption spectrum are informationally equivalent (Palmer, 1978) in that both diagrams are able to show what discrete energies are absorbed. Since one of these representations can be calculated and derived from the other, one can be considered a derived representation of the other.

It is this translational process that can cause tremendous difficulties for students. When students are asked to interpret both the energy level diagram and the spectra, students need to master a set of skills or processes, including:

- Ability to understand that the differences between energy levels in the energy level diagram (and only those specific differences) are what show up in the absorption spectrum
- Ability to understand that the colors of light correspond to different energies, and a larger energy transition (i.e., from n=1 to n=4) will absorb light with larger energy, and different color
- Ability to understand the relationship between wavelength and energy, for example that lower energy light has a larger wavelength

In addition to these particular representations, students also access their prior knowledge of the structure of the atom in order to interpret the lines in both the energy level diagram and atomic spectrum. Two atomic representations presented in the introductory chemistry class are 1) the Bohr or "solar system" type model and 2) the Schrödinger or orbital model as shown in Figure 4.4. While the Bohr model depicts electrons on concentric rings that represent each energy level, the orbital model consists of a probability plot of electron position for each energy state. For example, the 1s orbital is in the n=1 state.

Figure 4.4. Representations of the Atom

Bohr Model	Orbital Model
	 

As the selected transcripts that are explained in the following sections show, students often rely on their prior knowledge of the structure of the atom to make sense of the energy levels and spectral lines. These are foundational concepts that assist students in interpreting and translating between the energy level diagram and the absorption spectrum. Students may reason about the Coulomb force acting on the electron in the n=1 state versus the n=2 state to justify that there needs to be an input of energy in order to excite the electron to a higher energy level.

Each of these representations (energy level diagram, absorption spectrum, Bohr model and orbital model) assigns different symbolic conventions. These differences are contrasted in Table 4.2, which includes a comparison of how each representation depicts the same idea.

Table 4.2. Differences in depiction of certain aspects of atomic absorption of light in each representation

	Representation			
Idea	**Energy Level Diagram**	**Absorption Spectrum**	**Bohr Model**	**Orbital Model**
Energy Level	Horizontal Line (labeled n=1)	(indirectly represented)	Circle (inner concentric ring labeled n=1)	(the orbital has an associated energy, though not depicted)
Electronic transition	Arrow (i.e., from n=1 to n=2)	Vertical Line (Energy associated with transition)	Arrow (i.e., from n=1 circle to n=2 circle)	(Not depicted)
Infinite Separation of electron and nucleus	Zero of energy	Black region (past Ionization Energy)	(not depicted)	(not depicted)
Light	Wavy arrow coming in at angle	Vertical line	Wavy arrow coming in at angle	(not depicted)

Thus, an expert chemist may see the energy level diagram, match it to the picture of the atom, and understand that exciting an electron from the n=1 to the n=2 state requires energy since the electron is being pulled further away from the nucleus into a less stable or higher energy configuration. In order to raise the electron to a higher potential energy state the electron needs to absorb energy to uphold conservation of energy. Thus the absorption of a particular wavelength of light becomes represented as a black band in the absorption spectrum for the corresponding color. As is evident, there are numerous representational translations in this process, along with a connection to the physical forces involved in holding the electron to the proton. This complex set of inferences and understandings is perhaps an illustration of "disciplined perception" (Stevens & Hall, 1998) where experts in a field can "quickly register perceptual features that are relevant to their particular practice, features invisible at a glance to non-experts." The challenge with this material is to have educators find a way to allow novice chemists to "see" what they see, by scaffolding representations effectively and making these connections and assumptions explicit.

Another issue involved here is the new introduction in students' minds of a quantum way of thinking, instead of the usual classical or continuous way of thinking they are familiar with. This may be one of the first times that students have been exposed to quantum concepts like quantized energy levels and discrete energy absorption. Note that if the n=1 to n=2 transition requires 984 kJ/mol of energy, then 983 kJ/mol or 985 kJ/mol will not affect the electron, and the light would be transmitted. If 985 kJ were absorbed, it would appear as an additional black line in the spectrum, but as is evident in Figure 4.3, only one energy value at 984 kJ/mol is absorbed. If light hits an atom with more than the energy required to move it from the first to the second energy level, nothing will happen because the energy of light must exactly match the difference between energy levels; it is an all-or-nothing process. The photons of light also contain specific amounts of energy and the energy of the light cannot be split up or partitioned in some way.

4.3.2 Analysis of Data

Based on the grounded approach to analysis of the data, four main types of behavior in interpreting and navigating between the representations and conceptual mastery were found.

There were 4 types of behavior that were observed and will be discussed in the following analysis:

A. **Literal Reasoning**
B. **Threshold Reasoning**
C. **Exact Difference Reasoning**
D. **Meta-Reasoning**

Each type of reasoning is described with excerpts from transcripts from student interviews.

A. Literal reasoning

When asked to construct an absorption spectrum from given energy levels, students in this group drew peaks in the spectrum that had energy values that exactly matched the numerical values of the energy levels. Thus, to some extent they saw both representations as being equivalent, but one was merely rotated 90 degrees.

Student 28

Student 28 performed about average on related midterm questions on Midterm #4, and scored a "1"on the Interpreting Spectra dimension. She was an interesting case because she confidently asserted early in the interview that differences of energy are important when looking at excitation of electrons, but in her drawing of the absorption spectra as is depicted in Figure 4.3, she fell back to labeling the peaks with the same numbers as the energy levels. Then she became confused and frustrated when asked about which energies of light would be absorbed.

43 I: 14:30 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table] What does that mean?

44 28: This is the minimum amount of energy, cause this is the IE of H, so this would be the minimum amount of energy needed to eject an electron. So the electron could like, so let's say this amount was given , the amount added to the electron or the atom then the electron would move from this to level to this level and would fall back down after that and then so that difference is that amount of energy that you would need.

47 I: 15:42 Can you draw the absorption spectrum of Hydrogen?

48 28: So the absorption spectrum would look like this. So these would be the lines that are the energies that would be absorbed. So these are just the black lines and the rest of them are colors.

59 I: 18:04 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

60 28: Then I would say that, that would be greater, so then it would I think that in that case, the electron would just go off completely.

61 I: Would any other electron move?

62 28: I don't know, now I'm confused. I know that would be the energy needed to eject the electron but then I'm not like back to that thing where I said like when one electron moves off another one goes up to take it's place. I don't really think that's the case but I'm not really sure.

63 I: Why not?

64 28: Just because I know that the excess energy outside would go to the emitted electron for kinetic energy. But then I'm not sure if the excess energy would also go to sending the electron up, and I also remember the excess energy is also absorbed, I think. I never really thought about this lecture that much!

65 I: 19:36 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

66 28: I don't think it would do anything just because it's not one of the specific energies.

67 I: Any energy below 1312 do anything?

68 28: I feel like if it was below then it could send an electron up an energy level but not eject it.

69 I: Can you give me an example?

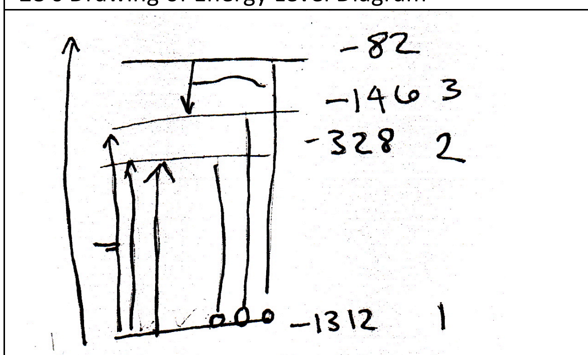
70 28: Like maybe the 328? But then I feel like that's not right either, I don't really know.

71 I: So what if it was 328? That magic number?

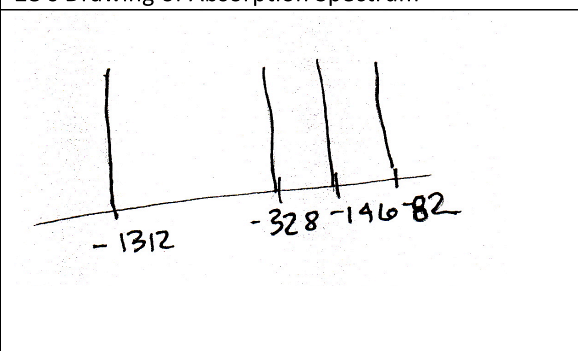
72 28: Maybe. I feel like really not sure about any of this.

Figure 4.5. Student 28's drawings

28's Drawing of Energy Level Diagram



28's Drawing of Absorption Spectrum



When asked about ionization energy, Student 28 spoke about needing a difference in energy between the energy level value and zero energy, but when asked about the absorption spectrum, she copied down the energy level values exactly to label her spectral lines. Although in isolation she seemed to remember some rules, she didn't access them or found them implausible when asked about energy absorption in a different context. This student had a difficult time understanding exactly how the spectral lines were related to the energy level values.

B. Threshold reasoning

Students in this category may or may not match up the spectral line values exactly to the energy level values. Some of the students in this category are able to calculate the difference between two energy levels and assign this number to the line spectrum. However, what distinguishes this group of students is their common us of "threshold" reasoning. They believe that if energy is supplied that is greater than the difference between the n=1 and n=2 levels, then energy will be absorbed. The electron will be excited to the n=2 level and the extra energy may be transferred to another aspect of the system somehow.

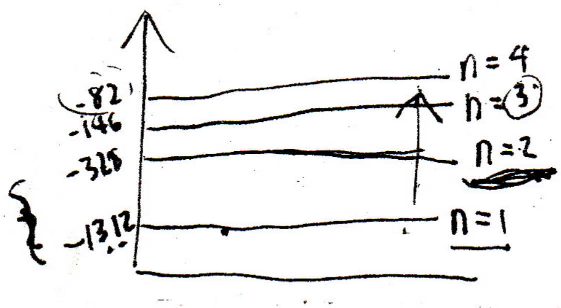
Student 26 – threshold reasoning with Kinetic Energy

Student 26 scored a "2" on the Interpreting Spectra Code, signaling an inconsistency in her explanations. She recognized that differences between energies may be important, but she was unable to expand on this or draw an absorption spectrum, expressing much frustration in the process.

33	**I:**	08:03 So this question has Hydrogen energy levels. Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
34	**26:**	[drawing] I think it would be like, -1312, -328. [inaudible]
35	**I:**	So how many electrons does hydrogen have?
36	**26:**	Has 1 electron
37	**I:**	So one electron, but this has 4 energy levels, so how are those related?
38	**26:**	Um, I think it's saying like this is the energy. Like if it is excited, if there is energy put in, like if the, like if this is like s or the first one, the electron is moved outwards more, so it's like in an excited state. Like say it reaches n=4, then this amount of energy would be needed to actually remove it like to ionize it.
39	**I:**	How much energy does it take to excite it? n=1 to n=4?
40	**26:**	09:57 I'm not really sure, I think it's the…I'm not sure about this.
41	**I:**	How about n=1 to n=2? How much energy does that take?
42	**26:**	I feel like it would be the difference between n=1 and n=2, but I'm not too sure... So it would be the difference between these two levels - would be the amount of energy needed to move the electron from the n=1 to the n=2 level.
43	**I:**	What are you not sure about?

44 **26:** I'm not sure if that concept is right, if it actually is the difference. Cause like the way I see the numbers is that the numbers would be the energy it takes to actually remove the electron if it was in these levels, and so I'm not really sure about the concept if the difference in these energies is actually the energy it takes to excite it.

Figure 4.6. Student 26's Drawing of Energy Level Diagram



Student 26 correctly interpreted the numbers in the table as related to the energy needed to ionize or remove the electron if it was in each of the levels. She calculates that it takes 146 kJ/mol to remove an electron in the n=3 level by subtracting -146 kJ/mol from 0 kJ/mol. She was able to calculate differences from zero in this case. However, she was unable to extend this to electrons moving between two levels. She had a good understanding of the energy level diagram but was unable to construct a cohesive difference reasoning between all the energy levels to explain the absorption spectrum.

53 **I:** 11:56 What if you shine light that is this difference? This happens to be 984?

54 **26:** I think it excites it, and it would probably go to n=2 energy level. Yeah but the concept I'm not sure so it's just like me taking a stab at that.

55 **I:** That's totally fine. What if, if you had to guess, what if I shined 986? So it doesn't quite match that energy level difference, a little bit above. What would you think happens then?

56 **26:** I don't think it would reach all the way to the third level because it's not enough energy. It would probably reach the n=2, but it would still like remain there. The remaining energy would be transferred to kinetic energy. But like I said, I'm not sure what that means.

She also stated that 986 kJ (a bit more than the difference from n=1 to n=2) would be absorbed with the "remaining energy" turning into kinetic energy. She believed that a photon could partly be absorbed into binding energy and partly put elsewhere. This was also false reasoning connected to a classical thinking.

Student #10: Step Ladder analogy to a fault

Student #10 scored a "1" on the interpreting spectra code, meaning that she exactly assigned the numerical values of the energy levels to the peaks in the atomic absorption spectrum. In her explanations of absorption, similar to student 26, she spoke about a threshold energy that must be overcome in order for the electron to reach the next energy level.

22 **10:** Um, so let's say there is a light with a short wavelength which means it has a lot of energy. If it has enough energy then it can excite the electron so the electron can jump to a different energy level.

23 **I:** What do you mean by excite?

24 **10:** Basically it has enough energy to move it up a level. So ,levels are discrete, you can't, it's like a step ladder basically, so it can only be in one step or another, it can't be really in between. So if you have enough energy though you can push the electron up another step, and even if you have a lot of energy, it can push the electron off the step and into a new area.

25 **I:** What are these steps in the atom? What is the electron doing in the atom?

26 **S:** I guess sometimes it emits light when it comes back down from a level for example and depending on what level they are on it also tells you what color too because of the wavelength.

Student 10 constructed a conceptual framework combining aspects of the quantum and classical world. She acknowledged that "levels are discrete" and the electron "can't be really in between" that provided evidence of an understanding of discrete energy states. However, she used her classical rules of energy absorption to say that if the electron has enough energy to get to the next level or more – it can "push the electron up another step" and the light energy will be absorbed. She was envisioning the energy levels in the atom exactly like a step-ladder with electrons able to move to the next step if they acquire any amount of energy over a minimum barrier to reach the next level. This is an unfortunate consequence of using a classical analogy in describing quantum behavior.

Student #9 – excess energy as "jiggling"

Student 9 also demonstrated threshold reasoning and scored a "1" on the Interpreting Spectra Code. He spoke about energy and the energy barrier in a very similar way to student 10, but wrote down only 2 absorption lines "because that's the way I remember it happening." Similar to Student 26, he said the extra energy will go to "jiggling it" in the energy level, again falling back to continuous ideas of energy absorption. Both student 9, 10 and 26 do not grasp the idea of all or nothing absorption, and think that the photon can be partially absorbed.

29 **I:** Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

30 **9:** 13:58 [starts drawing horizontal line] So, this is the ionization energy, so if this much energy were inputted into the hydrogen molecule, it would eject it entirely and ionize it. And then this one would be to switch from the n=1 to the n=4 shell. The absorption spectra is gonna like show you where the most energy would be absorbed by the addition of energy to a hydrogen molecule, atom, atom, and so it's gonna have a peak at which energies would be absorbed and graphed against. I don't know what it's graphed against.

31 **I:** Why only those 2 absorptions?

32 **9:** Because that's the way I remember it happening.
35 **I:** What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
36 **9:** 17:15 So then the electron is ionized cause it's enough energy for it go to fully ionized to go from the n=1 subshell or orbital to infinity.
37 **I:** How about 500 kJ/mol?
38 **9:** 500kJ/mol? It would only be able to move … then… nothing, nothing would happen.
39 **I:** Why?
40 **9:** Cause there wouldn't be enough energy to overcome the barrier between any of the subshells.
41 **I:** So how about if it was enough to get to the next one, 984 kJ?
42 **9:** Then you would be able to move up a subshell at least. Go from the n=1 to the n=2 subshell.
43 **I:** So why is this not on the spectrum?
44 **9:** I remember drawing it this way, I really don't know.
45 **I:** 18:47 How about 985?
46 **9:** Then there would be some kinetic energy associated with the electron and it would start moving.
47 **I:** Would it still move to n=2?
48 **9:** Yes.
49 **I:** And what would the 1kJ of kinetic energy do?
50 **9:** I don't really know what it would do representatively. The way that I see it, it moves up and then it can start moving around and like jiggling around in it's little subshell

When asked why an energy of 984 kJ/mol does not show up on the spectra, he remarked that he doesn't remember drawing it that way. In his thought process, the spectra had little connection to the numbers in the energy level diagram, and is perhaps simply a depiction of some other aspect of the system. He also envisions energy absorption as a threshold process where the excess energy gets incorporated into the system as additional “jiggling”.

Student #52 – absorption as the excess photon energy over threshold amount

Student 52 had a related but slightly different take on the threshold reasoning. She saw the extra bit of energy over the threshold amount as the energy that ***is*** absorbed.

13 **I:** 4:33 So, what happens when light hits the atom?
14 **52:** Depending on how much energy it has, an electron can move up orbitals or it can just leave the proton. Go from like the n=1 to n=2 to n=3 and it just gets excited and gets further away from the nucleus.
15 **I:** Why?
16 **52:** I don't know, it was more KE. If it's excited, it just has more energy and so it jumps, that's why it's excited.
17 **I:** 05:30 Describe this process of jumping.
18 **52:** It takes the energy from light and uses that to go to higher orbitals. I think it moves, just further away from the nucleus, so it's easier to be separated.
19 **I:** 06:24 When can it go up to energy levels?

20 **52:** When there is like the exact amount of energy needed in order to move from one energy level to the next energy level, because it's all "quantized". That means that the levels are discrete energies, so that if [gestures] you are here, and you have to enough energy to get to the next one, and like it won't move up unless it has enough energy to get to the next one, and anything between that it's just gonna stay at the same one that it's at.

21 **I:** 07:00 What does quantized mean?

22 **52:** Well it's not like riding a bike up a hill…I think of it as like a piecewise function, not a nice linear one The electron can't be in between 2 levels.

41 **I:** 16:15 So what energies would the hydrogen atom absorb?

42 **52:** Anything between these numbers. It takes whatever this is...[calculates] 984kJ. So if you don't have enough energy to get to the next energy level, then whatever you have left over is what is absorbed. Like if you have more than enough to get to one energy level but not enough for the next one, then whatever you have left over in there is what is absorbed. It takes 984kJ to go from there to there and if you have more, let's say to 1000, you would get to here, not to here and whatever energy you have left over is absorbed. So like 16kJ will get absorbed.

43 **I:** Any other absorptions?

44 **52:** Maybe.. it can go from n=1 to n=3, and if it has enough energy to go to n=3, it gets there. If it has more than enough to get there but not enough to get to n=4, then the electron is not gonna stay in between n=3 and n=4. Instead the extra energy gets absorbed.

This is interesting because students 9, 10 and 26 all expressed the idea that the light is absorbed partially, and any extra energy over the n=1 to n=2 difference will be incorporated into the system somehow. Student 52, however thought that the electron is excited to the n=2 level, and any excess photon energy was the energy that was absorbed. She saw absorption as relating to the excess energy that remains after the excitation.

Student 18 – beginnings of an exact difference reasoning

Student 18 scored a “2” on the Interpreting Spectra Code, and struggled on Midterm #4. She was able to explain the idea of quantized energy levels early in the interview.

61 **I:** So let's say we shined different energies of light on hydrogen, what will happen?

62 **18:** I think if you shine a light that's in between like somewhere in this region, nothing will happen.

63 **I:** Why?

64 **18:** Because it's quantized.

65 **I:** So what does that mean?

66 **18:** It can only like only certain levels of energy like.. it will do nothing, nothing, nothing, and then it will like go to the next energy level. If you do 1000 then nothing's going to happen.

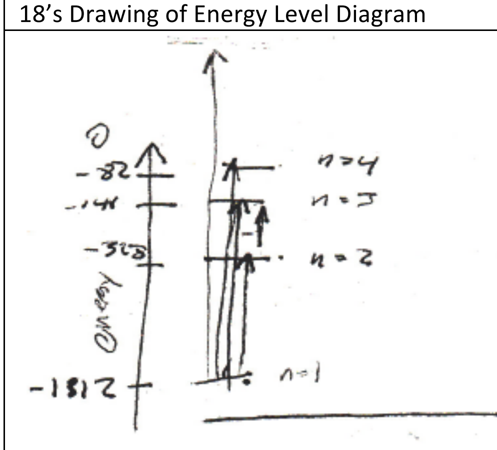
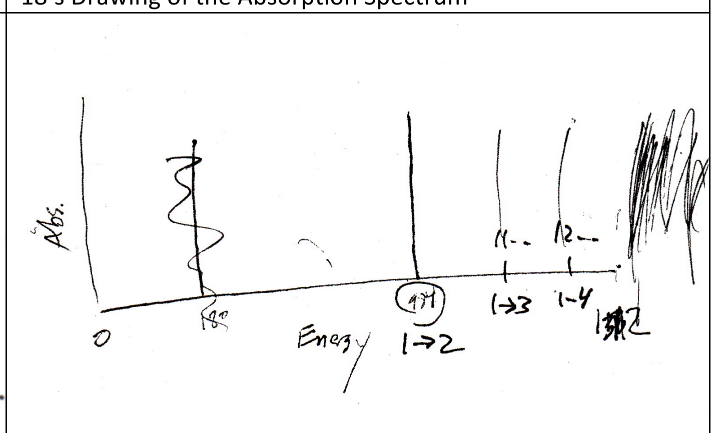
67 **I:** So did you have some idea of that you can relate it to?

68 **18:** You mean quantization? I just kinda thought of it like, I don't know if this is correct when we were first learning about the different electron shells kinda, if this was the nucleus [draws] you have the first shell and you have like 1s and then like there are other shells around it too. I just thought about it as it just kinda goes up to the next one and so if it's somewhere in here it's not going to do anything because it hadn't reached that energy level actually. It's kinda how I picture it in my head.

Then, she was able to reason through and construct correctly both the energy level diagram and the absorption spectra, and calculate differences between energy levels. However, when asked if light of an energy a little more than the n=1 to n=2 transition would be absorbed, she responded affirmatively, albeit with hesitation, signaling an acknowledgement of the possibility of an all or nothing absorption process. She hesitantly expressed confusion over her threshold reasoning and began to grasp the process of discrete energy absorption.

73 I: 16:30 So if you shine 984 kJ of light, what happens to the light?
74 18: Um, what happens to the light? I think that energy gets changed to potential energy of the electron and it goes up here.
75 I: So, does it get absorbed? transmitted?
76 18: So, it would be absorbed.
77 I: So, what if you shine like 982 kJ?
78 18: Then I think it just stays here.
79 I: Ok, then what if you shine 986 kJ?
80 18: It would go to this one, and then that's it. And I guess the other 4 kJ, I don't know, I kinda imagine it would just pass along through, but I'm not sure if that's even right.
81 I: Ok, then if you keep going, what's the next transition?
82 18: Uh, so let's see, so you have to shine, yeah, so you have to shine 180 kJ to get to the next level, and the energies get like smaller because you are farther away from the nucleus, so there is less attraction.
83 I: 18:05 So then from this, can you tell me what energies of light will hydrogen absorb?
84 18: Ok, so I guess it would absorb 984, and 180 kJ, and this difference.
85 I: You were saying 990 would absorb as well?
86 18: I think like it absorbs part of that. Now, that doesn't make sense cause when you look at a absorbance spectra it's just like line line...

Figure 4.7. Student 18's drawings

18's Drawing of Energy Level Diagram	18's Drawing of the Absorption Spectrum
	

Student 18 stated that "the other bit of light will just pass on through, but I'm not sure." She was however starting to recognize some inconsistencies with her description that was evident in her statements that she was "not really sure." She went one step beyond 9,10 and 26 however in that she actually drew a spectrum and labeled the peaks corresponding to the differences between energies, although she was extremely hesitant in the process (she mistakenly lists 180 kJ as a peak, but then corrects herself later in the interview). Even with this correctly constructed diagram, she incorrectly remarked that a photon of energy 984 or 990 kJ would be absorbed partly, although she expressed some skepticism. She was beginning to realize that her explanations were not consistent or might not be described by the spectrum.

99 **I:** So before 1312, take your best guess.

100 **18:** So if you do here 984, that's absorbed, then 180 is the next one that's here and then, so then 66, I guess. No wait, maybe it's just.. if you put in 1312 then it's going to be ejected, but if you put in 328… I'm getting confused with the negatives. if you put in 328 kJ, nothing would happen. You haven't put in 984 yet... Now I'm confused as to what to add... so maybe I do 1312-180, or 1312-148. No I don't know what I'm saying.

C. Exact difference reasoning

Students in this group were successful at matching the spectral line values to differences in the energy levels. In addition, they demonstrated a proficiency in the all-or-nothing photon absorption process. They explained that only the photon energies that exactly match a difference between energy levels would be absorbed.

Student "66"

Student 66 scored a "3" on the Interpreting Spectra Code, and he explained and justified why the energy level diagram and absorption spectrum looked the way they do. He also quickly calculated differences between energy levels and related it to the lines in the absorption spectrum, and translated between the two representations, demonstrating an integrated understanding.

29 **I:** 15:30 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

30 **66:** Um, I think first you have to understand that you have to assign a certain zero and that zero is infinite separation of the electron and the nucleus. From there, I guess we can deduce our understanding of different orbitals and see which energy state which the electron can reside at lowest energy and so these are relative according to zero. The numerical expression indicates sort of the stability of the electron because the lower the energy is the more stable.

31 **I:** How about in terms of the structure of the atom?

32 **66:** I guess these represent different shells.

33 **I:** 17:00 How much energy is needed to ionize hydrogen?

34 **66:** Since it's at its most stable state or lowest energy state available is -1312 kJ/mol, to make it reach what we call infinite separation or ionization energy I guess would be the difference between zero and this number.

35 **I:** So, why is it from here?

36 **66:** Because at its most stable state, this is where the electron will reside, because this is the lowest energy.

37 **I:** Is this for every element?

38 **66:** No, this is only true for one electron for H or like hydrogen.

39 **I:** 19:57 Can you draw the absorption spectrum of hydrogen?

40 **66:** From my understanding, the absorption atoms and elements because it only absorbs the energy that the electron can be moved up to a higher energy orbital, so how you would calculate that would be the difference of the energies between the lowest orbital and the available higher energy state orbitals the electron can occupy. Because there is so many different states, higher states, that they get progressively closer. So I guess what you see is many. I guess it moves.. the most, and I graphed it according to... [calculates differences]

41 **I:** 21:32 So the difference between 1,2 and 1,3 and 1,4?

42 **66:** Yes.

He demonstrates an “exact difference” reasoning, and understands that the light energy must exactly match a difference in energy levels - any other value will not be absorbed.

49 **I:** What happens if you shine light of energy 982?

50 **66:** The energy you put in is transmitted. I want to say its transmitted because it is neither enough energy to move it to a discrete orbital, a higher energy state orbital, or correspond to that [points to difference]

51 **I:** What happens at 984?

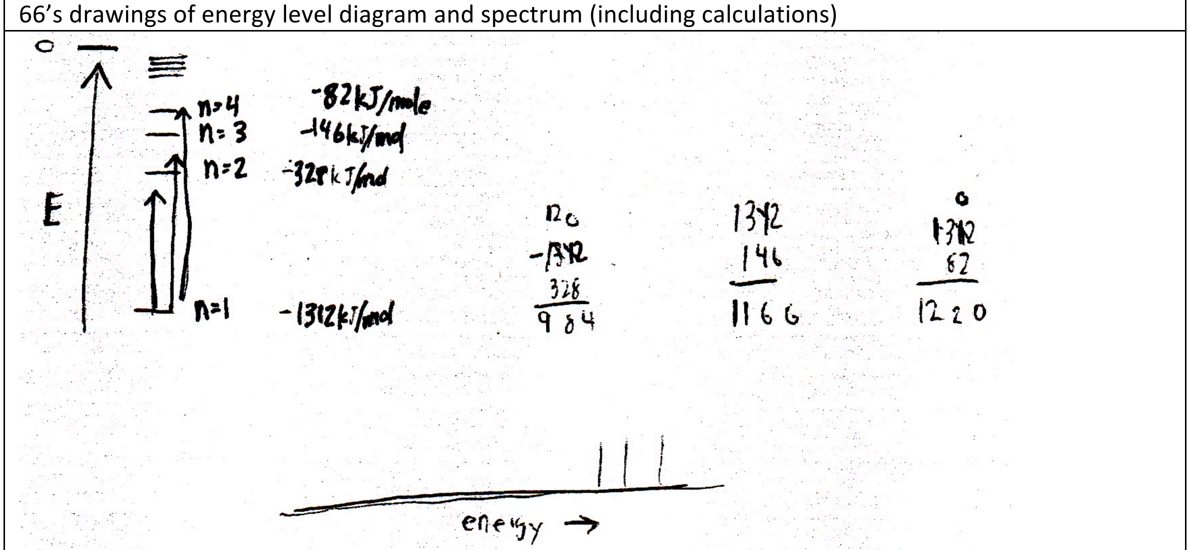
52 **66:** It’s absorbed.

53 **I:** 985?

54 **66:** Then I think you would observe that that energy of light, it would be observed, transmitted.

Figure 4.8. Student 66’s drawings

66’s drawings of energy level diagram and spectrum (including calculations)



D. Meta reasoning

Some students correctly assigned the spectral peak values, and also reflected and commented on how this type of behavior was "strange" or "weird." They not only mastered the algorithm or calculation involved in the translation between the energy level diagram and line spectrum, but showed an appreciation for how this quantum behavior contrasted with the classical behavior they were accustomed to. This behavior showed an advanced conceptual understanding of the topic at hand. Students who exhibited meta reasoning were able to show a conceptual understanding of how starkly different quantum thinking is from the classical world. Along with an algorithmic mastery of the calculations and a competence in translating between representations, they glimpse the "shocking" nature of quantum rules.

Student "40"

Student 40 also scored a "3" on the Interpreting Spectra Code, and explained quantization of energy thoroughly. At the end of her explanation, she remarked on how this way of thinking was a bit unusual to her.

11 I: 04:10 What do you mean by discrete units and packages?

12 40: Um, can I draw something?, so if we're, so we've seen.. I'm not going to draw it as I think of it I'm going to draw it much much simpler, but if this is the nucleus and these are the various levels, it doesn't of course look like this but it's how we represent it, and if something is going from here to here, and if we didn't have certain places from which it can only go from here to here, instead of going from here to here to here, then when looking at the energy emitted you would see a whole spectrum. You would see a whole wide range of energies. But, instead we only see a few discrete lines, only a few specific amounts of energy, which shows you that there has to be more than one, that it's not just a whole region, that it has to be more than one defined levels where the electron can be.

50 I: How much energy is needed to ionize Hydrogen?

51 40: 1312 kJ/mol. Because the convention is that you represent zero as no interaction at all with the electron and the nucleus. Zero is the point of complete ionization, which means that you would need that amount. That because the first energy level is at -1312 you would need 1312 to get up to zero from there.

52 I: 19:37 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

53 40: Ionization.

54 I: 19:41 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

55 40: Not much. 500 kJ/mol here not enough to ionize and not the right amount to do anything else. It couldn't absorb it, basically the electron could not absorb that energy of light.

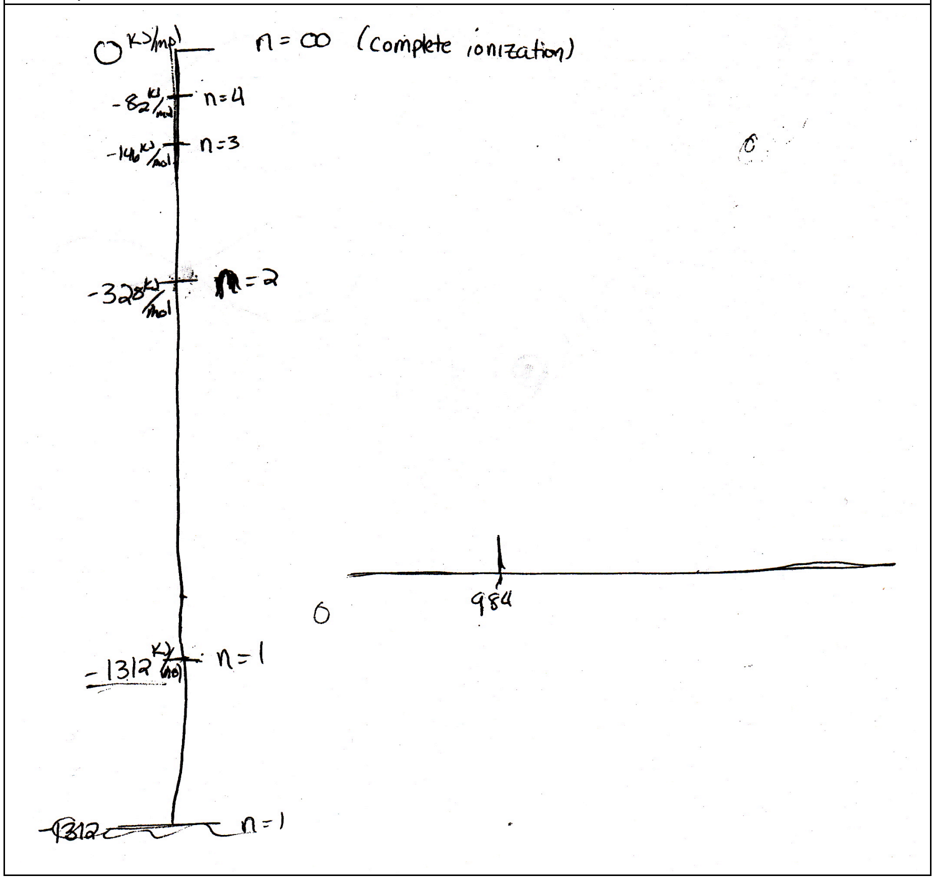
56 I: How about 984?

57 40: You will…assuming you are interacting with an electron, the electron you will remove it to the next energy level, and that would be a n=2 electron until hydrogen decides to emit energy ... oh wait! Of course you can go to higher energy levels because that's the only way you are going to get more than one line in your emission spectrum. So yes! It can get up higher.

58 I: 20:45 How about 985?

59 **40:** Kilojoules? That's not the right.. That's again you are in the intervening space it can't absorb it. You can't just get rid of 2 kJ/mol. That's.. I don't think it works like that! It seems unfair, like it ought to, but I don't think it does.

Figure 4.9. Student 40's drawings. Student 40's drawing of energy level diagram and spectrum



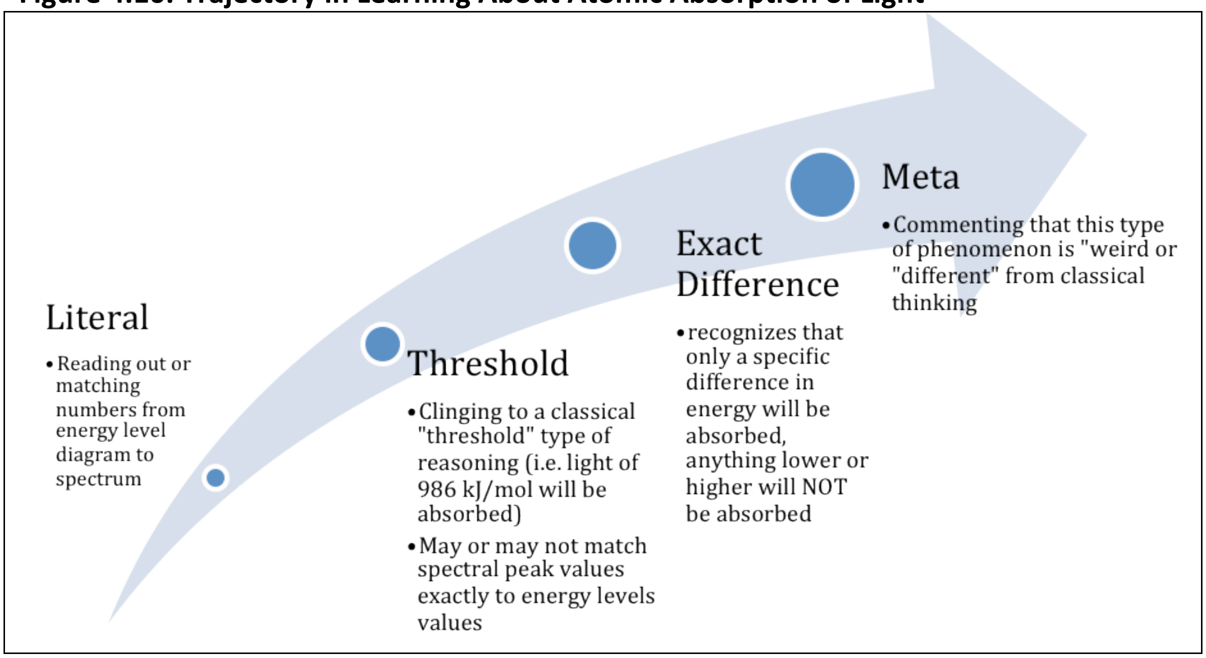
Student 40 had a very deep understanding of both representations and what they depicted. She connected the spectrum back to experimental data and remarked that if energy states weren't quantized, continuous absorption would be observed. She clearly drew both representations, and understood that the "intervening space" is where the electron is not allowed to be. If light is shined with an energy that doesn't match a difference between levels, nothing will happen. Student 40 also recognized that this way of thinking was at odds with the way she normally encountered classical absorption. She remarked, "I don't think it works like that! It seems unfair, like it ought to, but I don't think it does." She recognized that a new set of rules applied to the situation.

In student 40, we see a glimpse of meta –representational competence (MRC) (diSessa 2004). She made statements such as "but if this is the nucleus and these are the various levels, it doesn't of course look like this but it's how we represent it". She was showing an ability to be reflective of her drawings and acknowledged that certain pictures had limitations or boundaries of applicability. This type of thinking is closer to perhaps how scientists use representations in their professional work.

4.3.3 Discussion - Charting out a Progression

From this data and analysis, it's possible to hypothesize a progression in interpreting atomic spectra. In Figure 4.9, a trajectory is outlined for how chemistry learners may progress while learning about atomic absorption of light. In this analysis, it was observed that students fell into one of these types of reasoning. However, it is not claimed that students must transition linearly from one step to the next in their learning process. Instead, Figure 4.9 depicts a list of general reasoning behavior that exist in the sample population. These types of reasoning are ranked from a more novice approach with the smaller blue dot, to a more expert-like approach with the larger blue dot in the figure below, but should not be interpreted as a list of steps students necessarily must progress through.

Figure 4.10. Trajectory in Learning About Atomic Absorption of Light



This starts with a literal mapping of features between two representations, to a partial threshold understanding of how the spectral peaks are constructed, to a more developed difference reasoning, and finally to a fuller acceptance and recognition of how this type of quantum reasoning is starkly different to more common and familiar types of thinking in the classical regime.

4.4 PART II: How does classical thinking impact understanding of spectra?

Research has shown that students fall back to classical ways of thinking when learning quantum content, for example, thinking of electrons as having a deterministic orbit and having only particle-like properties. In understanding atomic spectra, students' prior classical knowledge also impacts their learning and understanding of discrete energy absorption.

This section aims to address the following questions:
#2b How does classical thinking impact understanding of spectra?

- What classical concepts may be hindering understanding of atomic spectra?
- What classical concepts may be productive or useful footholds in understanding atomic spectra?

4.4.1 Three classical ideas and their impact

The impact of three classical ideas is explored in the sections below along with excerpts from student interviews. Based off of prior analysis, a discussion of the impact of student classical ideas is presented. Excerpts from student interviews are used to illustrate key points.

A. **Classical Idea #1 - Use of threshold reasoning**
B. **Classical Idea #2 – Energy conservation**
C. **Classical Idea #3 – Forces and Atomic Spatial Model**

A. Classical Idea #1 - Use of threshold reasoning

As results from Chapter 3 and Part I of this chapter show, when students interpret the energy level diagram and the atomic spectra, many are able to quickly grasp the concepts of discrete energy states, but they remain struggling with the idea of an all-or-nothing absorption.

The classical analogy of a step ladder, presented in lecture and in the textbook, is an easy way for learners to conceptualize that the electron can only be in the n=1 state OR the n=2 state, it cannot exist anywhere in between. However, this analogy breaks down at some level. Students do not comprehend this, leaving a flawed model in their minds. Students view energy absorption as a threshold process. As student 10 states, "so if you have enough energy though you can push the electron up another step, and even if you have a lot of energy, it can push the electron off the step and into a new area." Electron excitation is conceptualized as a process where if the system has more than some minimum "threshold" energy, then the electron can get "pushed up" to the next state.

diSessa (2004) speaks of how functional residue can affect how students interpret representations where "properties of old functional niches show as maladaptation to new functional niches. People naturally carry over old ideas into new circumstances, and it would be unusual for the ideas to be perfectly fit to the new circumstances." One demonstration of this is how some students were stuck in a classical way of thinking in terms of thresholds and continuous absorption, and had not completely adapted into the new quantum framework of discrete absorption. Perhaps this might be described as more of a *conceptual residue* from the classical framework into the quantum framework, and students' ways of thinking classically carry over to quantum contexts where they are inappropriate.

This idea also relates to how student's prior knowledge influences their interpretations of representations (Mayer, 2005). Their intuition, which has been developed in the classical world around them, must adjust when forced to perform in the quantum regime. If links and assumptions are not articulated clearly and repeatedly to students, such clinging to residue from other niches can impair understanding in the new regime.

Student 28's explanations show how she is grappling with both of these types of regimes as she struggles to make sense of the spectrum. Her confusion marks her journey as she is charting a new course into a new and different type of thinking. She expresses her frustration when she remarks, "I feel like really not sure about any of this." Students 26 and 18 are overlapping the classical and quantum niches as they describe absorption happening when enough energy is given for the electron to jump from one level to the next yet they still hold on to a classical type of thinking when they explain that even if a "little more energy" was given, the electron would still make it to "n=2" with a little bit left over. This type of reasoning is neither completely quantum or classical, but is a hybrid between the two.

Due to a misconception originating from classical thinking, Student 26 says that 986 kJ, a little more than the n=2 to n=1 difference will get absorbed, with the "remaining energy turning into Kinetic Energy". Even though the student observes the spectrum, she has an incomplete understanding of what it means, or implies, with respect to the energy of light that gets absorbed. This is in contrast with student 40 who clearly explains that absorption of 986 kJ is forbidden because "it just doesn't work that way."

The classical idea of a threshold energy needs to be challenged in instruction so students see how discrete energy absorption does not occur in this way. This is one of the most strongly held classical ideas in students' minds that is influencing their learning of atomic spectra. Such classical reasoning prevents them from grasping the nature of quantum energy states and light absorption, thus they do not comprehend one of the fundamental aspects of quantum chemistry. They do not understand that if absorption happens in a continuous manner, line spectra would not be observed.

B. Classical Idea #2 – Energy conservation

On the other hand, energy conservation is a classical idea that has tremendous potential to help students understand atomic spectra. Visualizing electron transitions as corresponding to an "energy input" or "energy release" allows students to connect the energy level diagram with the line spectra, strengthening an integrated conceptual understanding.

Student #23

Student #23 scored a "3" on the Interpreting Spectra Code and demonstrated how Energy Conservation Ideas can assist in building meaning of the representations.

29	**I:**	07:01 So, now kinda putting these 2 things together, you have this hydrogen atom and you are shining light on it, what are some things that can happen?
30	**23:**	Depending on the intensity or energy of light, the light can either pass through it if it doesn't meet the specific energy level requirements, or if we do manage to meet the n1,n2 requirement, we can excite the electron from the first orbital to its second shell.
31	**I:**	So what does that mean - to excite?
32	**23:**	07:33 It means to give the electron enough energy. That it can essentially.. Because there is sorta like an energy barrier from in residing in the 1s subshell in order to get to the 2s subshell.
33	**I:**	So let's say the light comes on and matches that difference to excite the electron, what does that look like, or what does that mean? The electron can be excited.
34	**23:**	It means that the electron it has enough energy to increase one orbital and just move away from the nucleus.
37	**I:**	08:30 How about if you shine light with an energy greater than the Ionization energy?
38	**23:**	In that case, that would have enough energy to completely remove the electron away from the atom and the excess energy, cause energy must be conserved, would be converted into kinetic energy.
59	**I:**	So, go through and tell me what happens to the electron when it absorbs these energies?
60	**23:**	13:12 The electron is in the stable state is down here, so when it absorbs an energy 984 kJ/mol, it will get excited into sorta like… Because each of these energy levels corresponds to a different shell, so in that case it will get excited to the n=2 shell, and n=3, and n=4.

At this stage of learning, energy conservation ideas should be intuitive for students and Student #23 used them comfortably in describing the absorption process. These concepts are effective tools to assist students in bridging understanding between the energy level diagram and the atomic spectra.

C. Classical Idea #3 – Forces and Atomic Spatial Model

Another classical idea that more successful students integrate more frequently is the idea of the spatial model of the atom and presence of the Coulomb attraction of the electron to the nucleus. Student #23 described the forces that the electron experiences as it moves to different energy levels, and related this back to the absorption or emission process.

45 **I:** 09:34 How much energy is needed to ionize Hydrogen?

46 **23:** 1312 kJ.

47 **I:** How do you know that?

48 **23:** Ionizing an electron means that we completely remove it, so it's like we are moving it from n=1 to n=infinity, and in this case it's the energy required to move it from essentially this the most bottom level to the energy equals zero.

49 **I:** So why does it stay at the bottom level?

50 **23:** Because it's the idea that that's the most stable. So we learned sorta about Coulomb's law of kq_1q_2/r, and sorta like going back to the PE diagram, it was the whole idea that as atoms... Yeah as those 2 atoms get closer their potential energy increases, so they get more stable. There is a point where they're both like bonded and that's the most stable energy, and then as you push them closer, repulsions come into play.

51 **I:** So hydrogen only has 1 electron, but there are four energy levels here. So, what do those mean? How come there are 4?

52 **23:** 10:49 Essentially... It kinda doesn't matter how many electrons hydrogen has. The idea is there are they always exist, these subshells always exist. It's the idea whether its essentially feasible or not to keep moving that electron up. Because I know that as the electron increases, sorta, like if it gets into this n=3, n=4, it's not going to be stable enough that it will most likely almost immediately fall back.

53 **I:** Why is it not stable?

54 **23:** Because it's sort of stuck in between the ideas that it doesn't have enough energy to completely leave the nucleus so it can still feel that attraction, so it will be pulled back.

Student 23 stated that an electron in the n=3 or 4 state will "still feel that attraction," thus it will "fall back" to the ground state in the emission process. This signals a connection between the picture of the atom and the forces involved – as "they get closer their potential energy increases, so they get more stable," thus requiring more energy to remove an electron at a lower energy level.

Student #65 – Connection to attractive force of nucleus and spatial model

Student 65 integrated ideas related to attraction to the nucleus in his description of absorption.

16 I: 06:47 What happens when light hits a hydrogen atom with energy greater than the ionization energy?

17 65: I would imagine you would have an atom, a nucleus, and electron around it spinning, and then this wave comes in, or photon, comes in and hits that exact electron and basically the photon kinda gets absorbed into the electron *and the electron takes that kinetic energy and is able to jump just farther away from the nucleus and it just keeps going up until it gets to a certain point for which the nuclear charge doesn't have any pull on it and then instead of pulling it back, it just keeps going.*

18 I: 07:26 What happens when light hits a hydrogen atom with energy less than the ionization energy?

19 65: Then it would depend on how much less, or the exact number, cause in an atom for each energy level, there is specific differences between each one that's unique to each atom, and that…. And it can only absorb that difference.

20 I: Why?

21 65: Like, I guess in class they explained it in different ways. Like how it's like a ladder. So you have step…They also explained how it's a probability, and you take the formula, and there is a certain probability of being between. Um, but I guess the only one I really liked, or understood was how light in that instance behaves like a wave, and there are certain nodes in which it can exist, so I guess that would kinda explain why there are specific differences

His conceptual model incorporates ideas of nuclear attraction into his idea of absorption. The energy from the photon goes into "pulling" away the electron from the nucleus. This classical idea provides a foothold in understanding the process. He connected back to the spatial model of the atom when he remarked that the electron "is able to jump just farther away from the nucleus," signaling an appreciation of the atomic model in his descriptions.

4.4.2 Discussion

How does threshold reasoning impede student learning?

When students cling to classical ideas of a threshold type of reasoning, they fail to understand the significance and remarkableness of atomic line spectra. Since they believe that any energy can be absorbed if it is greater than some threshold value (i.e., the n=2 energy level), then they do not fully comprehend how a line spectra is created, thus they fail to understand it's usefulness in characterization of materials or as applications in electronics, lasers, or other technology. Therefore, they fail to be "shocked" by quantum theory since they have not fully stepped out of their classical world.

How are energy conservation, nuclear attraction, and the spatial model of the atom important and useful in student learning?

Unlike the case of threshold reasoning, ideas of energy conservation and attraction to the nucleus offer valuable scaffolds and tools in making sense of atomic absorption and emission. Using these concepts appropriately helps student apply their classical knowledge in contexts that strengthen their quantum understanding. The challenge here is to use these ideas carefully and in conjunction with quantum ways of thinking. These ideas serve to strengthen their conceptual framework – forging connections to the classical world that are useful and productive in thinking in the quantum regime.

4.5 Summary

This chapter aimed to answer the following research questions:

- **Q#2a: How do students interpret and connect representations of the energy level diagram and the line spectrum?**
- **Q#2b: How does classical thinking impact understanding of atomic spectra?**
  - What classical concepts may be hindering understanding of atomic spectra?
  - What classical concepts may be productive or useful footholds in understanding atomic spectra?

From the analysis in this chapter, four main types of reasoning were found:

A. **Literal Reasoning**
B. **Threshold Reasoning**
C. **Exact Difference Reasoning**
D. **Meta-Reasoning**

These ways of thinking offer a productive stage-like model of student learning of atomic spectra. Although students may not necessarily progress through each stage, this offers a way of organizing student patterns in understanding of spectra. Many students cling to classical ideas and discuss a threshold that must be met for energy absorption to occur. A more developed understanding consists of a full appreciation for how the spectral lines exactly match differences between energy levels and an understanding of the all or nothing discrete absorption process. More expert-like students are able to master the procedure for the translation and experience a conceptual epiphany about how this behavior is starkly different from their classical understandings.

From an examination of student explanations of atomic absorption of light, it is evident that many students are unable to completely leave the classical world and remain clinging to threshold reasoning to explain spectra. This is not a productive way of thinking when trying to explain spectral lines. However, many students also incorporate classical ideas of energy conservation, nuclear attraction and the spatial model of the atom; ideas that are indeed useful and effective in strengthening understanding of the quantum regime.

Chapter 5: Issues in Guiding Students to a Normative View

5.1 Introduction

The analysis in Chapter 3 and 4 demonstrated that learners of atomic spectra struggle with:

1. Developing a full understanding of discrete energy absorption. Many students hold strong classical ideas about energy absorption and demonstrate threshold reasoning about atomic absorption of light, not grasping that is an all-or-nothing process and the light energy cannot be divided or split up in some manner.
2. Constructing difference reasoning. Students fail to see that the absorption spectral lines match energy level differences in the atom. Many students don't see that the spectral lines represent changes between energy levels, not the energy levels themselves, and have difficulty navigating the two representations of the energy level diagram and the atomic absorption spectrum.

Mastering both an appreciation for discrete energy absorption and constructing difference reasoning are both important pieces in understanding atomic spectra. Knowing these learning struggles, this chapter aims to address the following research question:

- **Q#3: What are possible challenges in guiding students to a normative understanding of atomic spectra?**

Interview data from two students interacting with a visual designed to scaffold understanding of atomic spectra are analyzed to gain insight on possible successes and challenges of guiding students to a normative view of atomic spectra. Data from these two students are used to explore certain challenges in the process and not to make a generalized case about the entire class population.

5.2 Prior Work on Visual Animations

Students have difficulty connecting the energy level diagram to the atomic line spectra. Chapter 4 found that students may or may not see the energies in the atomic spectrum as corresponding to energy differences between energy levels, and often literally match the numbers on the energy level diagram to the energies of the spectral lines.

Research has been done to develop visuals and animations to assist students in understanding atomic spectra. Although data has not been published that shows the details of how students interact with the visuals, researchers have provided anecdotal evidence of successes of these animations.

In recent years, two different physics education groups have both developed visuals that address atomic spectra. These visuals make explicit links between the energy level diagram and the atomic line spectra and allow students to interact and play with the animations.

Researchers in the pHET group at Colorado State University (McKagan et.al, 2008) have designed an interactive visual named "Neon Lights & Other Discharge Lamps" (http://phet.colorado.edu/en/simulation/discharge-lamps) which shows in detail how the atomic line spectra are produced by gas discharge tubes. They discuss the benefits of such visuals in furthering student learning, but detailed student data has not been published to date discussing insights gleaned from specific student interactions.

The Physics education group at Kansas State University (Zollman, Rebello & Hogg, 2002) has also been working to develop visuals to help students learn quantum mechanics. In particular, a visual animation called "Absorption Spectroscopy" (available online at: http://phys.educ.ksu.edu/vqm/html/absorption.html) was designed to explicitly link the representations of the energy level diagram and the line spectra. Users can construct an energy level diagram, add arrows to the diagram that represent electron transitions, and view the corresponding spectral lines. One very nice feature of this visual is that the energy levels can be changed (i.e., moved to lower or higher energies), and the changes in the spectral lines can be observed simultaneously, thus, offering a direct tangible connection between the two representations.

The researchers provide some brief anecdotal evidence that students successfully (Zollman, Rebello & Hogg, 2002) link the spectral lines to differences in the energy levels with instruction that incorporated this visual, but specific details of student thinking are not provided. This visual explicitly connects both diagrams, holding much potential to assist students in connecting and navigating both of these representations.

This seems like a promising intervention for understanding atomic spectra, but the question remains, How are students are bringing and incorporating their classical ways of thinking when interacting with these connected representations? Are students able to grasp the discrete nature of energy absorption from this curriculum?

Part of the connected representation developed by the KSU Group (Zollman, Rebello & Hogg, 2002) was used during a section of an interview for the data and analysis in this chapter. Students were asked to interact with this visual containing a connected representation and then probed for their ideas and understanding of atomic spectra to find out if curricular tool such as these are successful in moving students to a better understanding of spectra and discrete energy absorption. The successes and limitations of visuals like these in student learning are discussed.

5.3 Methodology

5.3.1 Interview Subjects

This chapter describes an exploratory study and two students were interviewed as they interacted with a connected representation. Their ideas about atomic spectra were examined using a protocol analysis.

Student 18 was a white female student from a middle-class background (as self- reported on a in-class survey). At the beginning of the course, her major was undeclared. Her performance on the exams placed her in the middle of the class with an average test score of 72%.

Student 28 was also a white female student who was a middle-performer in the class, with an exam average of 78%. She also reported to be of a middle class background and was intending to be a life science/biology major.

Both students were chosen because they were talkative and explained things in detail during the interview, and had been very comfortable with the interview setting. In addition both of these students were chosen because they demonstrated an intermediate understanding of interpreting spectra, both scoring a "2" on the interpreting spectra code. They were felt to be ideal candidates for some sort of intervention where they could be moved up the scale to a higher level of understanding. These students were contacted in the spring of 2010 to come back for a short follow up interview for another related research project, and during that time asked if they would be willing to come back for additional interview, to which both students expressed interest. In Spring 2011, these two students were contacted and interviewed for approximately one hour and were asked questions related to conceptual understanding of atomic spectra and were asked to interact with a quantum visual animation on absorption spectroscopy.

Table 5.1. Student Performance results for the Fall 2009 Course

	MT1	MT2	MT3	MT4	Final	Average
Student 18	64%	63%	77%	78%	77%	72%
Student 28	75%	78%	86%	71%	81%	78%
Class Average	71%	70%	76%	80%	74%	74%

Table 5.2 Codes assigned to Student 18 and 28

	Probabalist/ Determinist	Discrete(3)/ Continuous(1)	Interpreting Spectra Code	Energy/Force Code
Student 18	3	2	2	4
Student 28	2	1	2	2

5.3.2 Interview Methods

The interview took place on the campus of the university in a small private office room. The students were first informed of the CPHS approval, and asked to sign an additional consent form for their participation. They were then asked about their general plans for school and any changes in their intended major in order to ease the tension and reduce any anxiety. Students were also told not to worry if they did not recall the specific content from the course and were told that the researcher simply wanted to have them think through some problems as best as they could. The full protocols are included in the Appendix A.2. A general description of the tasks is given in the following section.

5.3.3 Interview Tasks

The goal of this study was to gather some insights on how a connected representation may assist struggling students in understanding atomic spectra and discrete energy absorption.

Students were asked to look at the Absorption Spectroscopy Visual (from KSU, see figures 5.1 through 5.3) on a laptop and describe what they saw. They were allowed to play with the visual and observe the connection between the energy level diagram and the Line Spectra. Students were then given a printed screen shot of the visual, and asked to do two things:

1) construct the absorption spectra from a given energy level diagram
2) and then the reverse, construct the energy level diagram from the spectra.

A few more questions were asked that had students draw out pictures of the atom at different energy states (this part was not analyzed for this current chapter). Then, at the end of the interview, students were asked to reason out loud through some multiple choice exam questions, and were asked to work though a short answer question from a previous exam. All the questions were asked in a semi-structured clinical interview format, with follow up questions being asked based on the ideas that students presented. The interview took 35 minutes for Student 28 and approximately one hour for Student 18. A full list of questions and example follow up questions is provided in the Appendix A.2. The transcript conventions were the same as for Chapter 3 and 4. Both the student and interviewer's utterances were transcribed verbatim

Figure 5.1. Absorption Spectra with connected energy level diagram
(from http://phys.educ.ksu.edu/vqm/html/absorption.html)

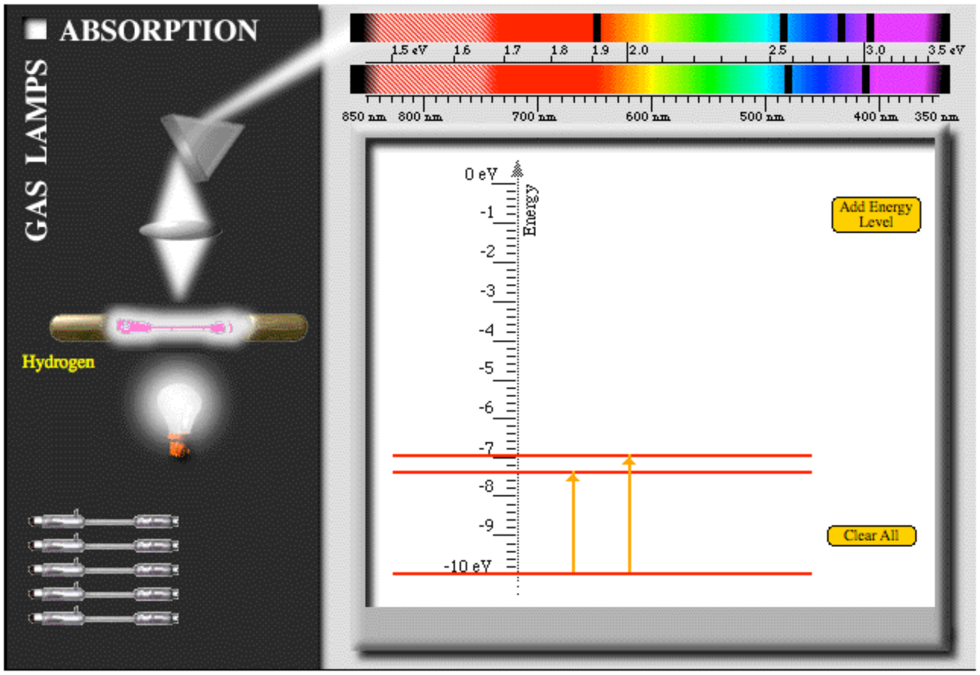


Figure 5.2. Energy Level Diagram provided to students. They are asked to draw the associated spectrum
(from http://phys.educ.ksu.edu/vqm/html/absorption.html)

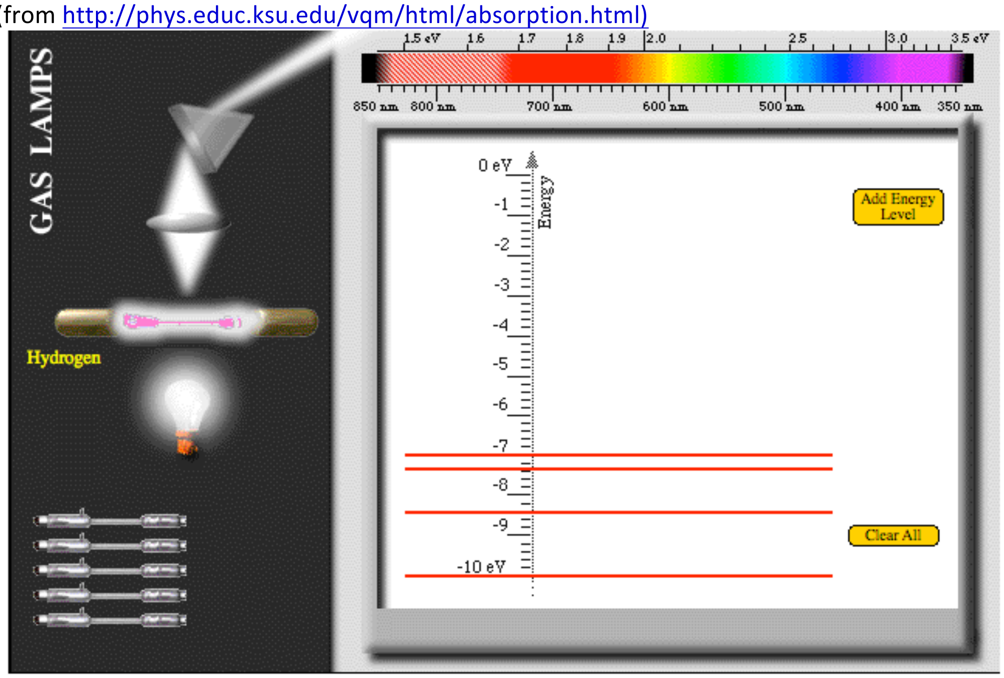
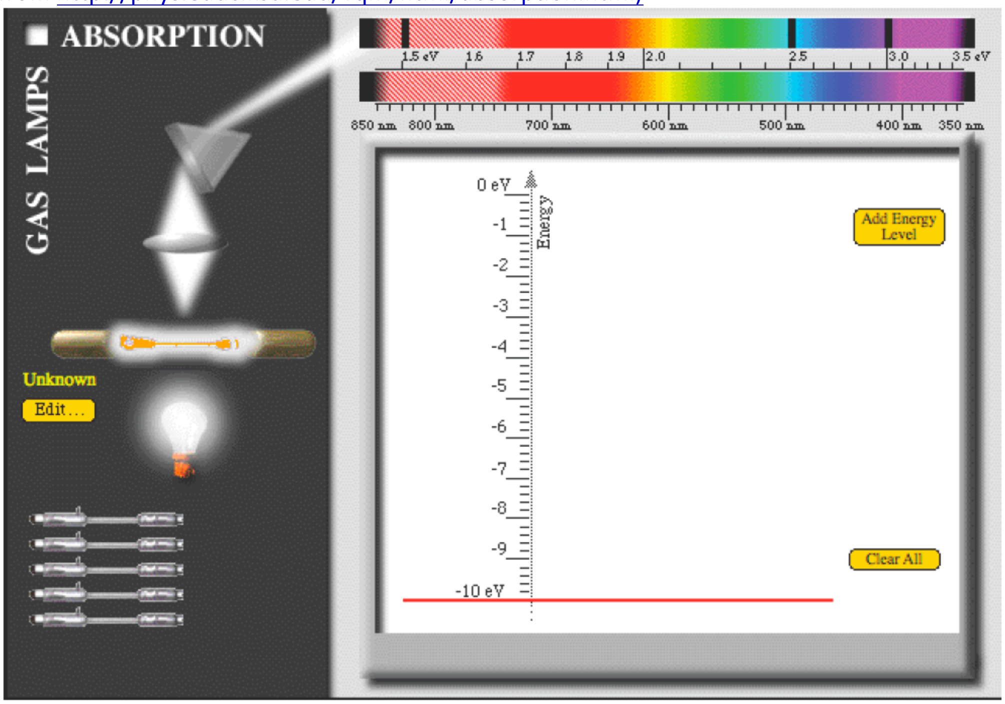


Figure 5.3. Absorption Spectrum provided to students. They are asked to draw the energy level diagram
(from http://phys.educ.ksu.edu/vqm/html/absorption.html)



Students were encouraged to interact with the visual as much as they liked, and also were prompted not to worry if they did know all the information, simply to think aloud as much as possible.

5.4 Data and Analysis

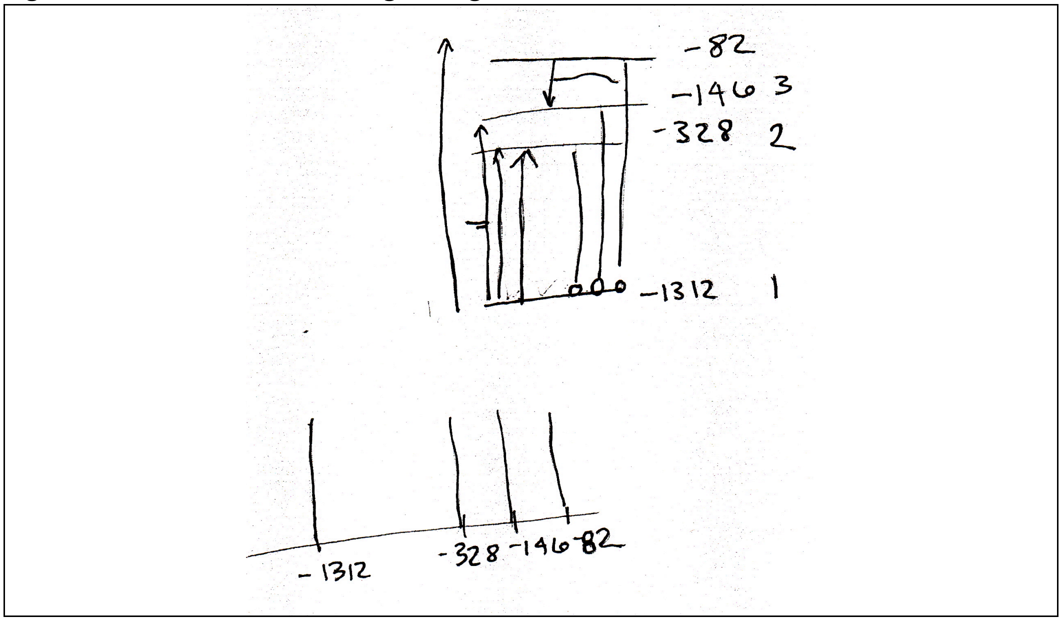
Fall 2009

Initially, in Fall 2009, Student 18 scored a "2" on the Continuous to Discrete dimension and demonstrated threshold reasoning when she said that light of energy 986 kJ, a little bit more than the difference between the n=1 and n=2 levels, will get absorbed. Her initial description is provided in Chapter 4.

Student 28, also discussed in Chapter 4, exhibited a literal reasoning when interpreting the spectra as she directly mapped the energy levels to the spectral lines, and drew the diagram shown in Figure 5.4.

Both students scored a "2" on the Interpreting Spectra dimension, as was detailed in Chapter 4.

Figure 5.4. Student 28's drawing during the Fall 2009 interview



Spring 2011

5.4.1 The Case of Student 18 – building a *difference* reasoning

Even though in Fall 2009 Student 18 assigned spectral peak values as corresponding to differences in energy levels, she had forgotten this idea when presented with atomic spectra over a year later for the Spring 2011 interview. First she was asked to familiarize herself with the representations.

8 **18:** No! Ok, wait! Now I'm starting over! [laughs] Maybe this is the light bulb, and well obviously this is the light bulb... Ok now I'm thinking this is the light bulb and it's shining light through the hydrogen gas and that is maybe absorbing... Hydrogen molecules are absorbing certain wavelengths (inaudible) um.. and then what is not absorbed is passing through and then this.. the prism allows you to see the colors! ok! ok! *whoa! and then.. so this is saying what is absorbed and what is not absorbed so that's saying what wavelengths the molecules absorb. ok. yeah.*

After realizing what the prism and path of light is depicting, she then observed that the black lines represented the energies of light that are absorbed.

17 **18:** Um…. Are these connected? Like is this line… oh, this is just going to this! [realizes the spectrum is coming from gas lamp] and this is like what you are referencing. Ok. *So I guess this would be light that's absorbed, or different levels of energy that are absorbed.*

Then, Student 18 began to interact with the visual. She noticed that as the energy levels were positioned higher and lower, the spectral lines moved in tandem.

29 **18:** So.. I mean I think like the lower you put it, the lower energy wavelength it goes to.. So I guess… I mean I would think that like maybe this [points to spectral line, gestures vertically] is just another way of expressing this [points to energy level diagram, gestures horizontally] yeah...

30 **I:** Ok, play around with it and try to get it to match up to one of the lines.

31 **18:** Ok. So if you matched up to that… like that would mean that this is the amount of energy, like maybe that's a certain bond (points to black spectral line), and then that's the amount of energy the bond contains or something (points to energy level)

32 **I:** If you look at the numbers, can you assign some numbers to that arrow?

33 **18:** Wait, ok, like these numbers? [points to energy level diagram] So if you pretend that this is...um.. So I guess like this is the.. What is this again? Oh wait! These are the same.. That's eV and that's eV… so that's 1.9 [position of higher energy level], and this is 8 [spectral line]..um, what...[laughs, confusedly]

34 **I:** Move it around a little and see if those numbers will make sense.

35 **18:** so that's at 3 [higher energy level], and that's at 7 [spectral line]. *Um, like I don't get why like if this at 1.9 [spectral line], why it's not at 1.9 here?…[energy level]*

At this point, she remains at the literal level of representation use - she does not understand why the numbers don't exactly match in the two diagrams. Next, when guided to make sense of the numbers in both diagrams and see how they may be connected, she has a sudden realization that it is the differences in the energy levels that match the lines in the spectra.

36 **I:** What happens if you put this at 1.9?

37 **18:** [quiet for a while staring at screen] Uh… then it [the spectral line] disappears. I don't know… what is happening. And it only appears around six and a half-ish, and I don't get what these numbers represent[energy levels]. And I don't get why they are all negative.. yeah... [laughs]

38 **I:** Why don't you line that up again to one of… One of the black bars.

39 **18:** [silent] So, this is …I'm guessing that's a place where light doesn't go through because the wavelength was absorbed by the hydrogen gas…

40 **I:** And this is… so this is… like ... If this is a wavelength, maybe that's like the amount of energy the wavelength has? And so this… *OH! Wait a Second!!! Maybe I get it! I get it! Ok! Wait, do I get it? Yeah! Cause this is the difference*.. Is this number... ok

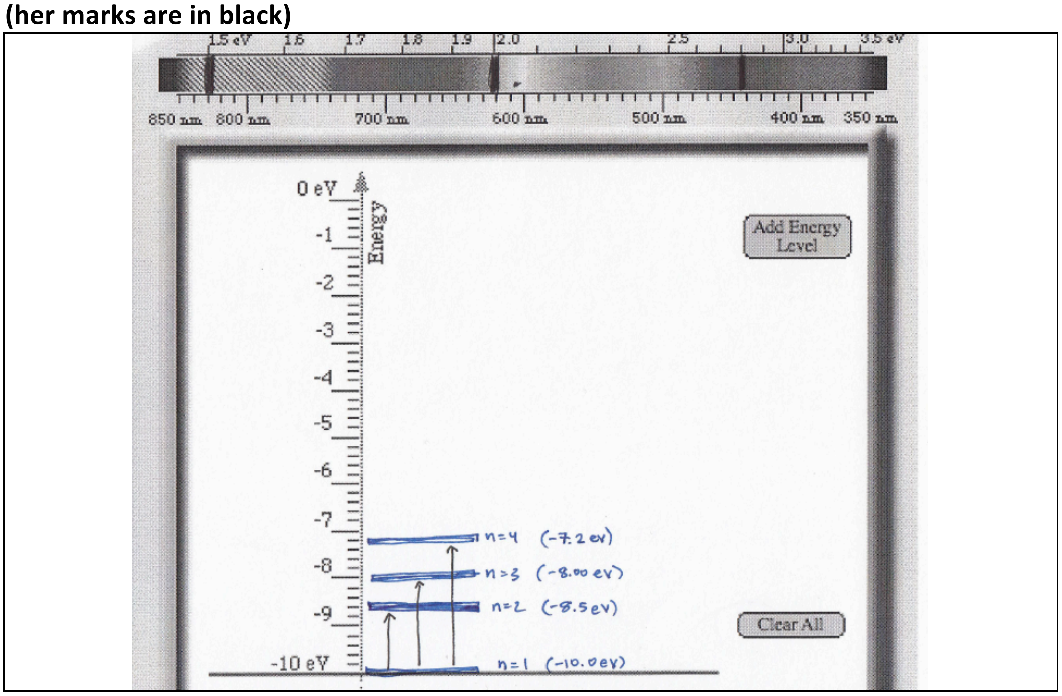
41 **18:** So, how did you know that? Or how did you get that?

42 **I:** How did I just figure that out? I think cause, oh, cause in my head I was like ok like if these represent like 2 different energy levels, it has to go up that much, and then I saw that... That this number, like this distance corresponded to that [points to spectra] yes.

Student 18 successfully moved from a literal type of reasoning, thinking that the values for the lines in each diagram should be the same, to a realization that it is the differences in energy levels that match the spectral lines. For the rest of the duration of the interview, she is successfully able to hold onto this type of reasoning. She correctly constructed the spectra from a given energy level diagram and then correctly constructed the energy level diagram from a given spectra, showing the robustness of her newfound knowledge.

70 **18:** Uh, because given that it's at number 1.5 and that's.. There's an energy difference.. Like these numbers [point to spectra] correspond to like this difference [points to energy level diagram] yeah, so and then so for 2.5.. Ten minus 2.5 is 7.5, yeah that would be right here, that's this one [points to 2.5 spectral line] and then 3 would be 7. Yeah.

Figure 5.5. Student 18's construction of the spectra from a given energy level diagram (her marks are in black)



At the end of the interview, when asked about absorption of light energy between the n=1 and n=2 levels, she demonstrated a successful grasp of an all-or-nothing absorption of energy.

104 **I:** This is a short answer, this was on the final actually.

105 **18:** Ok.

106 **I:** So go ahead and… you can just talk through you don't have to write it if you want.

107 **18:** Ok, so an electron.. Would it absorb energy E_2? Ok, I'm saying no because, um, cause it doesn't correspond to a specific energy wavelength that hydrogen has and so the energy would just go through and um…

108 **18:** So, I don't think it can absorb the energy and it would just go around or just into the atmosphere [laughs] But yeah, because it's not enough where it would make the electron leave the atom, but it doesn't correspond to a specific level of energy that is around the hydrogen atom so… or the hydrogen atom has I guess ...um… I don't know if these... if energy levels are… I mean I guess they are associated specifically with the hydrogen atom but I don't really get... I don't see where they are… but I don't really get where they are, I mean... like if they are surrounding the atom but like it's hard for me to conceive that it's not like something you can.... not even something you can... you can see... but like just something that isn't really concrete, so that I have trouble with that.

Although she expressed some confusion and frustration at visualizing what the energy levels are, she correctly stated that because "it doesn't correspond to a specific level of energy that is around the hydrogen atom" the energy is not absorbed. At this point, it's not completely clear if the visual is helping her with this conclusion, or if she came to this conclusion by some other means.

But, based on the data from this student, this visual intervention of the connected representation seems like it may be a useful tool in moving or guiding students to thinking in terms of differences of the energy levels when thinking about the atomic spectrum. It may assist in moving students from a literal type of thinking to an exact difference type of thinking. Students are assisted in tracking the connection between the energy levels values to the values of the spectral lines by looking at the numerical relationships between the two. The link between the two representations is visible and tangible, and students are pushed to make sense of what that relationship is.

5.4.2 The Case of Student 28 – limitations of the connected representation

Additional challenges become apparent through an observation of another student, Student 28, interacting and working with the connected representation, As she worked through her explanations, 28 showed proficiency in interpreting both the energy level diagram and the atomic spectra. However, when asked about atomic absorption of light at the end of the interview, it is apparent she still holds on to a classical thinking and demonstrates threshold reasoning, showing the limitations of this curricular approach.

At the start of the interview, Student 28 expressed some confusion over the difference between the absorption and emission spectra, but after looking at both diagrams, she remarked that she is more comfortable with the emission spectra, which was then utilized for the remainder of the interview.

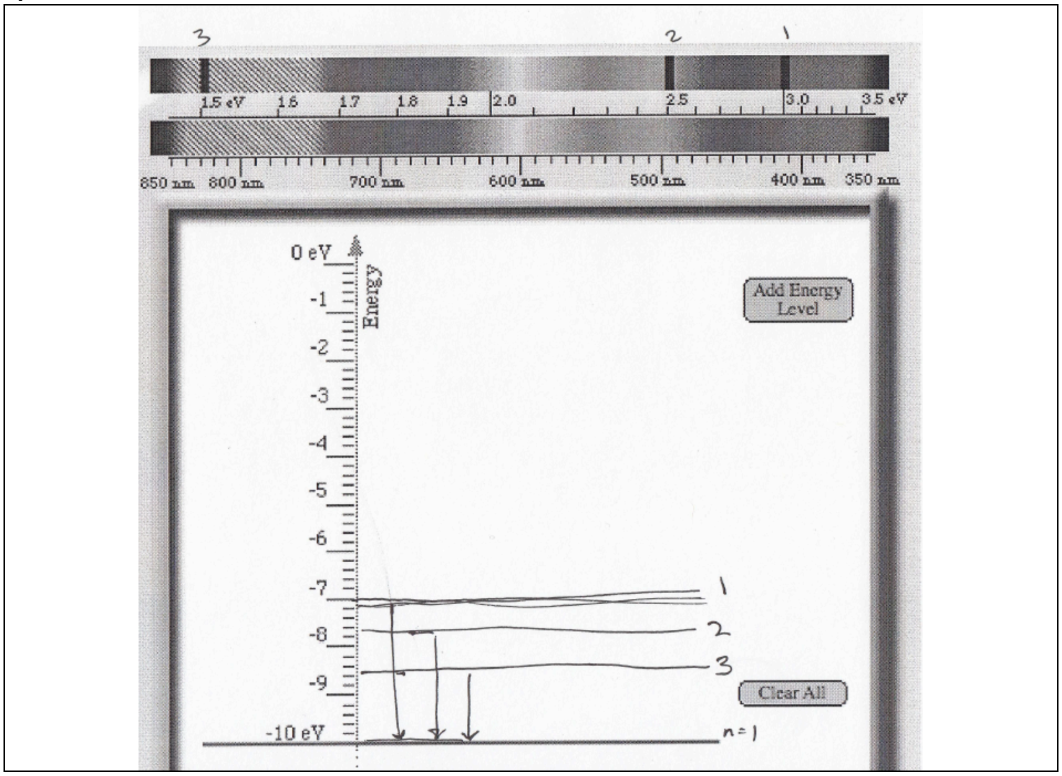
> 22 **28:** Yeah, um, so this is what the reader I guess is picking up that are emitted... Are these, I guess, energy levels, and then the other colors that aren't are the black lines, it means that these [points to emission spectra] are these black lines [points to absorption spectra] and then all the other colors are those that are absorbed, yeah… and so these two charts complement each other.

Then, 28 quickly recognized that the numbers in the spectra correspond to differences in the energy levels. This was surprising because in the initial Fall 2009 interview, she demonstrated a literal type of reasoning and exactly matched the spectral lines to the values of each energy level. In Spring 2011, she correctly assigned a value of 2.4 eV for a electron transition from an energy level of -10 eV to a final energy level of -7.5 eV.

> 41 **I:** So how much energy is involved in that transition?
>
> 42 **28:** That would be like two and a half, I guess, two and a half eV's. Um, so yeah, the higher energy would be in this direction [points right on spectra] or the higher energy voltages, or the greater distance between the electron levels, and the higher energy is shorter wavelength as well...

Then, she after interacting with the visual, she demonstrated a mastery of drawing the spectra from the energy level diagram and vice versa on a piece of paper.

Figure 5.6. Student 28's drawing of the energy level diagram from a given Emission spectrum



57 **I:** Can you draw similar levels? Similar to that…

58 **28:** [draws] So I'm going to say 1,2,3 [labels spectra] so this is one.

59 **I:** How did you know to put it there?

60 **28:** Um, maybe that it's because there are... I guess this should be a little bit lower... Maybe down here, um, because it's around 3, I guess, electron voltages in energy. So that would be 3 emitted, 3 eV, as it falls, and then this one would be 2.5. It would be lower energy, so that would be about here [draws] and then this one is only 1.5 and that's even lower energy so that's here... so this one falls and [inaudible]

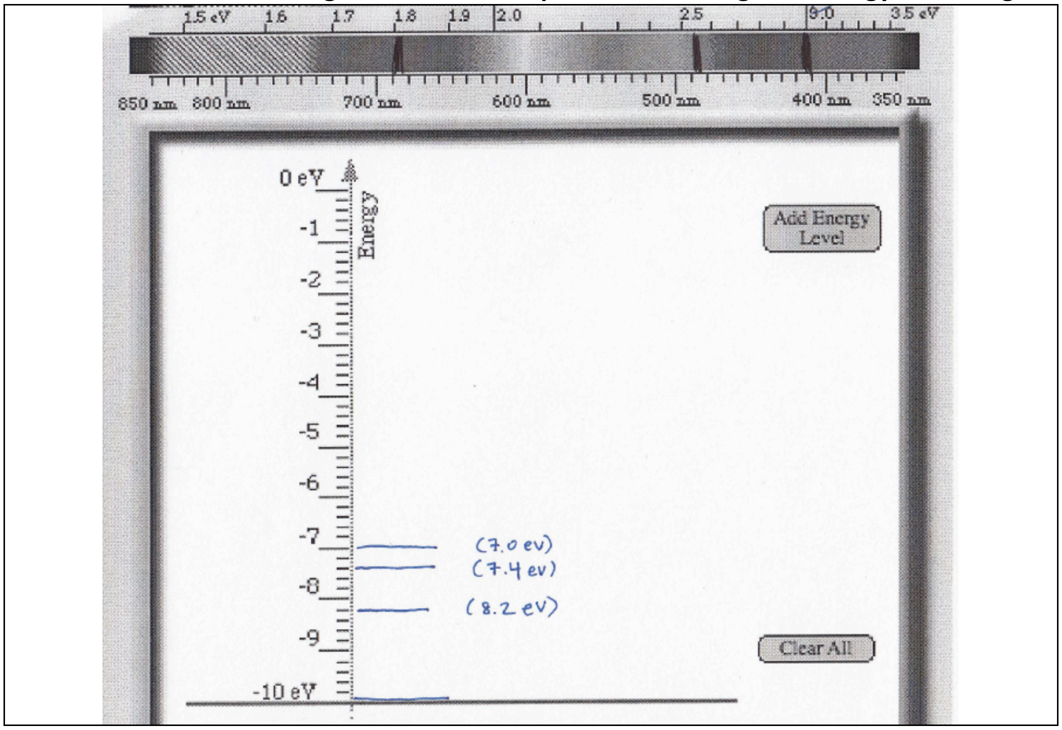
61 **I:** Ok, and another similar problem. This time I'm going to flip it, so I'm going to give you the energy levels, can you draw me the spectrum? And sorry, ignore these things, so just draw it on the bottom.

62 **28:** Ok, just draw the black lines?

63 **I:** Just draw the black lines.

64 **28:** I'm gonna say that this one is about 3 [draws on spectra] so over here. And this one is it looks like a little over 2.5, so about here. And then this one is over 1.5, so maybe like 1.8. So it would be over here, and this one is zero so…

Figure 5.7. Student 28's drawing of an Emission Spectrum from a given energy level diagram



She quickly and confidently is able to draw both the energy level diagram and the emission spectrum using this difference reasoning.

Finally, at the end of the interview, she was asked to explain one more item, a short answer question from a previous exam. She produced some surprising explanations.

She was asked to explain if light of energy in between two energy levels would be absorbed, and to answer the following question:

Figure 5.8. Question on Hydrogen Atom's Energy Absorption

11) Hydrogen Atom

Consider the following energy level diagram for a hydrogen atom.

Can an electron in state n = 1 absorb a photon of energy E_2?

Circle one: Yes No

If you answered yes, where does the excess energy go?

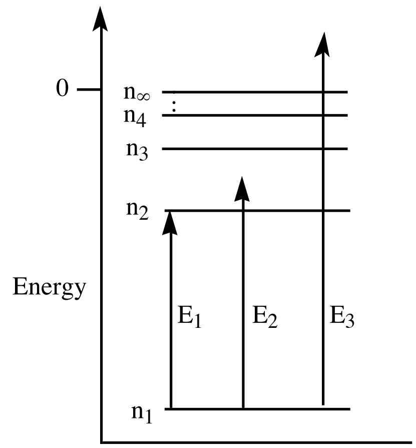
If you answered no, why not?

Can an electron in state n = 1 absorb a photon of energy E_3?

Circle one: Yes No

If you answered yes, where does the excess energy go?

If you answered no, why not?



Her responses reveal some very interesting ideas on how she reconciles the line spectrum with her ideas of continuous energy absorption (threshold reasoning).

73 **I:** There's one more. It's a short answer question that was actually from the final.

74 **28:** Ok. [reads question aloud] Yeah, I'm thinking that it can absorb this energy, but based off of that last question, I don't remember the specifics. But, I feel like it does. It is transferred into kinetic energy, so I would say that um… Should I be writing this down on here?

75 **I:** No, it's ok.

76 **28:** Ok, I would say it would absorb the energy up to n=2 or $E_{2,}$ I guess, um and then the excess energy as it falls down to that level and then down to this level, the excess energy here would be kinetic energy, and then as it falls more, that would be light energy between the 2 levels.

First, she mistakenly turned this question into a problem dealing with emission of light, instead of absorption. However, if we follow her reasoning, she expressed some interesting ideas. She was demonstrating threshold reasoning, or a belief in classical-type continuous energy emission. When asked to explain her reasoning more fully, she reiterated that indeed the intermediate energy of E_2 can be absorbed, and this still matches with the line spectrum she drew earlier in the interview.

77 **I:** Ok, so just one more question… so the reasoning that you just gave... So if it absorbs here [points to E_2], the excess would be kinetic, what would an absorption spectrum look like for that situation? Or, what energies of light would be absorbed? Just overall?

78 **28:** I would say that it would still, it would just show up here [n_1 to n_2], as the energy that's absorbed.

79 **I:** Ok.

80 **28:** Um, just because, um, I don't.. This, this wavelength up here [excess over n=2] as it falls would not be emitted, it would, because it would fall here [to n=2] and then this wavelength [n_2 to n_1] would be emitted, so I'm thinking that it would still show up just as that - this line of energy [n_2 to n_1] on the spectrum.

She described a process where energy of E_2 will be absorbed, and then this same energy becomes emitted in a two-step process, evidence of threshold reasoning.

1. First the excess energy over the n=2 level will be released but will not show up on the spectrum.
2. Then, the electron will move from n=2 to n=1, and she surprisingly says that this E_2-E_1 difference will be emitted and matches the spectral line!

Her thoughts are probed further in a follow up question.

81 **I:** So what goes on, like right there (over n=2) when it falls? That little bit?

82 **28:** Um, I wanna say that they they would turn into heat of some kind? Because it wouldn't be a wavelength equal to that of light energy so I want to say kinetic energy would be heat or temperature.

She is interpreting the emission of light as a 2 step process: 1) a “little bit of energy” is transformed as heat, and 2) the difference between n=1 and n=2 levels is emitted as light.

Although she correctly masters a difference type reasoning, she still holds onto continuous energy absorption, and has a constructed a model in her head where both types of reasoning coexist and correctly explain the line spectra. Then, she is again asked to explain on the diagram what happens exactly with light energy E_2.

83 **I:** So if you were to draw a spectrum like the ones we did here…

84 **28:** Mm-hmm.

85 **I:** What would it look like?

86 **28:** So, say this is the wavelength for n=2 or the energy required for n=2. Um, there would be, there would be a line here.

87 **I:** Or E1, whatever energy that is, got it.

88 **28:** Yeah, ok, oh yeah, yeah, so this would be E1, I guess would be [inaudible] but yeah so that would be the E1 energy.

89 **I:** Ok.

90 **28:** *And then E2 wouldn't show, just because the excess little portion would be heat.*

91 **I:** Ok, and then what would be your next one? It's not on that diagram, but if you were to draw another arrow here.

92 **28:** Mm-hmm.

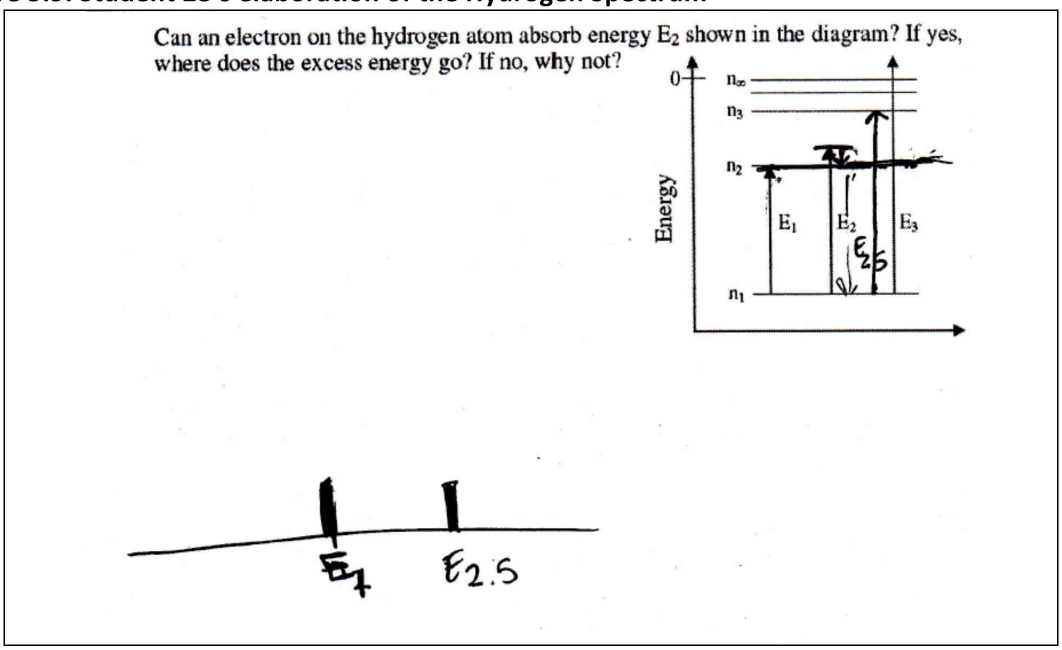
93 **I:** For your next line in your spectrum.

94 **28:** And then next one would come up to n equals or n3, so it would be... This would be higher in energy, so it would be further down this direction, and then that would be the... Let's say this is E two and a half...

95 **I:** Ok.

96 **28:** This would be E two and a half or I guess n=3.

Figure 5.9. Student 28's elaboration of the Hydrogen Spectrum



She described that on the energy level diagram only E_1 (the difference between n=1 and n=2) and what she calls $E_{2.5}$ (difference between n=1 and n=3) correspond to lines on the spectra. She states that absorption for an E_2 (energy which does not match energy level difference) does in fact occur, but the energy E_1 will be emitted as a photon, and the "excess little portion" being emitted as heat. Though, again, she is confusing absorption with emission, her reasoning is an interesting case of mixing classical reasoning with quantum observations, and her model is reconciling the two ways of thinking.

5.5 Results and Discussion

For Student #18, seeing both representations side-by-side and connected aided her in her transformation. She was able to recognize that differences between energy levels are important. Her case was a clear example of a quick change from a literal type of thinking to an exact difference type of thinking, and highlights the possible strengths of this curricular tool. This example also shows the importance of having students construct understanding on their own and play with representations to fully grasp their meaning. After interacting with the visual, Student 18 demonstrated a robust understanding of both the line spectrum and the energy level diagram as she is able to construct one from another successfully. In addition, in a follow-up written question, she correctly remarks that energy absorption is a discrete process, only light that exactly matches differences between energy levels will be absorbed.

At first glance, this intervention showed evidence that it may hold potential in guiding students to a normative view.

However, with the case of Student #28, the persistent and strong influence of classical ideas proved that this connected representation by itself is not enough to guide students to a full understanding. Student #28's classical ideas of energy absorption influenced her interpretation of the connected representation, so that she still held on to her ideas of continuous energy absorption with a threshold type of thinking, and developed a framework such that with her threshold reasoning, she could still argue for the presence of a discrete line spectrum.

These findings suggest that curricular tools need to be developed where students are not only pushed to think in terms of a difference type of reasoning, but are pushed to challenge and ultimately abandon their classical views of energy absorption as a threshold process.

5.6 Summary

Showing students a connected representation (of the energy level diagram and the atomic spectra) shows some promise in moving students to a difference type of thinking, but it is clearly not enough. Students' classical ideas are deeply rooted and strongly held, and the transition from thinking about energy absorption as a continuous process (as meeting some minimum threshold) to a discrete process must be better scaffolded to change students' classical ideas. Otherwise, as the case of Student 28 shows, learners may be left with a hybrid set of reasoning in their heads, stuck somewhere between the classical and quantum worlds.

Chapter 6: Conclusion

6.1 Summary of Results

This dissertation aims to explore how students are thinking about atomic absorption and emission of light, in the area of introductory quantum chemistry. In particular, the impact of classical ideas of electron position and energy on student understanding of spectra is studied.

The questions this study aimed to answer were:

- Q#1: How can student thinking about concepts related to atomic spectra be characterized?
- Q#2a: How do students interpret and connect representations of the energy level diagram and the line spectrum?
- Q#2b: How does classical thinking impact understanding of atomic spectra?
- Q#3: What are possible challenges in guiding students to a normative understanding of atomic spectra?

Previous work had not specifically studied the learning struggles students exhibit as they are learning about atomic spectra and the discrete absorption of light. From the analysis in Chapter 3, a way of characterizing student interpretation of atomic spectra was developed, and four codes emerged that detailed dimensions of thinking that students possess: Deterministic to Probabilistic, Continuous to Discrete, Interpreting Spectra, and Energy/Force dimensions. The last 3 areas were a useful addition to the research base to outline a way of characterizing student understanding of spectra. These dimensions captured the variety of student ideas in the sample population, which was representative of the class as a whole.

It was found that more successful students were able to integrate two concepts: 1) that the energy values of the spectral lines match an exact difference between energy level values and 2) that energy absorption is an all-or-nothing process, and the energy of the photon cannot be partitioned in some way. An overwhelming majority of students who mastered thinking about energy absorption as a discrete process also viewed the spectral lines as representing differences in energy, 34 out of 38 students. Along with this, it was found that holding onto a deterministic view of electron position in the atom had little impact on successful interpretation of spectra. These results have the potential to improve chemistry instruction with this topic, and by spending less emphasis on the probabilistic nature of electron position, and more on the spatial model of the atom, forces, and energy conservation, students may be better assisted as they move to a normative view of atomic absorption of light.

From an analysis of ten student interviews, four main types of representation use and conceptual understanding in the topic of atomic spectra were found: Literal Reasoning, Threshold Reasoning, Exact Difference Reasoning, and Meta-Reasoning. An exact-difference reasoning consisted of a full appreciation for how the energies of the spectral lines exactly matched the differences between energy level values, and an understanding of the all or nothing discrete absorption process. More advanced students were able to display a procedural mastery for the translation and also experience a conceptual mastery and epiphany about how this behavior is starkly different from their classical understandings. In this work, some classical ideas, such as threshold reasoning, hindered students from fully understanding the quantum nature of bound electrons. Other more productive classical ideas, such as energy conservation, attraction of the electron to the nucleus, and the spatial model of the atom, were found to strengthen student understanding by building a more integrated and connected system of knowledge between different conceptual strands, in accordance with Stevens, Shin & Krajcik's discussion (2009).

In Chapter 5, data was analyzed from two students who initially struggled with interpreting spectra. Their interaction with a representation designed to scaffold their understanding of spectra was studied, and their successes and obstacles were explored. For Student #18, seeing both representations side by side and explicitly connected aided her transformation as she was able to recognize that differences between energy levels were the important feature. Her case was a clear example of a change from a literal type of thinking to an exact difference type of thinking, and highlights the possible strengths of this curricular tool. However, the tool was not adequate for the other case study to make the shift. Student #28's classical ideas of energy absorption influenced her interpretation of the representation, as she held on to her ideas of continuous energy absorption with a threshold type of thinking. She developed a framework such that with her threshold reasoning, she could still argue for the presence of a discrete line spectrum.

6.2 Implications

From an in-depth characterization of student thinking and an exploration of the impact of classical ideas on quantum understanding, two main implications can be discussed.

1. **Students' classical ideas must be challenged and/or utilized when teaching quantum chemistry and line spectra**

Students hold on strongly to classical ideas of energy when presented with quantum concepts. For example, from the data analyzed in this study, it was found that when learning about discrete energy absorption, only 58% of the sample studied (N=65) correctly described discrete energy absorption. The rest of the population frequently demonstrated a threshold type of reasoning that was influenced by their classical ideas. In the analysis presented in Chapter 3, 60% of students integrated energy conservation and ideas related to attraction of the electron to the nucleus in their descriptions of energy levels, light absorption, and atomic spectra. These productive ideas are tools in guiding students to a normative view of atomic spectra.

Instructors need to be aware of students' prior ways of thinking and how these ideas influence learning of new material. Instructors can capitalize on productive classical ideas, such as energy conservation, electronic attraction to the nucleus, and the spatial model of the atom, when designing instruction and teaching quantum concepts to help build strong conceptual frameworks in students. Students may then build an integrated understanding rather than be left with a system of isolated facts. Instructors should be aware of the strong influence classical ideas may have, especially as they manifest in student understanding as hybrid ideas between classical and quantum thinking.

2. **Atomic spectra are a rich context for teaching and assessing quantum principles.**

This work is a step to move quantum chemistry to a place where students are grappling with fundamental concepts rather than memorizing formulas, symbols or algorithms. Through understanding the representations of the energy level diagram and the atomic line spectra, students may be led to think about the nature of energy states in the quantum regime, grapple with absorption and emission, and connect back to model of the atom. It offers a context where students have the chance to fully acknowledge and appreciate the nature of quantum principles.

Teaching atomic spectra in the general chemistry classroom allows learners to grapple with quantized energy states and atomic structure. By understanding students' thinking processes more fully, better instruction can be developed that addresses the classical ideas that students incorporate during learning.

6.3 Future Work

Though this work has added to the understanding of student learning of quantum principles, and has extended the current research to examine how students' classical ideas shape their understanding of discrete energy absorption and line spectra, more work needs to be done. In this dissertation, it was found that a large fraction of the sample population was using classical views of energy absorption when interpreting atomic spectra. The question remains: how can students be successfully guided to viewing energy absorption as a discrete process? Chapter 5 provided an exploratory study into issues that may hinder moving students to a normative view of spectra. More work needs to done to understand what curriculum strategies are helpful in teaching students about quantized energy levels and discrete energy absorption. Knowing now that students resort to thinking about energy absorption as a threshold process, work can be done to determine how to specifically challenge students' classical notions.

Another extension of this work would be to probe introductory college students' understanding of process of emission, absorption and transmission of light. From the first analysis of the data, it was evident that students do exhibit confusion of these concepts, and more targeted interview items can be tested with students to probe their conceptual understanding.

In particular, there is a need for curriculum interventions and other visual animations to push students to understand how classical rules are fundamentally different from quantum rules. Curriculum that directly speaks to the idea of discrete energy absorption, and that challenges student thinking of the process in terms of a threshold should be included in chemistry instruction so that students appreciate the full nature of quantum principles. This work can also be extended by looking at student understanding of related quantum concepts, such as orbitals, molecular orbitals, and the photoelectric effect, and seeing how classical ways of thinking impact the comprehension of these topics in a similar population.

6.4 Concluding Remarks

The quantum model and the idea of discrete energy states and absorption of discrete energies is a strikingly new and different concept that students encounter at the introductory chemistry level. Current instruction fails to significantly challenge students' classical notions, and in many cases, they remain clinging to classical ways of thinking and don't fully grasp the consequences of quantum mechanic principles. Students remain stuck with a hybrid way of thinking of quantum phenomena using classical analogies and rules. Teaching atomic spectra is a rich tool in assessing student quantum understanding and probing thoughts on energy absorption, all in an engaging context based on easily attainable visual observations in the classroom or laboratory. Though insights have been found in this dissertation, more needs to be done to understand the complicated learning process that students undergo when transitioning from the classical to quantum world.

References

Asikainena, M.A., & Hirvonen, P.E. (2009). A study of pre- and inservice physics teachers' understanding of photoelectric phenomenon as part of the development of a research-based quantum physics course. *American Journal of Physics, 77*(7), 658-666.

Bao, L., & Redish, E.F. (2002). Understanding probabilistic interpretations of physical systems: A prerequisite to learning quantum physics. *American Journal of Physics, 70*(3), 210-217.

Brown, T.E., LeMay, E.H. & Bursten, B.E. (2008). Chemistry: The Central Science. New Jersey: Prentice Hall.

Budde, M., & Niedderer, H., Scott, P. & Leach, J. (2002). 'Electronium': a quantum atomic teaching model. *Physics Education, 37*(3), 197-203.

Carpenter, T. P., Fennema, E., & Franke, M. L. (1996). Cognitively guided instruction: A knowledge base for reform in primary mathematics instruction. The Elementary School Journal, 97(1), 3-20.

Clement, J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. Journal of Research in Science Teaching. Special Issue: The Role of Analogy in Science and Science Teaching, 30(10), 1241-1257.

Cervellati, R., & Perugini, D. (1981). The understanding of the atomic orbital concept by Italian high school students. *Journal of Chemical Education, 58*(7), 568-569.

Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, 5, 121-152.

diSessa, A. A., & Sherin, B.L. (2000). Meta-representation: An Introduction. *Journal of Mathematical Behavior*, 19(4), 385-398.

diSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction*, 22(3), 293-331.

Gilbert, J. K. (2005). Visualization: A Metacognitive Skill in Science Education, in Gilbert, J.K., ed., *Visualization in Science Education*, Dordrecht, The Netherlands, Springer. 9-27.

Hammer. D. (2000) Student resources for learning introductory physics. *American Journal of Physics, 68* (S1), S52-S59.

Harrison, A.G., & Treagust, D.F. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple-model use in grade 11 chemistry. *Science Education*, 84 (3), 352-81.

Hoffmann, R., & Laszlo, R. (1991). Representation in chemistry. *Angewandte Chemie*, 30, 1-16.

Hunt, E. & Minstrell, J. (1994). A cognitive approach to the teaching of physics. In K. McGilly (Ed), *Classroom Lessons: Integrating Cognitive Theory and Classroom Practice*. Cambridge, MA: The MIT Press.

Ireson G., (2001). On the quantum thinking of physics undergraduates, in Behrendt H., Dahncke, R. Duit, Graber W., Komorek M., Kross A., and Reiska P., eds., *Research in science education – past, present, and future,* Dordrecht, The Netherlands, Kluwer Academic, 83-88.

Johnston, I. D., Crawford, K. & Fletcher, P. R. (1998). Student difficulties in learning quantum mechanics. *International Journal of Science Education, 20*(4), 427–446.

Ke, Jiun-Liang, Monk, M. & Duschl, R. (2005). Learning Introductory Quantum Physics: Sensori-motor experiences and mental models. *International Journal of Science Education, 27*(13), 1571–1594.

Kozma, R.B. and Russell, J. (1997). Multimedia and Understanding: Expert and Novice Responses to Different Representations of Chemical Phenomena. *Journal of Research in Science Teaching*. 34(9): 946 – 968.

Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction*, 13(2), 205-226.

Krajcik, J. S. (1991). Developing students' understanding of chemical concepts. In Glynn, S.M., Yeany, R. H. & Britton, B. K., Eds., *The psychology of learning science*. Hillsdale, NJ, England: Lawrence Erlbaum Associates, Inc., 117-147.

Linn, M.C., Clark, D., & Slotta, J.D. (2003). WISE Design for Knowledge Integration. *Science Education, 87*(4), 517-538.

Mannila, K., Koponen, I.T., & Niskanen, J. A. (2002). Building a picture of students' conceptions of wave- and particle-like properties of quantum entities. *European Journal of Physics, 23*(1), 45–53.

Mashhadi, A., & Woolnough, B. (1999). Insights into students' understanding of quantum physics: visualizing quantum entities. *European Journal of Physics, 20*(6), 511-516.

Mayer, R. (2005). Cognitive theory of multimedia learning. In R. Mayer (Ed.), The Cambridge handbook of multimedia learning (pp. 31-48). Cambridge, UK; New York: Cambridge University Press.

McKagan, S.B., Perkins, K.K., Dubson, M., Malley, C., Reid, S., LeMaster, R., & Wieman, C.E. (2008). Developing and researching PhET simulations for teaching quantum mechanics. *American Journal of Physics, 76(*4&5), 406-417.

McKagan, S.B., Perkins, K.K. & Wieman, C.E. (2008). Why we should teach the Bohr model and how to teach it effectively. *Physical Review Special Topics - Physics Education Research, 4*(010103), 1-10.

Michalchik, V., Rosenquist, A., Kozma, R., Coppola, B. P., Kreikemeier, P., & Schank, P. (2008). Representational resources for constructing shared understandings in the high school chemistry classroom. In J. Gilbert, M. Nakhleh, & M. Reiner (eds.). *Visualization: Theory and practice in science education*. New York: Springer, 233-282.

Nakiboglu, C. (2003). Instructional Misconceptions of Turkish Prospective Chemistry Teachers about Atomic Orbitals and Hybridization. *Chemistry Education: Research and Practice, 4*(2), 171-188.

Olsen, R.V. (2002). Introducing quantum mechanics in the upper secondary school: a study in Norway. *International Journal of Science Education, 24*(6), 565–574.

Palmer, Stephen E. (1978). Fundamental aspects of cognitive representations. In E. Rosch & B. Lloyd (eds.), *Cognition and categorization* (pp. 259-303). Hillsdale, NJ: Erlbaum.

Papaphotis, G. & Tsaparlis, G. (2008). Conceptual versus algorithmic learning in high school chemistry: the case of basic quantum chemical concepts, Part 2. Students' common errors, misconceptions and difficulties in understanding. *Chemistry Education: Research and Practice, 9*(4), 332-340.

Petri, J., & Niedderer, H. (1998). A learning pathway in high-school level quantum atomic physics. *International Journal of Science Education, 20*(9), 1075-1088.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., et al. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, 46(6), 632-654.

Schwarz, C. V., & White, B. Y. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction, 23*(2), 165-205.

Seymour, E., & Hewitt, N. (1997). *Talking about Leaving: Why Undergraduates Leave the Sciences*. Boulder: Westview Press.

Shakhashiri, B. Z. (2011). *Chemical Demonstrations, Volume 5: A Handbook for Teachers of Chemistry*. Wisconsin: University of Wisconsin Press.

Smith, C., Maclin, D., Grosslight, L. & Davis, H. (1997). Teaching for understanding: A study of students' preinstruction theories of matter and a comparison of the effectiveness of two approaches to teaching about matter and density. *Cognition and Instruction*, 15(3), 317-393.

Stevens, R. & Hall, R. (1998). Disciplined perception: Learning to see in technoscience. In M. Lampert and M. Blunk (Eds.), *Talking mathematics in school: Studies of teaching and learning* (pp. 107-149). Cambridge, UK: Cambridge University Press.

Stevens, S., Shin, N., Krajcik, J. (2009, June). Towards a Model for the Development of an Empirically Tested Learning Progression. Paper presented at the Learning Progressions in Science Conference, Iowa City, IA.

Stewart, J. & Rudolph, J (2001). Considering the Nature of Scientific Problems When Designing Science Curricula. *Science Education, 85*(3), 207-222.

Taber, K.S. (2002). Conceptualizing Quanta: Illuminating the Ground State of Student Understanding of Atomic Orbitals. *Chemistry Education: Research and Practice in Europe, 3(2),* 145-158.

Teichert, M.A. and Stacy, A.M. (2002). Promoting Understanding of Chemical Bonding and Spontaneity Through Student Explanation and Integration of Ideas. *Journal of Research in Science Teaching*, 39: 464 – 496.

Tsaparlis G. & Papaphotis G. (2009). High-school students' conceptual difficulties and attempts at conceptual change: The case of basic quantum chemical concepts. *International Journal of Science Education, 31*(7), 895-930.

van Zee, E. & Minstrell, J. (1997). Using Questioning to Guide Student Thinking. *The Journal of the Learning Sciences, 6*(2), 227-269.

Wu, H. (2003). Linking the Microscopic View of Chemistry to Real-Life Experiences: Intertextuality in a High-School Science Classroom. *Science Education*, 87(6): 868 – 891.

Wu, H.-K., Krajcik, J. S., & Soloway, E. (2001). Promoting conceptual understanding of chemical representations: students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching*, 38(7), 821 - 842.

Zhang, J. & Norman, D. (1994). Representations in distributed cognitive tasks. *Cognitive Science, 18*(1), 87-122.

Zollman, D.A., Rebello, N.S., & Hogg, K. (2002). Quantum mechanics for everyone: Hands-on activities integrated with technology. *American Journal of Physics, 70*(3), 252-259.

Appendix A: Interview Protocols

Appendix A.1. Interview Protocols

1. Describe how you visualize the atom. (ask about both Hydrogen and Oxygen)
(sample follow up questions)
   - What is an orbital? Probability of what? why do electrons "live" in orbitals?
   - Have them draw a picture of the 2p orbital for O– what does this represent?
   - Why do electrons have discrete energies? What does this mean?
   - Describe "quantized" as if you had to explain it to someone who hasn't taken chemistry.

2. Describe how you visualize light.
   - If bring up Wave, Particle, Ray Models – ask "What do these different models get you?"
   - Describe what happens when light hits a Hydrogen Atom.
     - with an energy greater than the IE?
     - with an energy less than the IE?

3. (Hand student paper with table below)
The first 4 electron energy levels in hydrogen, H are provided in the table below.

Energy level	Hydrogen, H
n=1	-1312 kJ/mol
n=2	-328 kJ/mol
n=3	-146 kJ/mol
n=4	-82 kJ/mol

- Can you draw an energy level diagram of Hydrogen? (talk through it) what does this represent?
- Can you draw the absorption spectrum of Hydrogen? (talk through it) How is this different from an emission spectra?
- How much energy is needed to ionize Hydrogen?
- What happens if you shine light on hydrogen with energy of 1512 kJ/mol?
  500 kJ/mol? 984 kJ/mol? 985 kJ/mol? (or slight variations of these numbers)

4. When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?
   (follow up questions)
   - Why are Ne and He tubes different colors?
   - Over time, would the tubes change color?
   - If you change the energy transferred to the tube, do you see a color change?
   - Is there any amount of energy that wouldn't light the bulb?

Appendix A.2. Interview Protocols for Chapter 5 Data

Warm-up:

1. Give students consent form and have them agree and sign
2. Since we spoke with you last spring
   - What is your current major, plan of study? Has anything changed? If so, why?
   - What other chemistry classes have you taken?
   - What is your feeling towards chemistry in general?

This project is related to the last unit of the course, I'm going to show you some pictures and diagrams. I know it's been a while, so just do your best to think aloud and describe what you see.

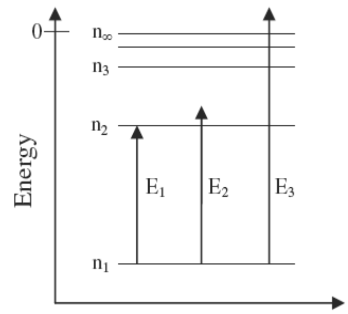
1. Connecting Representations - Show visual of spectra and energy level diagram of Hydrogen ***http://phys.educ.ksu.edu/vqm/html/absorption.html***
   a. Explain to me everything that you see… Don't worry about actual magnitudes of numbers (eV is unit of energy)
      (Possible follow up questions)
      i. What do the black bars represent? Why black?
      ii. What does the arrow represent to you? Why up or down?
      iii. How many lines do you see? Why that number?
   b. Have them move the energy level and observe that the spectral lines are changing
      i. What does that mean to you? Why is it changing?
   c. Show Spectra of Unknown Sample
      i. Can you figure out where the energy levels of the atom are? (give paper with diagram)
   d. Show Energy level Diagram of Unknown Sample
      i. Can you tell me what the Spectra would look like? (give paper with diagram)
   e. Why do you think there is no line at (i.e., 2.7eV)?

2. **Connecting to Spatial Model of Atom (***This was not analyzed for Current Study***)**
   a. Print out an energy level diagram for Hydrogen
      i. Draw the atom at n=1
      ii. Draw the atom at n=2
      iii. Describe any similarities or differences
         1. If they bring up radius, then ask which one is at lower energy?
         2. Why is n=1 lower than n=2?
         3. Would this be different for a different atom? Ask them to draw out a different atom and talk it through.

3. **Students complete and talk through short answer Midterm Question.**

Short Answer Question: Answer in the Box Provided

Can an electron on the hydrogen atom absorb energy E_2 shown in the diagram? If yes, where does the excess energy go? If no, why not?



Appendix B: Interview Transcripts and Codes for 55 Students (for Chapter 3)

Student No: 01

	Evidence	Code
Probabalist/ Determinist	the electron has a probability of being in that sphere, can be outside that sphere, just usually not. more of the bohr sort of model with orbits around it, it's easier for me to visualize the valence electrons (she draws it) The nucleus is a ball with protons and neutrons. I kinda just visualize the outer orbitals being the outer ring,	**2**
Discrete/ Continuous	quantized means, in terms of photon, it's the amount of energy associated with that particlular photon, certain wavelength, carries a certain "packet" of energy, a fixed amount 08:48 if you shine 1160 kJ/ol, it would go to n=2 , nothing will happen if less than 1-2 difference. The light will go into the KE of vibration or the electron speeds up, but it doens't get to a higher energy level	**1**
Interpreting Spectra Code	07:40 the difference between any one of these levels can be absorbed, calculates, 1166, jumps from n=1 to n=... also 1-2, 1-3, 1-4	**3**
Energy/Force Code	04:35 excited means it goes into an upper orbital, energy is being delivered, in order to accomodate that extra energy it needs to go to a higher energy level different because of Ne has more electrons, stronger nuclear charge, more difficult for electron to overcome that attraction The energy has to go somewhere, so it gets released	**3**

Line No.		Transcript
1	**I:**	00:21 Describe how you visualize the atom
2	**S:**	kinda like a proton, like a ball, like a sphere, I guess
3	**I:**	Where is the electron in the atom?
4	**S:**	Oh, ok, so visualizing it, I know that it's an s-orbitals so it's a sphere and the electron has a probability of being anywhere, so it's kinda like a sphere around a central ball
5	**I:**	So, can it be outside of the sphere?
6	**S:**	the electron? yeah, it could be, I guess, it's just usually not, so it's easier to visualize like a cloud
7	**I:**	ok, how about the oxygen atom? How are the electrons in its' orbitals?
8	**S:**	01:11 well, since it's got more orbitals, I kinda see those orbitals not necessarily as simply as the hydrogen, but more of the Bohr sorta model, with circular orbits aroud it, cause it's also easier for me to visualize the valence electrons in that way
9	**I:**	Can you draw it for me?
10	**S:**	[draws] TSo, you got the nucleus which is a ball with protons and neutrons. I kinda visualize it just in terms of the outer orbitals beingkinda like the bohr's orbitals so it would still have the same s and p orbitals but the valence electrons [inauduble]oxygen has 2p4
11	**I:**	So the 2p22p4 are kinda outer?
12	**S:**	yeah
13	**I:**	Can you draw me a 1s and 2s orbital? show me how they compare?
14	**S:**	ok, just size wise pretty much
15	**I:**	So 2s, where is the electron likely to be found?
16	**S:**	well, there's a 90% probability that it's in this sphere at all times
17	**I:**	How about 2p?

18 **S:** 2p? 2p is like the dumbell one, I can't draw! so it's kinda like this but more 3D on the x-y-z plane
19 **I:** 2:46 So, now think about light, How are you thinking about light now?
20 **S:** I think it's easier to think about it in terms of a stream of photons, just because we were talking about how a photon is a quantized packet of energy that can excite electrons, and it's just easier to think about it as a particle
21 **I:** what does quantized mean?
22 **S:** quantized..um.. so in terms of the photon, it's the amount of energy associated with that particular photon, which is associated with that particular wavelength, so it carries a certain packet of energy with it, so for example when it excites an electron it delivers a fixed amount of energy to that electron allowing it to either jump or not jump or get ionized with extra KE
23 **I:** So if you have an atom and you shine light on it, what types of things happen?
24 **S:** 3:34 Well, it depends on the energy of the light, the wavelength of light, because, uh, the electron can get excited to a higher level or it can get ionized completely.
25 **I:** What does that mean, ionized?
26 **S:** It flies away
27 **I:** What happens if you shine light with an energy greater than the IE?
28 **S:** oh, then that electron got ionized, it has a certain amount of KE so it moves away faster, it's easier for me to picture this in terms of.. I did a science fair project on photosynthesis and the whole chlorophyll compound and that's kinda how that works, so I'm using chlorophyll gets.. one of it's electrons gets not ionized per say excited to a higher state where it gets picked up by the system, so it's kinda weird for me thinking of the ion just flying... or the electron just flying out when it gets ionized so it's almost like a sea of electrons with the metals so that's kinda how I envision it
29 **I:** Ok, so when you say excited? What do you mean by that?
30 **S:** 04:35 it goes.. When it gets excited, it goes into an upper orbital, so it leaves what orbital it's in and goes to a higher orbital
31 **I:** So why does that happen with an absorption of light?
32 **S:** because energy is being delivered,so in order to accomodate that extra energy it needs to go to a higher energy level
33 **I:** 06:43 On this I have the energy levels of hydrogen. Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
34 **I:** So, what does the zero represent?
35 **S:** The ionization energy, so this amount of energy -1312 minus 0 would causewould cause the electron to leave
36 **I:** So how come the electron is at the n=1 level?
37 **S:** cause it's the lowest energy level,so it's more stable that way
38 **I:** and, what do these other levels represent?, n=2,3,4
39 **S:** they, well, in terms of the energies, they are the quantized.. is what happens when some certain energies such as a photon hits that electron, it can.. it doesn't necessarily have to be ionized, it can go up to these discrete energy levels before it hits ionization
40 **I:** 7:28 ok so let's say what's one energy of light that can be absorbed for this atom?
41 **S:** anything between oh well, for example um, the difference between any one of these levels can be absorbed,
42 **I:** Can you calculate one possible energy that's absorbed?
43 **S:** [calculates, 1166], so for example, 1166
44 **I:** So if we shine exactly 1166, what happens to the electron
45 **S:** it jumps from nlevel 1 so that will go to a higher energy level

46 **I:** any other energies that get absorbed?

47 **S:** oh yeah, between 1 and 2, 2 and 3, 3 and 4, 1 and 4, basically any one of the steps

48 **I:** If the electron is in the n=1, and you shine 1160 kJ/mol, what happens? or does anything happen?

49 **S:** So, since this is the step from 1 to 3, it would probably go to the n2 and not go further

50 **I:** what if you shine energy that's less than this amount [984]

51 **S:** then nothing will happen.

52 **I:** so what happens to the light?

53 **S:** it goes into I guess KE in terms of vibrations or the electron speeds up? but it doesn't get to a higher energy level.

54 **I:** what happens if I shine 1512 kJ/mol?

55 **S:** then the electron gets ionized and shoots off with an extra 200 kJ of KE

56 **I:** 9:36 so going off of what we just talked about can you draw me an absorption spectrum, what energies of light hydrogen absorbs.

57 **S:** you would have 4 peaks, from n1-2, n1-3

58 **I:** 10:40 How is this different from an emission spectra?

59 **S:** um, it would be the...basically the opposite, what happens when electron goes down a level, so if the electron would move from n2 to n1 it would emit a certain photon for example associated with it, same quantized little energy packet, but different, we see it as color

60 **I:** So why does it emit light when you're going down?

61 **S:** uh, because the energy has to go somewhere, so it comes out as a packet of energy, a photon

62 **I:** When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

63 **S:** 11:25 um, I was thinking it would be because of the electron flow.. Same principle, um neon electrons getting excited to another energy level and then dropping back ot their original stable stateand when they drop back emitting a certain wavelength of light

64 **I:** Why are Ne and He tubes different colors?

65 **S:** 11:57 uh because all these energy levels are at different intervals for every element so for Helium it would be a different little quantized energy packet than say for neon

66 **I:** So, why are they different?

67 **S:** um, because of I'm thinking it's because well Neon will have more electrons so that more of everything… a stronger charge to the nucleus, so it would be more difficult for electrons to overcome that attraction, if that makes sense…

Student No: 02

	Evidence	Code
Probabalist/ Determinist	they are in their little like spheres, but they are not just going (gestures in an orbit) as opposed to one direct thing, a cloud of it (what is an orbital?) isn't it like where you are more likely to find e-?	3
Discrete/ Continuous	07:24 (less than IE?) It wouldn't do anything. I mean if it had a certain perfect amount it would go to the next energy orbital but otherwise it wouldn't do much 16:02 (984?) it would go from the n=1 to the n=2 (985?) probably just be transmitted it has to be the perfect amt. (why?) that's what they told us in lecture.. probaby because the orbitals are fixed orbitals, so you have to have, like you can't be somewhere in between the orbitals the electron can't be somewhere in between the orbitals, it has to be either in one or the other so it has to be the perfect amount to go from one to the other	3
Interpreting Spectra Code	so in order to move from 1 to 2 it would need the different between the energy level	3
Energy/Force Code	08:05 they emit different wvlengths. Probably because different energies are required to move it upso they emit different energy when it comes back cause different atoms, different number of electron and different amount of hold on the e-, cause kinda like the IE are all different because some of them have more nuclear charge, hold onto it more, I assume it's the same general idea	4

Line No.		Transcript
1	**I:**	Describe how you visualize the atom
2	**S:**	01:39 I still think of a little like, like the pictures with the little circles around it, I still think of it like that even though I know it's like a 3D thing, I still think of it flatly. I don't like 3D things, it adds another dimension I'm confused in, I try to keep it as simple as possible
3	**I:**	02:22 Can you expand?
4	**S:**	the electron don't go in perfect circles, they are kinda like everywhere, in little clouds.
5	**I:**	are they everywhere?
6	**S:**	they are in their little like spheres, but they are not just going [gestures in an orbit] as opposed to one direct thing, a cloud of it what is an orbital?
7	**I:**	isn't it like where you are more likely to find e-?
8	**S:**	do they live in one orbital?
9	**I:**	unless you add energy and then it goes to the next one and it goes back to the other one
10	**S:**	03:39 draw a picture of 2p orbital of Oxygen
11	**I:**	p's are the dumbell ones so it would look like this,
12	**S:**	how about 2s?
13	**I:**	here.
14	**S:**	do they overlap?
15	**I:**	probably not, but in my picture they do. the electron stay within their orbitals. so if they overlap they would be going between orbitals
16	**S:**	04:43 why need energies to go in between?

17 **I:** because they have to be in a certain energy state to be in a certain orbital. They have a certain amount of energy so they are in that like home state orbital or whatever so then if you add the right amount of energy it can go to the higher state or orbital, higher energy state

18 Describe how you visualize light.

19 **S:** 05:23 generally I think of it as the wavelgth, like the wave model as opposed to the other ones, but for certain like it made more sense like when they did certain things, like there were certain explanations where it made more sense to use the particle model.. but if you ask me straight up, I think of it as a wavelength

20 **I:** 06:10 so why the other models?

21 **S:** because they can't use the wave model to explain certain stuff

22 **I:** is light more like one model than another?

23 **S:** personally I think is light is something we don't understand so we use a whole bunch of different models to try and like explain it all, I don't think we have a good like one way to explain light

24 **I:** What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

25 **S:** 06:47 it ejects an e-. It's enough energy… IE is the energy to eject it and whatever is excess goes into KE of the e-

26 **I:** What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

27 **S:** 07:24 It wouldn't do anything. I mean if it had a certain perfect amount it would go to the next energy orbital but otherwise it wouldn't do much

28 **I:** When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

29 **S:** 07:49 when you put the current in it excites the electron it goes to higher energy states then when it goes back to the original energy state it emits a certain wavelength of light

30 **I:** 08:05 Why are Ne and He tubes different colors?

31 **S:** they emit different wavelengths. Probably because different energies are required to move it up so they emit different energy when it comes back down

32 **I:** why different?

33 **S:** cause different atoms, different number of electron and different amount of hold on the e-, cause kinda like the IE are all different because some of them have more nuclear charge, hold onto it more, I assume it's the same general idea

34 **I:** 09:39 Over time, would the tubes change color?

35 **S:** I wouldn't assume so. you are still putting in the same amount of energy and it's still going from one energy state to the other so it should technically be emitting the same amount of energy, I assume

36 **I:** 10:05 Is there any amount of energy that wouldn't light the bulb?

37 **S:** probably any amoutt that wouldn't excite the e-

38 **I:** Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

39 **S:** 10:39 maybe, isn't it just this thing with the little lines? [gestures up and down] I could be wrong… this thing with the little lines, ok. I think I did this backwards, but whatever. For an electron in this energy in the n1 energy level it would require 1312 kJ to like eject it. and then the n=2 , the one in the n=2 energy level , or wait these are the ones it moves from one to the other , so in order to move from 1 to 2 it would need the different between the energy level

40 **I:** How much energy is needed to ionize Hydrogen?

41 **S:** 12:36 1312

42 **I:** Can you draw the absorption spectrum of Hydrogen?

43 **S:** 13:00 isn't it just ilke one line at 1312

44 **I:** Any other possible absorptions?

45 **S:** probably.

46 **I:** what are they?

47 **S:** I don't know. From 1 to 2 , it would just be the difference between these right? From here on it's dark, from here it's the differences…

48 **I:** can it go from 2 to 3?

49 **S:** yeah, but doesn't it always start from the first one becaue it has to start from one but it can from 1 to 3 and 3 to 2

50 **I:** How is this different from an emission spectra?

51 **S:** 14:38 I don't even know what that is. I don't know the names of any of these

52 **I:** How is this different from how it can fall down?

53 **S:** oh, if it's like at 4 it can go from 4 to 3 4-2 4-1 3-2 3-1 or whatever. This is a lower energy state, to get it up you have to put in a perfect amount of energy, but to drop it down, it wants to go down

54 **I:** What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

55 **S:** 15:25 it would eject the electron and then have 200 kJ going into the KE

56 **I:** 15:44 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

57 **S:** none of these have differences of 500? Ok, then nothing, it's just transmitted. It just passes through

58 **I:** 16:02 984?

59 **S:** it would go from the n=1 to the n=2

60 **I:** 985?

61 **S:** probably just be transmitted it has to be the perfect amt.

62 **I:** why?

63 **S:** that's what they told us in lecture.. probaby because the orbitals are fixed orbitals, so you have to have, like you can't be somewhere in between the orbitals the electron can't be somewhere in between the orbitals, it has to be either in one or the other so it has to be the perfect amount to go from one to the other

Student No: 03

	Evidence	Code
Probabalist/ Determinist	I don't think they are defined by the shapes, they are just more likely to be in that area	3
Discrete/ Continuous	07:19 I think it would, I'm not sure, but it would sort of make it, I'm not sure if it's vibrating but it would move it a little bit but not enough to remove it. 17:53 (exactly the diff?) it would, the electron would jump from energy level 1 to 2. (1 kJ more than that?) I don't know	2
Interpreting Spectra Code	14:57 you can subtract the 2 energies, but I don't really know how to translate it to... (possible jumps?) well, n2 to n1 or 3 to 1 or so on (go up?) I was thinking that but it can move from there but I'm confused.. I've always associated this with the light that it releases, so it would have to jump down levels to release light and so I just remember during lecture I write 1 to 2 and 1 to 3, and so know I'm confused.. 17:04 (500 kJ/mol) it wouldn't do anything, because it's not enough to eject it, and if you subtract the energy levels from n1 to n2 it's still not enough because it would be like	2
Energy/Force Code	and the closer the electron is to the proton or the nucleus the greater the PE because there is more attraction between the 2 05:05 (are electron in 2 or 3 level diff?) yes, I can't say confidently but I know it has something to do with the energy, like the attraction to it, it has to do with, it's related to the attraction between the proton and the electron and so because of that attraction between the two there is a certain amount of energy it requires to break that attraction 09:07 (different colors?) maybe the different levels because...I think maybe because H has one electron while Ne has more e-, like there is different levels the electron can jump to (transition from 1 to 2, same color for both atoms?) they should be! wait hold on.. I don't think so because the distance from the levels, the difference in the distance from the levels to the nucleus differs because of the ... I just know that as you go across the periodic table, the radius decreases so that plays a part in the distance between the level and the nucleus, so it's not exactly the same energy needed, released I guess when it goes back to the lower level, but there would be a similar color change, but it wouldn't be the same	4

Line No.		Transcript
1	I:	Describe how you visualize the atom
2	S:	01:03 they still have different shells which you can distinguish by like n=1, n=2 and the different between those are the energy, and the closer the electron is to the proton or the nucleus the greater the PE because there is more attraction between the 2. as you go futher out there is less potential energy and when you get more electron such as with oxygen you have not just different shells but sublevels and so you get into like the different shapes or that describe the prob of finding the electron
3	I:	02:40 Can you draw the 2p orbital of oxygen?
4	S:	um, would I include the s?
5	I:	sure
6	S:	I just know.. they are in different directions - x, y and z and the p-orbs in general have the 2 lobes and um with the second 2p there is a greater, another one like and then you have a node in between
7	I:	how about the s-orbital?

8 **S:** same area. so that's where hybridization comes in, you have both orbitals overlapping. I don't think they are defined by the shapes, they are just more likely to be in that area

9 **I:** 05:05 are electrons in the 2 or 3 levels different?

10 **S:** yes, I can't say confidently but I know it has something to do with the energy, like the attraction to it,

11 **I:** Describe how you visualize light

12 **S:** 05:37 there's different ways to look at light There's the wave model. And then there's the particle model and there is like disadvantages and advantages of looking both ways - or particle or photons I mean, and the wave model helps to describe like the frequency and the relationship between freq, energy, and wavelength and the photons are the packets of energy

13 **I:** What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

14 **S:** 06:45 first the IE is the energyit takes to remove an electron , so if it's enough energy that hits it it will remove the - or eject it , but if there is any remaining energy it would be transferred into KE

15 **I:** What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

16 **S:** 07:19 I think it would, I'm not sure, but it would sort of make it, I'm not sure if it's vibrating but it would move it a little bit but not enough to remove it. I guess it could also, depending on the amount of energy, it could move it to another level

17 **I:** why sometimes another level?

18 **S:** it has to do with, it's related to the attraction between the proton and the electron and so because of that attraction between the two there is a certain amount of energy it requires to break that attraction

19 **I:** When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

20 **S:** 08:30 there's electron being.. They're passing through a tube and if it has the right energy then it hits one of the Ne molecules, then the electron moves farther away from the nucleus and jumps back to it's original initial position and that releases light

21 **I:** 09:07 Why are Ne and He tubes different colors?

22 **S:** maybe the different levels because...I think maybe because H has one electron while Ne has more electron, like there is different levels the electron can jump to

23 **I:** Is the transition from 1 to 2, the same color for both atoms?

24 **S:** they should be! wait hold on.. I don't think so because the distance from the levels, the difference in the distance from the levels to the nucleus differs because of the ... I just know that as you go across the periodic table, the radius decreases so that plays a part in the distance between the level and the nucleus, so it's not exactly the same energy needed, released I guess when it goes back to the lower level, but there would be a similar color change, but it wouldn't be the same

25 **I:** 11:07 Over time, would the tubes change color?

26 **S:** like looking at one tube by itself? I don't think so.

27 **I:** 11:28 Is there any amount of energy that wouldn't light the bulb?

28 **S:** infrared?

29 **I:** How much energy is needed to ionize Hydrogen?

30 **S:** 13:23 1312 kJ

31 **I:** Can you draw the energy level diagram of hydrogen?

32 **S:** 13:33 yes, is that where you have the wavelengths down here and you have.. I don't know and the distances between the 2 gradually get smaller, so it goes off to infinity

33 **I:** Can you draw the absorption spectrum of Hydrogen?

34 **S:** 14:57 you can subtract the 2 energies, but I don't really know how to translate it to...

35 **I:** what are the possible jumps?

36 **S:** well, n2 to n1 or 3 to 1 or so on

37 **I:** can it go up?

38 **S:** I was thinking that but it can move from there but I'm confused.. I've always associated this with the light that it releases, so it would have to jump down levels to release light and so I just remember during lecture I write 1 to 2 and 1 to 3, and so know I'm confused...

39 **I:** What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

40 **S:** 16:44 it would remove or eject the ydrogren and it would have 200, it would change it to KE

41 **I:** 17:04 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

42 **S:** it wouldn't do anything, because it's not enough to eject it, and if you subtract the energy levels from n1 to n2 it's still not enough because it would be like

43 **I:** 17:53 how about exactly the difference between n1 and n2?

44 **S:** it would, the electron would jump from energy level 1 to 2.

45 **I:** 1 kJ more than that?

46 **S:** I don't know

Student No: 04

	Evidence	Code
Probabalist/ Determinist	so is it always a fixed distance away from the nucleus? 02:25 i would think so, yeah. so this orbital or cloud you were talking about, how does that relate? it's found in the cloud, and the cloud I suppose is also , like it starts at a fixed distance away, it's in a sphere and the sphere has a certain radius, so in that sphere, can it go close to the nucleus? no	2
Discrete/ Continuous	06:15 quantized is oppoiste of continuous, continuous you can move little by little, quantized is discrete steps, there is a void between the steps, move from one to another like... no halfway point i don't know what happens to that energy, i'm guessing it passes through or goes into heat or vibration or something 983, 985 nothing would happen. 500 nothing happens. this light would just heat it up or something, it would not absorb it	3
Interpreting Spectra Code	oh, that's not right... oh ok well H has an electron here and only here, so it's always gonna be starting from that point[(n=1]... so it will be... and so it would have one at 984, have one at 1166, one at 1230, 1312	3
Energy/Force Code	Then, because there's not much energy involved, when that particle of light hits the electron somewhere in the cloud, then that electron gets some energy and tries to arise, but it does not have enough energy to get to the next quantized energy state, the next cloud, the next energy shell. so it falls back down, and nothing happens, I'm guessing the light just passes through. now if you then give it more light say you have a continuous spectrum where you are increasing the v, at a certain point your are going to get enough energy to make it go into the next orbital, which for H was likeyou know there is orbital there because it can go to it but it's not like there's something there , but there is a discrete level, like calculatable level, where it can rise to	2

Line No.		Transcript
1	**I:**	00:52Describe how you visualize the atom
2	**S:**	um, a small but dense nucleus, and then electron, so hydrigen has one electron, so in a cloud, in a spherical cloud, as in like the electron can be somewhere in there, but we don't know where, but it's probably going to be somewhere in there.
3	**I:**	so tell me more, what is that cloud?
4	**S:**	it's like a probability distribution, i think it's a certain distance away from the nucleus,like a set quantized distance away, it can be found somewhere along that sphere but we're not, like you can't determine where it is because it's moving so fast
5	**I:**	what does quantized mean?
6	**S:**	so, I'm guessing it's like, I mean there was that issue with why doesn't the electron, like if the nucleus is positive and the electron is negative, why doesn't it fall inside, so it's like somewhere in the sphere, but like somewhere here, but it will always be a certain distance away, and it won't be less than that or more than that, so it has to be at that set level, that's why when you excite it from one energy level to the next, it has to be the exact, otherwise it falls back
7	**I:**	so is it always a fixed distance away from the nucleus?

8 **S:** 02:25 i would think so, yeah.

9 **I:** so this orbital or cloud you were talking about, how does that relate?

10 **S:** it's found in the cloud, and the cloud I suppose is also , like it starts at a fixed distance away, it's in a sphere and the sphere has a certain radius,

11 **I:** so in that sphere, can it go close to the nucleus?

12 **S:** no, which is why there is the.. so there's like a.. I guess this is... i don't think it can go close to the nucleus then i wouldn't see why it wouldn't just fall into the nucleus, but then again, they did talk about nodes, and I do know that like 1s isn't supposed to have any nodes, so nodes are areas where the electron can't be found, so you would almost think there would be node like between the nucleus and that cloud, but I don't know what is going on with that

13 **I:** 03:39 How would you describe oxygen?

14 **S:** um, so there's electrons in the 1s orbital, 2s orbital, and 2p orbital.

15 **I:** how are those related to each other?

16 **S:** So the first number 2 has to do with like essentially like a shell, so the second shell is a certain distance away like I was talking about I guess, but where in that distance its found is determined by like the fact that it's p means that it's founda long certain areas that if you plot out it looks like a dumbbell shape and it would be found most likely in those areas, so the cloud would be there

17 **I:** How does the 2s look? you said it had a node?

18 **S:** 04:35 it's just that electrons would not be found there

19 **I:** draw me the oxygen 2s, or 1s and 2s

20 **S:** [draws] so 1s maybe like down here, see that would be that distance, this is the node, and 2s wouldbe here, so the node is here this area where the electron is unlikely to be found

21 **I:** How about the 2p?

22 **S:** 2p would be.. doesn't have that type of a node, but has a planar node, [draws] it looks something like this so it would be found in some area here, i'm not really sure why its overlapping in that node. I don't know if the node corresponds to only electrons in 2s can't be there or if no electrons whatsoever can be there, but it's seems like there are areas of the 2p level overlap there

23 **I:** does 2p have a node?

24 **S:** it has a different type of node, like a planar node, which means that electrons probably won't be found in this plane whereas they will be found here

25 **I:** You had mentioned quantized, so what does quantized mean? How would you explain quantized to someone who is not in chemistry?

26 **S:** 06:15 quantized is like opposite of continuous, so whereas you can have a continuous spectrum where you can progress little by little, quantized is like discrete steps, there is a void between the steps, so you have to move from one to another like there is no halfway point in between

27 **I:** when you were first learning about this, did that seem odd to you?

28 **S:** 06:59 the idea of quantized isn't that unusual because there are like parallels with real world, like a series of steps or something that would be quantized, it did seem odd i would say and it still does that like there would be something in nature that did assume that manner, though cause you would think in a way that nature is continuous I mean on macrcoscopic view that's what you see. so the idea of quantized isn't so unusual, but applying it to something is.

29 **I:** 07:36 How are you thinking about light now

30 **S:** mostly as particles. I mean, from what I understand of the wave-particle idea like duality, is that it has some properties of particles and some properties of waves. Like, it's neither but there are these properties and we draw parallels to things we know, like we can conceptualize particles and conceptualize waves, I see what properties of waves light has, but when I;m picture it,I'm using the concept of particle more, and it's like things hitting especially things like hitting the nucleus or something with a certain energy and that energy is transferred onto electrons, I'm still.. I mean i understand the idea of cloud, but I'm still saying it's a discrete particle as well and that particle moving around

31 **I:** So when do you think about it as wave, or when is the wave idea useful?

32 **S:** 08:39 I'm only looking at it as a wave when I'm trying to understand something about the light itself and distinguishing it from another light so I'm like, so these are particles moving but now which particle is going to be more energetic, or something, then I realize it's not like the number of particles but it has to do with the wavelength, and so then I'm thinking about it like as a wave, but it's not like I'm ending the picture I had before of it hitting as a wave it's more like ok it's hitting but look at waves to see certain properties of it

33 **I:** 09:22 So let's say you have a hydrogen atom and you shine light on it - what happens?

34 **S:**

um, depends on how much light, or not how much light but the energy in the light, the frequency of the light, so like according to planck's equation, you have energy of different lights according to planck's constant times the frequency so if it's at a low v, which means high wavelength so it's like IR, Red, that side of the spectrum, then it doesn't have much energy in it. Then, because there's not much energy involved, when that particle of light hits the electron somewhere in the cloud, then that electron gets some energy and tries to arise, but it does not have enough energy to get to the next quantized energy state, the next cloud, the next energy shell. so it falls back down, and nothing happens, I'm guessing the light just passes through. now if you then give it more light say you have a continuous spectrum where you are increasing the v, at a certain point your are going to get enough energy to make it go into the next orbital, which for H was likeyou know there is orbital there because it can go to it but it's not like there's something there , but there is a discrete level, like calculatable level, where it can rise to

35 **I:** what do you mean by that?

36 **S:** 11:11 like essentially with O there is a 1s, 2s, with a H you would think there wouldn't be a 2s, but it has it it's just that it's not occupied cause it only has one electron, but you know it exists because unlike the last time where it was just light of small energy and it just fell down here it's going to that level and when it's coming back it's actually releasing that energy and emitting it as light of however much energy it took , so it's emitting light, so you see there's a distinction here and by that you can see that it's quantized, like only at certain energies of light when you hit it does this emission happen and then you have a spectrum

37 **I:** so this in-between one, is that emitting light?

38 **S:** no, it's not emitting light, um i guess like when I said I wasn't sure like when you are hitting it with the light I wasn't sure that when the light doesn't have enough energy to get it up whether it just passes through which isn't emission it's just passing through or whether it's absorbed, I'm guessing either can happen depending on the material. So you have light of a certain energy, it's not enough energy to get it up to the next orbital so it just goes up and falls down, oh emission happens because it hasn't gone to the orbital but I don't know what happens to that energy like is it just absorbed in this or I'm guessing it has to pass through, so I'm guessing this would be heat or something

39 **I:** So it's not emitted as a specific wavelength of light

40 **S:** right, but the energy has to go somewhere so it's vibrations or something

41 **I:** 13:05 so what happens if you keep increasing the energy of what you shine until it exceeds the ionization energy?

42 **S:** well, then it, the electron pass through or I mean so the ionization energy is the amount of energy it takes to separate like something into this so like separate the electron from the rest ofthe atom. So when you exceed that that electron essentially has enough energy to go out and depending on how much light you put in, is the amount of energy that the electron takes with it in the form of KE.

43 **I:** 13:51 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

44 **S:** [draws]

45 **I:** what does the zero represent?

46 **S:** um, zero energy which we set in this case to the IE, so it's going from a deficit of this much, but if it gains that much energy then it's ionized, separated

47 **I:** so Hydrogen has one electron, and these are 4 energy levels - how come there is 4 levels?

48 **S:** because we just we know this happens because when you give it whatever this difference is then it emits a certain light, so we know there is something special about this level. So that's how we experiementally know that these levels exist and we see these levels in other atoms as well, cause we don't see it in hydrogen because it only has one electron, it's like the level exists but it;s just unoccupied.

49 **I:** so what is the amount that would be absorbed?

50 **S:** uh, 984 kJ/mol

51 **I:** 16:08 so how much energy is needed to ionize Hydrogen?

52 **S:** 1312 kJ, that's how much energy it takes to get from this point to this point, and this point we said was ionized, like the point where it's ionized

53 **I:** so H in its ground state, where is it's electron?

54 **S:** if you look at just the PE, it would be this [points to -1312kJ]

55 **I:** 16:40 Can you draw the absorption spectrum of Hydrogen? What energies of light does it absorb?

56 **S:** [draws] so it would not absorb at every level, it would have a huge absorption at there [draws)] it would also absorb this at 984 and it would similarily have these differences here

57 **I:** can you calculate them for me?

58 **S:** oh, that's not right... oh ok well H has an electron here and only here, so it's always gonna be starting from that point[(n=1]… so it will be... and so it would have one at 984, have one at 1166, one at 1230, 1312

59 **I:** how about past 1312?

60 **S:** yeah, oh ok it would absorb anything past 1312 so it's actually like that

61 **I:** 19:03 OK, I'm gonna give you some scenarios and you tell me what happens. What if you shine light of energy 1512?

62 **S:** 1512 um it ionizes and goes off with a KE of 200kJ.

63 **I:** what if I shine light of 984?

64 **S:** 984kJ it would go up this high get to this orbital, but then this is unstable,so it would fall back down, and in the process releaselight energy of 984

65 **I:** would it also absorb 984?

66 **S:** well, yeah it would first absorb and then emit it again.

67 **I:** how about 983?

68 **S:** nothing would happen

69 **I:** and 985?

70 **S:** nothing would happen.

71 **I:** and then 500?

72 **S:** nothing happens

73 **I:** so if nothing happens, the light that's coming in, what is it doing?

74 **S:** well, that was my.. I wasn't sure but I'm guessing it's like well I know with IR is too little to ionize and it causes the molecules to just vibrate or something so it turns into heat, now in this case it's kinda different I guess because it's more energy than to get to one orbital so I don't think it's gonna heat.. well, I guess it will just heat it up or something

75 **I:** but it wouldn't absorb it?

76 **S:** it would not absorb it

77 **I:** or it wouldn't absorb it into an energy level transition?

78 **S:** yeah

79 **I:** 20:49 How is this different from an emission spectra?

80 **S:** emission spectra is the same idea, you have to have absorptions to do emissions, so if it absorbs this much energy it will again emit this much energy so it would look the same... no, it would have a difference, and the difference is that for emission it can fall back down to this much, like whereas for absorption we are always starting from here and going up, emission can go from like n=3 to the n=2, that difference which I calculated last time 182 would have a spike in its own spectrum

81 **I:** so what are all the possible spikes in emission, what are the transitions?

82 **S:** [draws them] this one, this one, this one....[six transitions]

83 **I:** So, hydrogen in its' ground state, would that have an emission spectrum?

84 **S:** what do you mean, without any energy coming in?

85 **I:** just in its ground state

86 **S:** no, it's not emitting

87 **I:** so what do you need to do in order to get this emission spectrum?

88 **S:** hit it with some energy in order toexcite it

89 **I:** 22:58 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

90 **S:** well, the electrons.. like you have a charge, so electrons are flowing through at high speeds, and those electrons have energy, so when it's hitting, it can transmit that energy ans excite the Ne atoms, and excite them to a higher level and then it'll fall back down and in the process it'll release a light which will be characteristic to that atom.

91 **I:** So why does it release light when it falls back down?

92 **S:** because you are going from a higher energy state which is less stable to a lower energy state which is more stable, so you are releasing, like it takes potential energy it takes energy to be at that state so that energy isn't needed anymore so you are releasing it and you are releasing that energy as light, so it would be at a certain frequency and color

93 **I:** Why are Ne and He tubes different colors?

94 **S:** 24:01 because these energy levels would be different for the 2,because the effective nuclear charge is different for the 2 atoms

95 **I:** 24:30 Over time, would the tubes change color?

96 **S:** Assuming you keep the current going?

97 **I:** the current is going the same

98 **S:** i don't know if there would be an ynatural degradation... but from this process no, it's just going exciting, coming down, exciting, coming down, I would imagaine because of somethign else it might stop

99 **I:** so what has to happen in order for it to change color?

100 **S:** something has to have to happen to the nucleus, like some kind of nuclear decay would cause the effective nuclear charge to change which means the energy shifts would rearrange and that woudl casue [inaudible]

101 **I:** Is there any amount of energy that wouldn't light the bulb?

102 **S:** 25:16 yeah if it doesn't get the - well which one are we talking about?

103 **I:** let's just say it's Hydrogen

104 **S:** if it doesn't hit the first, the next energy level, so if it would be at n=1 and can't get up to n=2, nothing would happen

Student No: 05

	Evidence	Code
Probabalist/ Determinist	S: The atom? Kind of like the nucleus would be like a sphere, and then with the orbitals kind of like rings around it, increasing. And then kind of also at the same time picturing the electrons don't have to be fixed on that ring. They can be like completely vague. I: OK. So explain to me what vague means. S: Like how we were talking about the electron cloud. So they can be in the area of [inaudible] typically. S: Oh, I don't really know exactly. That's how I kind of picture them, just to make it simpler, like I know it's like super complex, I just make it like simpler. Yeah so closer to circles.	2
Discrete/ Continuous	S: Quantized is like, steps, like you have to be on a certain one, and it's very specific and set, you can't mess with them. S: Then I think it would happen like it happens here, it hits this higher orbital then it comes back down. I: OK. Like does it have to hit one of those exact energies? S: Yeah. Quantized too.	1
Interpreting Spectra Code	12:43 (So for hydrogen, what are the possible absorptions that can happen?) For hydrogen? So it could absorb... (Um, where does the electron, where is it, in, like if you look at this, which one is the electron in?) This one. (So which of the possibilities, like where could the electron go?) Here. So. Oh so when that absorbs, then it goes back down. (OK. So it go like n=2?) Uh, no. I think, I'm not sure if there's like something here. But I know in absorption it can go down. 14:10 (1512?) I don't think it would do anything. It might like vibrate a little, but it wouldn't move. (OK. So why wouldn't it move for 1512?) Cause it's less than the first energy level. So it doesn't have enough energy to actually move it. (OK. So like 1512 is less than 1312?) Yeah. 14:08 (500?) 500? It would, I think it would ionize. I think it would just leave.	1
Energy/Force Code	14:10 (1512?) I don't think it would do anything. It might like vibrate a little, but it wouldn't move. (OK. So why wouldn't it move for 1512?) Cause it's less than the first energy level. So it doesn't have enough energy to actually move it. (OK. So like 1512 is less than 1312?) Yeah. 14:08 (500?) 500? It would, I think it would ionize. I think it would just leave. 14:10 (1512?) I don't think it would do anything. It might like vibrate a little, but it wouldn't move.	1

Line No.		Transcript
1	**I:**	00:40 OK. So, similar to what I asked you last time I saw you, can you now describe to me how you visualize the atom?
2	**S:**	The atom? Kind of like the nucleus would be like a sphere, and then with the orbitals kind of like rings around it, increasing. And then kind of also at the same time picturing the electrons don't have to be fixed on that ring. They can be like completely vague.
3	**I:**	OK. So explain to me what vague means.
4	**S:**	Like how we were talking about the electron cloud. So they can be in the area of [inaudible] typically.
5	**I:**	01:21 OK. So if I asked you about oxygen specifically, what would that look like? What would those rings be?
6	**S:**	Oxygen...

7 **I:** The number is eight.

8 **S:** Number eight. So then it would be like the nucleus with two electrons in the first ring. And then like 6 valence electron… and then I guess it just depends, on what you really need from it. If you need to know the orbitals, you can picture the orbitals, and kinda like, going up and down.

9 **I:** So what are orbitals?

10 **S:** Like the… The energy levels, higher energy orbital. Just like the floors aren't bolted together, like elevator…

11 **I:** 02:27 OK. So if I said what does the 2p orbital look like for oxygen? What would that look like, could you draw it out for me?

12 **S:** So, 2Pp... That's 2p. So then... 2p would have electrons in this thing…

13 **I:** So what would that look like in the atom?

14 **S:** The nucleus, then you have [unintelligible 02:39] and then 2P. You would have steps not really specific [unintelligible 02:52] .

15 **I:** 03:27 OK. And do you know why they have these specific energies?

16 **S:** I think they have to do with wavelength of light, it only absorbs certain energies or whatever. Things like that.

17 **I:** OK. And so the electrons in those orbitals, are all orbitals kind of these spheres? Are they all circular, like spherical shape?

18 **S:** Oh, I don't really know exactly. That's how I kind of picture them, just to make it simpler, like I know it's like super complex, I just make it like simpler. Yeah so closer to circles.

19 **I:** 04:15 OK. And why do you know that those electrons are in those orbitals?

20 **S:** Like how do we know they are?

21 **I:** I guess maybe a better question, so can an electron in the 1s, can it move to the 2S and 2P and back or do they like stay in their one?

22 **S:** Oh. Well, originally if the electrons here it gets excited and it will go. It depends on how much, it can go like here. And it always comes back down.

23 **I:** 05:00 OK. Next question, something I've asked you before, but now that you've had more instruction on it. Describe how you visualize light.

24 **S:** Light, like a wave. Kind of like visually, if there's a light coming into here, for you know an electron. I picture this circular thing, then it has like particles inside of it, and just kind of hits it.

25 **I:** OK. A like a squiggly tube that has these particles in it?

26 **S:** I think it's kinda like, kinda like lightning, cause lightning is like y'know little electron , and I picture it's made up of like particles, photons

27 **I:** 05:45 OK. And what exactly happens when light hits an atom with an energy greater than the ionization energy?

28 **S:** It still gets ionized, it's just like the rest goes into KE or something.

29 **I:** OK. What does that mean to be ionized?

30 **S:** It means like it doesn't just go out to these shells and then comes back, it just leaves.

31 **I:** 06:06 OK. What about the if the light hits with energy less than the ionization energy?

32 **S:** Then I think it would happen like it happens here, it hits this higher orbital then it comes back down.

33 **I:** OK. Like does it have to hit one of those exact energies?

34 **S:** Yeah. Quantized too.

35 **I:** 06:27 OK. How would you describe quantized? What does that mean to you?

36 **S:** Quantized is like, steps, like you have to be on a certain one, and it's very specific and set, you can't mess with them.

37 **S:** 06:45 I think, it's the energy. I don't know like the voltage how energy [unintelligible 06:36] . Maybe just like the specific energy they're glowing at has a specific color that's due to it? That's how it glows...

38 **I:** And why are they these energies?

39 **S:** Why they there? I guess, it just has to do with light has different wavelengths. So you can get because um, this so then you have to experiment with frequency or wavelength and you get the corresponding energy.

40 **S:** When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. Why are Ne and He tubes different colors?

41 **I:** 07:55 Because helium takes different wavelengths … Neon probably because maybe because it's different numbers of electron or something

42 **S:** OK. So how do the electrons play into this?

43 **I:** So say, this is light and this is voltage or whatever. So then it would hit their electrons. And then come back, and then well it goes back down. This is like, I'm not sure that happens, also when it goes up. I know it comes back down at least this, light so that's probably why you can see the special frequency of light which is color.

44 **S:** 08:42 And so are those energy levels different for Helium and neon?

45 **I:** I think, well, helium only has 1S. And then neon has 2P so I think it should be different.

46 **S:** 09:03 OK. What if it was the 1S in Helium and Neon and they both jumped up to their respective 2S and back down?

47 **I:** I don't know. I think they might be the same.

48 **S:** OK. So then they'd be the same color?

49 **I:** I don't know. Maybe.

50 **S:** Over time, would the tubes change color?

51 **I:** 09:32 Over time, I'm thinking they would, because if you keep moving electrons like moving it to get ionized, you would lose them. And then you run out of electrons maybe. So then it dies out.

52 **S:** Is there any amount of energy that wouldn't light the bulb?

53 **I:** 09:58 If you can't get it up to the 1S or the 2S or something.

54 **S:** 10:30 Do you mean like the graph or something?

55 **I:** like the, yeah the up and down.

56 **S:** Kind of. So n=1, I think it goes like... andit just keeps going. One, two, three, four.

57 **I:** And what do those represent?

58 **S:** The energy it takes to get there?

59 **I:** 11:07 OK. And how much energy is needed to ionize hydrogen?

60 **S:** To ionize hydrogen, I think it's this one.

61 **I:** OK. The negative 1312?

62 **S:** I think cause it only has 1S. So it only has one orbital. So I think you only need this one.

63 **I:** 11:35 could you draw an absorption spectra based on this?

64 **S:** So. I'm not sure what color this is. Like red, red is longer. And this one's like purple, I think. And then so if it has longer wavelength, then it has less energy. So then.. I think I drew it backwards but then N =4. I don't know.

65 **I:** OK. So you would see like those peaks for those colors?

66 **S:** Yeah.

67 **I:** 12:43 So for hydrogen, what are the possible absorptions that can happen?

68 **S:** For hydrogen? So it could absorb...

69 **I:** Um, where does the electron, where is it, in, like if you look at this, which one is the electron in?

70 **S:** This one.
71 **I:** So which of the possibilities, like where could the electron go?
72 **S:** Here. So. Oh so when that absorbs, then it goes back down.
73 **I:** OK. So it go like n=2?
74 **S:** Uh, no. I think, I'm not sure if there's like something here. But I know in absorption it can go down.
75 **S:** 13:44 It would be the opposite. So if you can see, so you absorb red. Then absorption would be a peak or whatever, but on emission it would just be like…
76 **I:** 14:08 500?
77 **S:** 500? It would, I think it would ionize. I think it would just leave.
78 **I:** 14:10 1512?
79 **S:** I don't think it would do anything. It might like vibrate a little, but it wouldn't move.
80 **I:** OK. So why wouldn't it move for 1512?
81 **S:** Cause it's less than the first energy level. So it doesn't have enough energy to actually move it.
82 **I:** OK. So like 1512 is less than 1312?
83 **S:** Yeah.

Student No: 06

	Evidence	Code
Probabalist/ Determinist	The cloud is where there's a 90 percent chance that the electron will be in there. (And for hydrogen what does that cloud look like?) It's a sphere.	3
Discrete/ Continuous	So what happens if I shine 985? M: Nothing. S: OK. And why nothing? M: Because it has to be at this very specific energy levels for it to do anything to it. It will just be transmitted.	3
Interpreting Spectra Code	M: And then, you'll have 1166… (calculates differences)... and then what's going to happen is, they're just going to get like closer, and closer and closer again, and then look it's ionized.	3
Energy/Force Code	So then well, because you're at a state of high energy and you're going to a state of lower energy. It's like when you make a bond, energy is released. Well most of the time. When those things are in a bond they are in a more stable state. It's like when you have a ball on the table and you push the ball off, and the ball falls on the floor, energy is going to be released. If there's a glass object right there, it might be broken. It's that kind of thing. Right here, the hydrogen is at a very stable state, and so, I guess they determined that experimentally, right? Isn't this also the unit for Rydberg? I don't really know why, but it is. You need that much energy to push that electron out of it's like really happy state. It's like the electron is in a well, basically and you need energy to get it out from under the well, like out onto solid ground. If that makes any sense? M: Well, because different energy levels are in different places. First of all, neon has a bigger nucleus, so it's going to have more of a positive charge in the nucleus. So it's 1s electrons are going to be held more tightly. It's just like different conditions, you know?	4

Line No. **Transcript**

1 **I:** 00:28 Describe how you visualize the atom

2 **S:** I'm visualizing it as a very, very, very small nucleus and then around that there would be a 1S orbital, which is more like a cloud of electron density or probability in which the one electron would be.

3 **I:** Tell me more about this cloud. The density.

4 **S:** So like, You can't actually know exactly where an electron is and what state it's in at every given moment. But what you can do is you can make different probability function for it. The cloud is where there's a 90 percent chance that the electron will be in there.

5 **I:** And for hydrogen what does that cloud look like?

6 **S:** It's a sphere.

7 **I:** Sphere? OK, can the electrons go outside the sphere?

8 **S:** Yeah.

9 **I:** Is it equally probable to be anywhere in the sphere?

10 **S:** Yeah.

11 **I:** Now tell me about oxygen. How are the electrons in oxygen?

12 **S:** For oxygen you have different orbitals and you also have different energy levels. For hydrogen you're only going to have one energy level and you're only going to have one electron. But since oxygen has many electrons, in the middle you're still going to have your sphere. That's going to be your 1S level. But instead of having just one electron, you'll have two electrons which still have that probability of being inside that sphere. And then you'll have an outer sphere, a bigger one around that. That will be your 2S level. It's just a higher energy level but it's still the same shape.But then for oxygen you have a 2P level, which looks different. It's a figure eight basically, but you have three of them. They're in each of the three planes; you're going to have a figure eight in the X plane. Electrons can be anywhere in that. A figure eight in the Y Plane; electrons can be anywhere in that. A Z Plane, electrons can be anywhere in that. These will be a little bigger than the 2S sphere. These are still a little bit bigger, but they're definitely bigger than the 1S sphere. Electrons will be in that. So the oxygen only has four electrons in the 2P shell. Then the two level and the one level; those are each a shell. And then 2S and 2P are the sub shells. Since oxygen has only four, it's going to have two electrons in the 2PZ shell and then one electron in the 2PX shell and one in the sub shells.

13 **I:** If you think about the 2S and the 1S, are they distinct regions in space or are they occupying the same space?

14 **S:** 03:30 I've actually always wondered that because the way they show it in pictures of the earth you have your crust and your magma that's how they show it in the books, so I've always wondered whether the 2S electron can be in the same space as the 1S electron. I'm not really sure.

15 **I:** How about the 2S and the 2P?

16 **S:** I think they overlap.

17 **I:** 3:47 Now we'll start talking about light. How are you thinking about light now, after the unit?

18 **S:** There are so many different ways to think about it. How many different ways can you have a color? You can have a color by seeing what's reflected to you when all the other colors are absorbed; or you can have a color by seeing what passes through a filter; or you can have a color by seeing a really hot object that's glowing, and that's emitting light; or you can have a color when an electron goes up to a high energy level and falls back down to the energy level and emits a light.

19 **I:** When they first start talking about light, they talk about this wave model or particle model. How do these two models kind of coexist?

20 **S:** An example of the particle model is, we can't see around corners, but waves can move around corners. But when you have the wave model, then when light enters the room through a skylight, light would just go straight down to the bottom and suddenly fills up the whole skylight.

21 **I:** How about the particle model, what is that?

22 **S:** You can't see around corners, what else is it used for? I don't know. We don't really do much with it, do we? It's more the wave model.

23 **I:** Well actually, for the particle model, particles of light how are they described?

24 **S:** Photons.

25 **I:** When do you kind of ever use photons in this unit?

26 **S:** In the photo electric effect?

27 **I:** 05:50 Now think about a hydrogen atom, and we're going to shine light on it. What happens to the atom when you shine a light on it?

28 **S:** It depends on what the energy of the light is. If the light is at a really low energy nothing is going to happen. If the light is at a very very specific energy, and it's at a pretty high energy, then the hydrogen atom will go from n equals one level to the n equals two level, and that's what it's just going to do

29 **S:** And then if it's like just a tiny bit more then that it's not going to do anything again. If it's a little more, at another specific energy, it will go to from one to three, then one to four. Soon enough, these energies, the higher they are, they'll start getting closer and closer and closer together, the requires it to go to higher and higher energy levels. So when you get to n equals 200, the energy it takes for hydrogen to get to n equals 200, is almost the same as it takes to get n equals 201. Which means the hydrogen atom is basically being ionized, the electrons are basically just going away from it into free space. That's a photo electric effect.

30 **S:** Then you can put high energy in and the atom will be ejected and you can calculate what speed it will be ejected at.

31 **I:** How do you calculate that?

32 **S:** 07:06 The energy of the light equals the energy that it takes for the light to be emitted, plus the speed it will be at. I can write it out if you want me to write it.

33 **S:** You have your energy equals the ionization energy, plus the kinetic energy of the light. You can calculate that energy by hv equals hve. You can calculate it - That will give you the ionization energy and the kinetic energy will be one half mv squared.

34 **I:** 07:51 Flip that page over. This has a table of the four energy levels of hydrogen. Can you draw me an energy level diagram?

35 **S:** In what way?

36 **I:** In lecture they showed these as a vertical arrow. And you're going to have the energies listed on there.

37 **S:** OK.

38 **I:** 08:30 OK, and could you also put in the n=1..=2 at. This is kind of like what you were just talking about.

39 **S:** Uh huh.

40 **I:** 13:12 Kind of from this, I want you to draw me the absorption spectrum of hydrogen. What is an absorption spectrum?

41 **S:** Absorption spectrum is the energy the specific energy of light that will be absorbed when it goes to a new energy level. OK. So then you're gonna have 984. OK, this is zero. This is zero, this will be like, 984, I'm not very good at scale.

42 **S:** And then, you'll have 1166… (calculates differences)... and then what's going to happen is, they're just going to get like closer, and closer and closer again, and then look it's ionized.

43 **I:** so Everything after...

44 **S:** Everything after... then you're going to get to 1312 I forgot to draw 1312 sorry.

45 **I:** 14:27 So, let's assume there's nothing after n=4 , it's not exactly true.

46 **S:** Yeah, yeah, so then, you just stop right here, and that would be the, I just kind of...

47 **I:** No, that's OK. How is this different from an emission spectrum? How would you get an emission spectrum?

48 **S:** The thing about absorption spectrum, is you can only go from n=1 to different things, but the thing about emission spectra is that you can go from n=4 to n=3 n=1 to n=2, etc. The way that I've seen them, I know it's not like this, the way I see them being is like this n=1, n=2, n=3, n=4 right?

49 **S:** One, two, three, four, and then you have, these different energy levels, basically I forgot a lot. Well, anyway, it's the concept.

50 **I:** Hydrogen, in its ground state, can it have an emission spectrum?
51 **S:** Well, no 'cause, where is it going to go?
52 **I:** What do you have to do to the sample before you can...
53 **S:** You have to excite it to a higher energy level...
54 **I:** OK, and also looking at this you were saying it absorbs from n=1 to n=2, can the electron be in between, n=1 and n=2?
55 **S:** No, it's quantized.
56 **I:** OK, so what does quantized mean?
57 **S:** That means like, it's like stepping on a ladder, you can't step up in the air half way there, you know, you either have to be on this rung of the ladder or this rung.
58 **I:** So how much energy is needed to ionize hydrogen?
59 **S:** 1312
60 **I:** 08:45 OK, and how come it's 1312.
61 **S:** It's because right here, how do I explain this? Right here, the hydrogen is at a very stable state, and so, I guess they determined that experimentally, right? Isn't this also the unit for Rydberg? I don't really know why, but it is. You need that much energy to push that electron out of it's like really happy state. It's like the electron is in a well, basically and you need energy to get it out from under the well, like out onto solid ground. If that makes any sense?
62 **I:** When you're on solid ground what is your energy?
63 **S:** I mean it would be 0, right?
64 **I:** It would be zero.
65 **S:** It's like this. This is what it's like. It's like this. Right? And then this is where the hydrogen's at, where it's bonded and this is where you're trying to get the hydrogen to be. Where it is ionized.
66 **I:** What is the X and Y axis there?
67 **S:** This is potential energy and this is distance.
68 **I:** OK. What if I shine 1512?
69 **S:** Then it will be ionized and you will have a certain kinetic energy. OK, so what happens if you shine 1312, the atom is going to be ionized right, and it will just kind of sit there. What we need is we need if you want it to be going at any kind of speed lets say 1512 is the energy of our photon, right? That equals 1312 plus 1/2 mv squared, and if I knew the mass of the electron I could tell you the velocity it would be at. But it will be at a certain velocity.
70 **I:** 10:05 Sounds good. What happens if I shine light at 500 kilojoules per mole?
71 **S:** Nothing.
72 **I:** Why?
73 **S:** The minimum amount of energy you need to do anything... Can we use that?
74 **I:** Yeah, definitely.
75 **S:** The minimum amount of energy you need to do anything would be 984. Because that's the amount of energy needed of light to be absorbed that will get you from N equals one to the N equals two; but if you have 500 that's not enough energy.
76 **I:** Then what happens? You shine this light and...
77 **S:** It's just transmitted.
78 **I:** It's just transmitted and what happens to the electrons?
79 **S:** Their just kind of like, nothing really happens.
80 **I:** 10:49 If you shine exactly 984 what happens?
81 **S:** It will go from the N equals one to N equals two.
82 **I:** What does that look like? What does that mean when it goes from N equals one to N equals two?

83 **S:** Basically what happens is. I saw a couple web things on this. I know this isn't accurate but this is the way I understood it. Here is my nucleus and here are the little thing going around. That's your hydrogen electron. And then you shine this light on it, and it shines it and it hits it. And then the hydrogen electron... here's your nucleus and there's the little hydrogen electron. It's like going around. then here is light, and the photon hits it, and it goes out, into here. Which would be like the 2s subshell. It would go out into here, and it'll stay there for a second, and then it will just drop back into there, and release some kind of energy.

84 **I:** 11:40 Why do you think does it drop back?

85 **S:** Because it wants to be more stable.

86 **I:** Why do you think as it drops, it releases light?

87 **S:** Well because, well because you are going from a less stable potential energy it doesn't release light does it, doesn't it release any kind of energy?

88 **I:** That's true. So why does it release energy?

89 **S:** So then well, because you're at a state of high energy and you're going to a state of lower energy. It's like when you make a bond, energy is released. Well most of the time. When those things are in a bond they are in a more stable state. It's like when you have a ball on the table and you push the ball off, and the ball falls on the floor, energy is going to be released. If there's a glass object right there, it might be broken. It's that kind of thing.

90 **I:** 12:25 Sounds good, OK. So what happens if I shine 985?

91 **S:** Nothing.

92 **I:** OK. And why nothing?

93 **S:** Because it has to be at this very specific energy levels for it to do anything to it. It will just be transmitted.

94 **I:** 18:56 No, that's good. A couple of more questions for you. One of the questions on the exam was about the florescent tube. If you have a tube filled with Neon gas and then you put a current through it, it glows with a certain color. So what causes that certain color?

95 **S:** 19:11 That is an electron is being excited. The electron is going right there and it's falling back down and when it falls back down it's emitting light of certain particular...cause like for the emission spectrum. I mean, it's going to be something like that.

96 **S:** I mean, well, maybe they'll be the same length. I don't know why I said that. You're just going to have these really specific peaks that...so let's say when that's happening it's being excited to the n equals three level and it's falling back down to n equals two level, or something like that. When it does that it's going to do that on a very particular wavelength. If that wavelength is in a section of visible light, then you're going to see this very particular color.

97 **I:** Let's say I have another tube, and this is Helium. Helium glows with a different color. How come the two different tubes are two different colors?

98 **S:** Well, because different energy levels are in different places. First of all, neon has a bigger nucleus, so it's going to have more of a positive charge in the nucleus. So it's 1s electrons are going to be held more tightly. It's just like different conditions, you know?

99 **I:** Let's say I had for some reason some energy levels like this, and some energy levels like that. What colors of light would each emit compared to each other? Just very hypothetically, if this has a larger energy difference than this one, then...

100 **S:** OK. A larger energy difference more would be like n equals two to n equals one there.

101 **I:** Which one would be red, and which one would be violet?

102 **S:** Would this one be violet, and that would be red then?

103 **I:** Why?

104 **S:** Because this takes less energy. And red is at a longer wavelength, so it's less frequency and less energy.

105 **I:** 21:13 If you look at this neon tube over time, let's say you stared at it for a couple of days. Would it change color?

106 **S:** Stare at it for a couple days...well...

107 **I:** Keep in mind the tube is the same gas in it, and it's the same current going through it.

108 **S:** Well...actually, I don't know. I don't know how many electrons are going from one energy level to the next. But I suppose it wouldn't just run out of electrons or change it's frequency. I don't know. I really don't know.

109 **I:** What would have to happen in order for the color to change?

110 **S:** Well, for the color to change it have to be going from different energy levels to different energy levels. but I don't know why.

111 **I:** Is there any amount of energy that wouldn't light the bulb?

112 **S:** Yeah, right. If you don't have enough energy to even excite the electron to a higher energy level, then the bulb won't get lit.

Student No: 07

	Evidence	Code
Probabalist/ Determinist	01:25 Hydrogen is a fuzzy sphere around the nucleus. In the sphere, an electron that's not quite a wave or a particle. I found this whole unit to be counter intuitive all the time	2
Discrete/ Continuous	08:21 so is it like when zero is when the electron is all the way off? The lines are different transtions of the e-. So if it gains the amount of energy of this minus that (2 to 1), it can move up to that (2). It would take 1312 kJ/mole to remove it.	3
Interpreting Spectra Code	So if it gains the amount of energy of this minus that (2 to 1), it can move up to that (2) oh ok, um, so yeah I guess you would have to find the differences between each of these, like photons of varying wavelength would hit the e-. And if you had one that was the proper energy that equaled the distance, between that and that or that and that, it would be promoted to that level, and so that amount of energy would be absorbed, and so those photons wouldn't be transmitted through, and that's how you would know that they'd been absorbed	3
Energy/Force Code	oh ok, um, so yeah I guess you would have to find the differences between each of these, like photons of varying wavelength would hit the e-. And if you had one that was the proper energy that equaled the distance, between that and that or that and that, it would be promoted to that level, and so that amount of energy would be absorbed, and so those photons wouldn't be transmitted through, and that's how you would know that they'd been absorbed	2

Line No. **Transcript**

1 **I:** 00:41 Describe how you visualize the atom
2 **S:** it was a lot more ordered before this unit, because now I'm not quite sure how I visualize it. But I guess nucleus and them mysterious cloud shapes surrounding it.... That are kind of changing... and have shapes that I don't really understand, especially when they are in molecules, that's like very very difficult for me to visualize, I need to work on that
3 **I:** yeah it gets very complex very quickly
4 **S:** yeah and I'm just bad with spatial things
5 **I:** So if you just focus on the hydrogen atom, what can you tell me about it? or you mentioned fuzzy something...
6 **S:** 01:25 it's just like a fuzzy sphere around the nucleus.
7 **I:** and what is in that sphere?
8 **S:** an electron that's not quite a wave or a particle. I found this whole unit to be counter intuitive all the time
9 **I:** was there anything that was more counter intuitive than other things?
10 **S:** well, I feel like I did what they told people not to do, like I just sorta like memorized how it was because i mean how can it make sense that if you go right along a row in the periodic table and you have more protons and neutrons, the atom gets smaller? like that doesn't make sense! but, you just have to memorize that until I guess you get to some level where it really makes sense

11 **S:** 02:22 Yeah, I just kept finding things like that . like there was this one passage I read where, it's like the after the d orbital and filling the ps, so like fairly low down it was something like the radius was smaller than it would have been had there not been the d orbital, and I was like wait a minute, how can that be? because you have like all these other extra electrons. I don't know I thought that the charge on an electron is supposed to exactly balance a charge of one proton, but then like having pmore protons ends up actually like pulling the electrons closer and making the radius smaller, so it seems like the protons must be stronger in some way.. I don't know anyway, it just kept on getting more confusing

12 **I:** 08:17 Can you draw me an energy level diagram of hydrogen [hand table with values]
13 **S:** oh um so is it, do mean like when the zero is when it's the electrons is not associated..
14 **I:** yeah
15 **I:** so what do those lines represent?
16 **S:** Those would be different transitions the electron would make. so if if gained the amount of energy of this minus that [n=2 to n=1]then it could move up to that [n=2]
17 **I:** so hydrogen has one electron, in the ground state, what energy is that electron at?
18 **S:** um, well it would take 1312 kJ per mol to remove it
19 **I:** 09:31 Can you draw the absorption spectrum of Hydrogen? or just talk through what is an absorption spectrum, how would you get that
20 **S:** oh ok, um, so yeah I guess you would have to find the differences between each of these, like photons of varying wavelengths would be hitting the electron. And if you had one that was the proper energy that equaled the distance, between that and that or that and that, it could be promoted to that level, and so that amount of energy would be absorbed, and so those photons wouldn't be transmitted through, and so you would know that they'd been absorbed
21 **I:** so can you calculate, what energies would be absorbed?
22 **S:** 10:33 [calculates] um, 984. 1166. 1230
23 **I:** 11:22 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?
24 **S:** Um, the electron gets promoted to n=2
25 **I:** What happens if you shine light on hydrogen with an energy of 500 kJ/mol?
26 **S:** Nothing,
27 **I:** so what would happen to the light?
28 **S:** well it would just um... I never quite understood the difference between light being reflected or transmitted.
29 **I:** what do you think?
30 **S:** Well it came up with the midterm whether something would be colorless or would be white, and I was talking to my GSI afterwards and he said well that would depend on if it was transmitted it would be clear, if it was reflected it would be white, and then I was like, well I thought those were the same thing basically, but they're not
31 **I:** well, I guess in this example, is the light getting absorbed or not?
32 **S:** no
33 **I:** So, then what happens if I shine light of 1512 kJ/mol?
34 **S:** then the electron is removed, it's ionized
35 **I:** how does the 1512 kJ/mol goes into...
36 **S:** well, 1312 of it goes to ionize it, and the rest is converted into KE

37 **I:** 13:02 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

38 **S:** well, certain photons are absorbed and promote the electron to different energy level, and as the electron falling back to the ground state, they release the photons which are in the visible range, so you see that color.

39 **I:** Let's say it was H. On this diagram, can you show me the energy getting released

40 **S:** So if it absorbs 984 then it would have gone up to this level, and then it relaxes back down to here, then it releases 1312

41 **I:** Why are Ne and He tubes different colors?

42 **S:** 13:50 because it would take a different amount of energy to promote the electron because of like the interactions.. like the nucleus is bigger with Ne, and there might be more electron repulsions I don't know with Neon, so it would just take a different amount of energy. and I guess to the electrons are not necessarily in the same energy level in Neon, they are gonna be in different 1s or 2p or whatever, so it would take different amounts of energy to move those to different levels

43 **I:** Over time, would the tubes change color?

44 **S:** 14:39 I guess I don't know enough about Neon to knowwhat the different energies are that electrons can absorb, so if there were other.. if it could absorb other photons in the visible spectrum, and those woud release those and those happen to be far enough in a different part of the visible spectrum and it's a different color, then I guess it could have different colors

45 **I:** Is there any amount of energy that wouldn't light the bulb?

46 **S:** 15:17 energy that wasn't strong enough to move any of the electron to another level

47 **I:** so for example in this hydrogen case, what energy, if we had a hydrogen fluorescent bulb, what energy would not cause the color

48 **S:** 983 won't

49 **I:** why is that?

50 **S:** it didn't have enough to get up to that next level, so it would just stay

51 **I:** 15:53 So when you are talking about these different levels, and you also mentioned orbitals, what is an orbital? how would you describe an orbital

52 **S:** 15:59 well, the textbook defines it as a probability area

53 **I:** if you were to describe this concept of certain energy levels, how would you describe that? lets say you were talking to someone not in chemistry, how would you explain what's going on with these

54 **S:** 16:30 if I was talking to someone not in chemistry, I would draw the Bohr atom, circular orbitals, well this is the closest one to the nucleus. The electron is a point negative charge and it can jump to this next level and any level 2,3 or 4, and they are like farther from the nucleus.

55 **I:** can it be in between level 1 and level 2?

56 **S:** no

Student No: 08

	Evidence	Code
Probabalist/ Determinist	00:39 according to the schrodinger model, it's a nucleus and it has one bubble where there is a probability of finding the electron anywhere inside. It can't be outside the bubble, has to be inside the "skin". I'm pretty sure that it can't be in or out of in..	**1**
Discrete/ Continuous	06:34 Excite means it gives an electron enough energy to put it into another orbital, a higher energy orbital, 2s to 2p, 3p to 3d. If it gets enough energy, has to be specific amount though, if it's not the specific energy, the light will pass through, won't do anything. 13:40 - 990, i don't think so either, it has to be exactly 984. 500 - nothing either I didn't really get it why it can't be partial, but I guess it's because in the Schrodinger model it can only be in these certain spaces, if there's not enough energy to put it exactly in that space, then it's not... it can't be anywhere else 14:58 I would use a soap bubble. the soap can only be in the skin of the soap bubble, can't be inside or outside. If there was another state a soap bubble could be at, you couldn't have it be in a state partially between 2, had to be one or the other	**3**
Interpreting Spectra Code	11:12 the ones that are that would make it go to each level (calculates) so 984 kJ would be one, from 1 to 2, and then 1166 would be from 1 to 3	**3**
Energy/Force Code	12:40 984 kJ goes from 1 to 2. So, it's like going around the nucleus, gets hit by a photon, jumps up to the next orbital, and then comes back down and releases light of 984 kJ. It doesn't like to be at the excited state as much as it likes to be at the lowest possible energy level. Emits light because the energy has to be conserved it can't just disappear 09:35 1312. cause that will take it from n=1 ground state to zero. Zero means that it has enough energy to overcome the nuclear attraction, so basically making it far enough apart that it's not feeling the attraction. The two tubes have different energy requirements, to excite the electron up to the next level, so they will have different wavelengths of energies of light coming out. due to attraction of the nucleus. basically the attraction of the electron to the nucleus is affected by the other electron in the electron shielding.	**4**

Line No. **Transcript**

1 **I:** 00:39 Describe how you visualize the atom

2 **S:** according to the schrodinger model, it's a nucleus and it has one bubble where there is a probability of finding the electron anywhere inside. It can't be outside the bubble, has to be inside the "skin". I'm pretty sure that it can't be in or out of in..[inaudible]

3 **I:** 01:33 How would you describe oxygen?

4 **S:** oxygen has a bubble, then it's got the p orbitals, those are on the x,y, and z. Looks like that [draws]. Three of those, and the s's also, and other bubbles… something about it being a standing wave, they did a demo with a cord… oxygen has 1s and 2s, 1s is a smaller one, and the 2s is out there. there are 4 in p. Nodes are like, if you drew a plane through it, that's where they don't cross that. The node is like the point in a wave that doesn't move... [elaborates]

5 **S:** 04:43 not sure about where they intersect, something to do with bonding, there is a + and -[goes off to describe overlap in bonding...]

6 **I:** 05:45 Describe how you visualize light

7 **S:** It's a wave and a particle, an EM wave. The light wave goes like this, the magnetic goes opposite. Has particle-like properties. It can hit an electron, which gets excited up to another energy level, then it will fall back down and emit a photon.

8 **I:** What do you mean by excite?

9 **S:** 06:34 Excite means it gives an electron enough energy to put it into another orbital, a higher energy orbital, 2s to 2p, 3p to 3d. If it gets enough energy, has to be specific amount though, if it's not the specific energy, the light will pass through, won't do anything. Unless it's enough to ionize it, in that case, then it will shoot the electron off plus the extra energy will be KE

10 **I:** 07:56 What happens when light hits a Hydrogen Atom with energy greater than the Ionization energy?

11 **S:** eject an electron will the total energy - IE, the extra energy, the KE, the electron will get

12 **I:** 08:29 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

13 **S:** the absorption one or a photoelectric one?? Oh just the lines… [draws] something like that

14 **I:** 09:35 How much energy is needed to ionize Hydrogen?

15 **S:** 1312. cause that will take it from n=1 ground state to zero. Zero means that it has enough energy to overcome the nuclear attraction, so basically making it far enough apart that it's not feeling the attraction.

16 **S:** 10:14 these 4 levels are energy levels the electron could be at. the first one is 1s, then 2s, then 3p, then I guess it goes 4s first, yeah... if it's not excited at n=1

17 **I:** 11:12 Can you draw the absorption spectrum of Hydrogen?

18 **S:** the ones that are that would make it go to each level [calculates] so 984 kJ would be one, from 1 to 2, and then 1166 would be from 1 to 3, and it doesn't usually go to 2 to 3, because it's at 2 for such a short time, it comes back down, very small chance like 1 in a billion, a very small chance. and 1230 is the last one

19 **I:** 12:40 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

20 **S:** 984 kJ goes from 1 to 2. So, it's like going around the nucleus, gets hit by a photon, jumps up to the next orbital, and then comes back down and releases light of 984 kJ. It doesn't like to be at the excited state as much as it likes to be at the lowest possible energy level. Emits light because the energy has to be conserved it can't just disappear

21 **I:** 13:30 What happens if you shine light on hydrogen with an energy of 980 kJ/mol?

22 **S:** nothing will happen, not enough to go to the next energy level, not enough to ionize it, goes through

23 **I:** 13:40 -how about 990?

24 **S:** i don't think so either, it has to be exactly 984

25 **I:** how about 500?

26 **S:** nothing either

27 **I:** 13:56 how about 1512?

28 **S:** yeah it would have 200 kJ of KE. Yeah, I didn't get it for a while. Went to a review session, and just memorized it. I didn't really get it why it can't be partial, but I guess it's because in the Schrodinger model it can only be in these certain spaces, if there's not enough energy to put it exactly in that space, then it's not... it can't be anywhere else

29 **I:** How would you describe it?

30 **S:** 14:58 I would use a soap bubble. the soap can only be in the skin of the soap bubble, can't be inside or outside. If there was another state a soap bubble could be at, you couldn't have it be in a state partially between 2, had to be one or the other

31 **S:** 16:03 [draws] increasing energy, it would be like... correspondingly 1312 would be there... beyond 1312, it's ionized, so anything this way is an electron with a kinetic energy

32 **I:** 17:11 How is this different from an emission spectra?

33 **S:** that's the energy given off when it goes back down. H in ground state has no emission spectra, it doesn't spontaneously give off light. [draws] 1-3, 1-4, 4 there, [draws them all out], ok fine, draw the arrow the other way… there are 6 emission lines

34 **I:** 19:27 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

35 **S:** the emission spectra. The current you put through is enough to excite the electron to a new energy level. Then when they come back down they release light in the visible spectrum, it's orange.

36 **I:** Why are Ne and He tubes different colors?

37 **S:** The two tubes have different energy requirements, to excite the electron up to the next level, so they will have different wavelengths of energies of light coming out. due to attraction of the nucleus. basically the attraction of the electron to the nucleus is affected by the other electron in the electron shielding.

38 **I:** Over time, would the tubes change color?

39 **S:** wouldn't make any sense. If you keep everything the same, it would be the same. you would have to change the amount of energy being put it. the higher energy you put in, then it becomes UV light and you can't see it...

40 **I:** Is there any amount of energy that wouldn't light the bulb?

41 **S:** 22:14 something that is a low enough charge that it doesn't excite the electron i.e. anything between those, like 900kJ would not light it...

Student No: 11

	Evidence	Code
Probabalist/ Determinist	and these clouds are like where... the darker the cloud .. cause it's just dots each dot is a probability and so the more dots you have the more chance you have to find the electron on that spot. I guess they are just moving around and they go through these hot spots more often	3
Discrete/ Continuous	13:30 (500) nothing (984) so if you shine well yeah it would emit light (990) it wouldn't do anything. (why?) I guess it's this whole thing of quantum, like it has to be exact, it's just how it is	3
Interpreting Spectra Code	07:41 then it doesn't move, but if it's exactly the difference between the 2 shells then it can just make it move. 11:27 hmmm, this was on the midterm, I don't remember. This absorbance and this is energy, it's just gonna be a bar. Absorbance would just be at this one, a bar here (a bar at each of the numbers?) no, it's not staying at each of these, it can go up and down, so if it has to absorb, it has to go up (so only one line?) yeah. 08:22 the different between these orbitals. So if the current pops the electron to the next one when it goes down like if its depending on the energy it's going to emit a different wavelength. And it's gonna be either red or purple	3
Energy/Force Code	it's an energy difference so when it falls down it doesn't emit the same wavelength or frequency (is 1s different for He and Ne?) It's not... I don't know that, It's just the different between 1 and 2 gonna be different. (why?) well I guess it's because there's more protons in the middle so the attraction is different	4

Line No.		Transcript
1	**I:**	Describe how you visualize the atom
2	**S:**	04:35 they showed the video in class of in spinning all around, but when I think about it I still think about it as a sphere, but if it's a problem, then I think about these probability clouds around it.
3	**I:**	describe
4	**S:**	so basically just means so in each orbital you have 2 electron and these clouds are like where... the darker the cloud .. cause it's just dots each dot is a probability and so the more dots you have the more chance you have to find the electron on that spot. I guess they are just moving around and they go through these hot spots more often
5	**I:**	are they staying within one shape
6	**S:**	I actually asked myself that I don't know. I guess they don't I don't see why they would cause they are all equivalent
7	**I:**	Describe how you visualize light
8	**S:**	06:12 so it's both an electromagnetic wave and photons, and photons are particles, and light is energy
9	**I:**	why photon, why wave?
10	**S:**	Wave because iike I think we observe how light reacts and stuff you can like diffract it like when you make it go through an opening that's like shorter than the wavelength then it [gestures spreads out] it's like a characteristic behavior of a wave and the photon thing it's because of this quantum problem cause you have to have one possible set energy.

11 **I:** What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

12 **S:** 07:41 then it doesn't move, but if it's exactly the difference between the 2 shells then it can just make it move. If it's more than that but less than IE it doesn't do anything. The light just goes through it.

13 **I:** What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

14 **S:** 07:34 well the electron is still ejected but it goes faster

15 **I:** When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

16 **S:** 08:22 the different between these orbitals. So if the current pops the electron to the next one when it goes down like if its depending on the energy it's going to emit a different wavelength. And it's gonna be either red or purple
08:45 because their orbitals are not the same. it's an energy difference so when it falls down it doesn't emit the same wavelength or frequency

17 **I:** is 1s different for He and Ne?

18 **S:** It's not... I don't know that, It's just the different between 1 and 2 gonna be different.

19 **I:** why?

20 **S:** well I guess it's because there's more protons in the middle so the attraction is different

21 **I:** 09:30 Over time, would the tubes change color?

22 **S:** so if you have a tube with neon gas in it and you just keep it on? No, it shouldn't.

23 **I:** can you?

24 **S:** well if you put higher current in it's going to ionize the things and then there would be no electron to move I guess

25 **I:** 09:58 Is there any amount of energy that wouldn't light the bulb?

26 **S:** if you put too little then yeah

27 **I:** Can you draw an energy level diagram of Hydrogen? hand piece of paper with table

28 **S:** 10:31 oh the thing like this? [gestures horiz lines] 0, n=1 , n=2, n=3, n=4. like the energy of each orbital

29 **I:** How much energy is needed to ionize Hydrogen?

30 **S:** 11:17 this much [indicates 1312]

31 **I:** Can you draw the absorption spectrum of Hydrogen?

32 **S:** 11:27 hmmm, this was on the midterm, I don't remember. This absorbance and this is energy, it's just gonna be a bar. Absorbance would just be at this one, a bar here

33 **I:** a bar at each of the numbers?

34 **S:** no, it's not staying at each of these, it can go up and down, so if it has to absorb, it has to go up

35 **I:** so only one line?

36 **S:** yeah.

37 **I:** How is this different from an emission spectra?

38 **S:** 12:28 this one. It would be. It would have the different from this to this [calculates] I don't think it can do this.. Has to go from something to 1. so you would have 4 bars with the difference in energy

39 **I:** What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

40 **S:** 13:17 you would eject the electron and it would have an energy of 200 kJ

41 **I:** 13:30 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

42 **S:** nothing
43 **I:** how about 984?
44 **S:** so if you shine well yeah it would emit light

45 **I:** 990?
46 **S:** it wouldn't do anything
47 **I:** why?
48 **S:** I guess it's this whole thing of quantum, like it has to be exact, it's just how it is

Student No: 12

	Evidence	Code
Probabalist/ Determinist	So the orbital looks like a sphere. It's most likely for the electron to be orbiting. (is it moving in a circle?) the e-? Yes. And it's kinda like a cloud and it tells you most likely where the electron will be, and it like orbits so it's just like bigger, how do I explain it? they have like an extra ring, that's what it looks like. it's like a bigger cloud. if you do like 3D like this, this is your cloud, and this is your second cloud, so I guess they are not really overlapping That means all the electron came off and it's not orbiting there's no energy so not moving	**2**
Discrete/ Continuous	17:18 (984?) it just goes to the second energy level (983?) well it absorbs it but it will come back down. Because it's not enough to get it to the next orbital. (985?) well it goes up and then an extra 2 kJ that's like PE. Yeah, if it's over this number then it will go up (500?) not enough. it will stay at the first energy level. (1000?) 1000 it will go past and it will just have PE of this extra 23:48 (can it be in between?) no it can't. It's kinda like steps, like you can't go half a step and then stay there, you have to go to the next step	**1**
Interpreting Spectra Code	16:46 if you add like this much it will go to the 2nd energy level (calcs) 984 17:18 (984?) it just goes to the second energy level (983?) well it absorbs it but it will come back down. Because it's not enough to get it to the next orbital. (985?) well it goes up and then an extra 2 kJ that's like PE. Yeah, if it's over this number then it will go up (500?) not enough. it will stay at the first energy level. (1000?) 1000 it will go past and it will just have PE of this extra	**3**
Energy/Force Code	(why emits?) emits light because it's releasing energy (how about when you put light in?) photons are giving the electron energy to kinda move faster 21:24 ok so it's light, so it's probably being heated. So anytime you add energy the electron get excited, so if you add heat to electron they get excited. Get excited means they are moving faster and colliding more often, and basically going crazy right. because it's not enough energy to pull them off, so they will go back down	**4**

Line No.		Transcript
1	**I:**	01:58 Describe how you visualize light
2	**S:**	like I guess they explain different properties of light. Like there is a particle exp where they shoot one through, also they have like photons and they get excited, has energy, but also is a wave, I don't know I thought it was a bit confusing
3	**I:**	03:17 Describe how you visualize the atom, like hydrogen
4	**S:**	just hydrogen. I know it's 1s, there is only 1. it means its paramagnetic because it's only half filled. So the orbital looks like a sphere. It's most likely for the electron to be orbiting.
5	**I:**	is it moving in a circle?
6	**S:**	the electron? Yes. And it's kinda like a cloud and it tells you most likely where the electron will be, and it like orbits, and there is like different orbs, the p-orb is like this, the d is like this and the f is like this, and it's like 3D.
7	**I:**	what is the p-orbital?
8	**S:**	it's like this, these are like the places the electron will mostly likely be
9	**I:**	05:42 How would you describe oxygen?
10	**S:**	oxygen - so you usually go from like s to p… so you fill up the x and then you go to 2s which is over here so you fill up those and then 2p. You have to fill up one first before you pair them that's just the rule.

11 **I:** are 2s and 2p overlapping?

12 **S:** so it's just like bigger, how do I explain it? they have like an extra ring, that's what it looks like. it's like a bigger cloud. if you do like 3D like this, this is your cloud, and this is your second cloud, so I guess they are not really overlapping. they show both clouds, so this set of electron will be in this cloud. 2p would look like this, but 3dimensionally. Kinda father out, but there is a node right here, which is basically space

13 **I:** 08:23 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

14 **S:** you see a spectrum. So there is like spectroscopy. You shine light and there's a gas or something and then you hit a prism and then it shows a spectrum of what's in hydrogen. Only specific wavelengths are in Hydrogen because specific electron get excited by the light by the photons and they move a different length, and for every element it's different, so your band of colors is different. Hydrogen transmits certain colors

15 **I:** what determines colors?

16 **S:** the number of electrons

17 **I:** 09:33 What happens when light hits the atom with energy greater than IE?

18 **S:** pops off an e-. I've never seen H without an e-, it's completely gone.

19 **I:** 10:27 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

20 **S:** [draws] this is zero that means the electron came off, that's why everything is like negative. That means all the electron came off and it's not orbiting there's no energy so not moving

21 **I:** 11:45 How much energy is needed to ionize Hydrogen?

22 **S:** [draws an arrow] in the ground state?

23 **I:** what does 4 levels mean?

24 **S:** I don't know. Cause I remember that you get the n's from 1s 2s, but how do you do that for H - only 1 e-. Every time you take off electron it moves up one, IE is when you pull it off. I'm not sure

25 **I:** 14:32 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

26 **S:** the electron comes off. 1312 to ionize, the extra 200 is KE, electron is moving

27 **I:** 15:00 What is an absorption spectrum of Hydrogen?

28 **S:** tells you what colors are absorbed by Hydrogen which is like which photons are absorbed. For colors, wavelength, that's when you have to talk about the wave model

29 **I:** 16:03 how about for H?

30 **S:** depends on the light. So if you have like a strong enough wavelength of light it means the electron can come off which means it is a really high energy of light, aand hydrogen absorbs this much energy for an electron to come off. and I know that intensity doesn't matter.

31 **I:** 16:46 if you add like this much it will go to the 2nd energy level

32 **S:** [calculates difference between n1 and n2] 984

33 **I:** 17:18 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

34 **S:** it just goes to the second energy level

35 **I:** 983?

36 **S:** well it absorbs it but it will come back down. Because it's not enough to get it to the next orbital.

37 **I:** 986?

38 **S:** well it goes up and then an extra 2 kJ that's like PE. Yeah, if it's over this number then it will go up

39 **I:** 500?
40 **S:** not enough. it will stay at the first energy level.
41 **I:** 1000?
42 **S:** 1000 it will go past and it will just have PE of this extra
43 **S:** 18:41 [calcs from n=2 to n=3]
44 **I:** 18:58 How is this different from an emission spectra?
45 **S:** emission is like when you heat it up what does it show.
46 **I:** how about for Hydrogen here?
47 **S:** so emission is going from , emission is .. This is the biggest, 2 to 1, 3 to 1, so they get excited. So for emission there is this specific light thing with this metal rod and then you excite the electron and then it pops an electron off and then when it goes back in it emits light
48 **I:** why does it emit?
49 **S:** emits light because it's releasing energy
50 **I:** how about when you put light in?
51 **S:** photons are giving the electron energy to kinda move faster
52 **I:** When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?
53 **S:** 21:24 ok so it's light, so it's probably being heated. So anytime you add energy the electron get excited, so if you add heat to electron they get excited. Get excited means they are moving faster and colliding more often, and basically going crazy right. For emission usually what happens is certain... when the electron come back down to an energy level they emit different amts of light.
54 **I:** Why are Ne and He tubes different colors?
55 **S:** it's different because every element has different electron in n levels, and they have different n numbers
56 **I:** why do they come back down?
57 **S:** because it's not enough energy to pull them off, so they will go back down
58 **S:** 23:19 so when they come back down, it's like from different energy levels to different energy levels, so that specific range is a specific color.
59 **I:** 23:48 can it be in between?
60 **S:** no it can't. It's kinda like steps, like you can't go half a step and then stay there, you have to go to the next step
61 **I:** Is there any amount of energy that wouldn't light the bulb?
62 **S:** 24:13 you usually hear that red light woudn't work, highest wavelength, lowest energy. einstein proved that it doesn't matter how much light it is, it's the type of light.

Student No: 13

	Evidence	Code
Probabalist/ Determinist	electron floating around it in orbital 1s. Orbital is pathway where the electron is gonna be. 1s is a circle. 01:24 this is oxygen (draws) electrons in 1s, 6 on the 2, the electron are moving in orbitals in electron clouds, there is a lot of space between them, 1s and 2s clouds are kinda far apart, don't move between the 2 clouds	1
Discrete/ Continuous	03:48 if it has enough energy, the electron can bounce out. Or it doesn't it's all or nothing	1
Interpreting Spectra Code	08:40 would absorb 1312 kJ, I think there is an equation for that.. I don't know.. Absorption spectra shows the colors that are absorbed. 10:09 if shine 1312 kJ, there is enough energy to.... Ummm, I'm kinda confused on how the numbers relate to each other... there is some equation for this minus this...	1
Energy/Force Code	04:33 it's the color, when the energy hit it it moves to another orbital, and then emission. Happens... electron moving out then falling back, it goes back to a lower level. I don't know why.	1

Line No.		Transcript
1	**I:**	0:28 Describe how you visualize the atom
2	**S:**	nucleus, electron floating around it in orbital 1s. Orbital is pathway where the electron is gonna be. 1s is a circle. [draws] picture is an orbital
3	**I:**	01:24 How would you describe oxygen?
4	**S:**	this is oxygen [draws] electrons in 1s, 6 on the 2, the electron are moving in orbitals in electron clouds, there is a lot of space between them, 1s and 2s clouds are kinda far apart, don't move between the 2 clouds
5	**I:**	02:52 Describe how you visualize light
6	**S:**	3 ways of looking at it, ray, wave, particle, ray is like shadows, wave is like the light the colors, particle is like the energy. I guess they happen at the same time
7	**I:**	03:48 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
8	**S:**	if it has enough energy, the electron can bounce out. Or it doesn't it's all or nothing
9	**I:**	04:33 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?
10	**S:**	it's the color, when the energy hit it it moves to another orbital, and then emission. Happens... electron moving out then falling back, it goes back to a lower level. I don't know why.
11	**I:**	Over time, would the tubes change color?
12	**S:**	05:23 wouldn't change color, because have same color, it's like a special color, electron have a color that corresponds to them.
13	**I:**	Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
14	**S:**	[draws]
15	**I:**	0712: How much energy is needed to ionize Hydrogen?
16	**S:**	this much [points to -1312]
17	**S:**	the first energy level, n=1 means the first energy level.
18	**I:**	why 4 levels?
19	**S:**	I'm not sure in the ground state its in an orbital, at n=1 in ground state. I guess they can move to different energies.

20 **I:** 08:40 Can you draw the absorption spectrum of Hydrogen?

21 **S:** would absorb 1312 kJ, I think there is an equation for that.. I don't know.. Absorption spectra shows the colors that are absorbed.

22 **I:** 11:14 How is this different from an emission spectra?

23 **S:** it is the opposite. The absorption spectra looks like the opposite of emission. Absorbed is what is absorbed, you can't see, emission is what you can see. The colors get absorbed because they interact with the particles. Interacts and gets absorbed. gets absorbed.. interacts with particles...

24 **I:** 12:09 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

25 **S:** if shine 1312 kJ, there is enough energy to.… Ummm, I'm kinda confused on how the numbers relate to each other… there is some equation for this minus this…

Student No: 14

	Evidence	Code
Probabalist/ Determinist	but I see an atom, maybe a little cliché, of a ball, a small particle, particle size of a nucleus where the proton is, and then kind of a, it's not a mass, but it's like a cloud around the proton the nucleus that is electron density and the cloud is made up of subshells and different electron within the atom, so around the ball there is this cloud around it, very very small	3
Discrete/ Continuous	like the electron moving from n1 to n2? Yeah, if it has that specific amount of energy that it needs to jump to the energy state, then it will just go, like from 1 to 2, or 2 to 3 18:46 990? If it was 990 – then it would, yeah it would excite it from n=1 to n=2 and the excess is not enough to really do anything else, so there would be a little bit of KE left over. So it would just excite it to the next energy level. That little bit of extra energy, I know it's conserved, but it's not enough to really make a difference, like it's not significantly more to keep it traveling up the energy levels but it would still move from 1 to 2? yeah	1
Interpreting Spectra Code	that's all I memorized from class… and the differences between n=1 and n=2, for example if you take 1312 – 328 that's how much energy it takes to excite the electron from n=1 to n=2 I believe.. What if I asked you the absorption spectra and emission spectra? What would the absorption spectra be? the absorption would.. like you have a color line, like ROYGBIV, the absorption what wavelengths were absorbed and where there is a dip or where the absorption is very low, those are the colors that you actually see, because it's absorbing all the other colors, and emission is just the inverse of that	3
Energy/Force Code	05:00 then an electron will be ejected and depending on the difference between the provided energy and the IE, there will be some KE, so the electron will just pop off faster or will just kinda sit there So they will absorb, the electron will get excited, and whatever certain wavelength they got excited to will be the corresponding color. To the light that's being transmitted It is… the electron is moving from a lower energy state to a higher energy state because it is absorbing that energy so it can go from n=1 to 2 to 3 to 4, but it's not enough to ionize it, so when the energy falls down, when it emits that energy, that's the color.. when it falls down to a lower state, it's emitting energy Energy levels, for example, um, you have the core electrons that are pretty tightly bound to the nucleus, and then the electrons, the valence electrons, depending on the environment, will jump to energy levels, and I think.., yeah, will jump to energy levels and um, the energy levels will... they don't change in relation to light, if a light shines on a certain energy level, depending on the ionization energy, it could produce energies such as the light – so it's all about energy.	3

Line No.		Transcript
1	I:	Describe how you visualize the atom
2	S:	00:41 it's hard to imagine a real atom because we have all these preconceived ideas of circles and electron clouds, but I see an atom, maybe a little cliché, of a ball, a small particle, particle size of a nucleus where the proton is, and then kind of a, it's not a mass, but it's like a cloud around the proton the nucleus that is electron density and the cloud is made up of subshells and different electron within the atom, so around the ball there is this cloud around it, very very small

3 **I:** 01:40 cloud?

4 **S:** electron, there is obviously electron, there is forces in that cloud, electron forces, repulsion polarity, but they can't really be seen, that's inside the cloud, um yeah forces

5 **I:** 02:15 what are the electron doing in there?

6 **S:** They are constantly moving around, constantly adapting to whatever the atom is in or around, under the environment that it is exposed to and, um the electrons, depending on the environment can jump from states or fall back down from states, are constantly adapting

7 **I:** 02:42 Oh, so what are these states?

8 **S:** Energy levels, for example, um, you have the core electrons that are pretty tightly bound to the nucleus, and then the electrons, the valence electrons, depending on the environment, will jump to energy levels, and I think.., yeah, will jump to energy levels and um, the energy levels will... they don't change in relation to light, if a light shines on a certain energy level, depending on the ionization energy, it could produce energies such as the light – so it's all about energy.

9 **I:** 03:40 So describe how you visualize light to be

10 **S:** Light I've always seen from Physics as a wave, it's hard to imagine as particles.

11 **I:** 04:10 So do you have an explanation for why we sometimes say it's a particle?

12 **S:** yeah, I remember learning in study group that the Schrödinger equation can also be looked at as a particle in a box… light is made up particles called photons and in those photons the electrons adapt into energy levels.. so I understand the particle concept of it, but I think I have a better grasp of the wave

13 **I:** 04:54 So what happens when light hits at atom with an energy less than the ionization energy?

14 **S:** Um. Nothing will happen. It might change energy levels from 1 to 2, like n=1 to n=2, but it won't ionize

15 **I:** Can any of the electrons move? 1 to 2, 2 to 3?

16 **S:** like the electron moving from n1 to n2? Yeah, if it has that specific amount of energy that it needs to jump to the energy state, then it will just go, like from 1 to 2, or 2 to 3

17 **I:** What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

18 **S:** 05:00 then an electron will be ejected and depending on the difference between the provided energy and the IE, there will be some KE, so the electron will just pop off faster or will just kinda sit there

19 **I:** 06:08 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

20 **S:** This was the part that I was struggling with, the last MT….So you have particles in this tube, He particles for example. When light goes through that tube, energy is going through the tube. So the particles of He will absorb certain photons if they reach that energy level that they need to emit light. So they will absorb, the electron will get excited, and whatever certain wavelength they got excited to will be the corresponding color. To the light that's being transmitted

21 **I:** 07:03 So why are He and Ne different colors?

22 **S:** Because the , He has higher IE I believe, so because of the different size of the radii…that depends on the IE. So if He has a higher IE, it's gonna take a lot of energy to absorb that photon.

23 **I:** So, would all He or Neon atoms look the same color?

24 **S:** No, it depends on the energy of the light

25 **I:** Ok, so tell me about that, how can you change the color?

26 **S:** You can put a higher or longer wavelength or shorter wavelength, it corresponds to energy, so if you have a higher energy… if the atoms are absorbing a higher energy, whatever that certain wavelength is, which is the corresponding color, will make the color change. So if its like, for example, the energy that it can absorb to make red light, then it will make red light, but if it's at a higher energy to absorb blue light, then it will make blue light

27 **I:** 08:44 So let's take Neon for example. What's happening in the atom to make red vs. blue light?

28 **S:** In the atom, let's say red light, in the atom, it is absorbing everything except, all the energy except the energy that would make red light. So it's absorbing all the other colors, and red light is being transmitted through… it's because it's absorbing that energy, and the resulting energy would happen to be the wavelength of the…

29 **I:** 09:20 So what's happening with the energy that's being absorbed?

30 **S:** It is… the electron is moving from a lower energy state to a higher energy state because it is absorbing that energy so it can go from n=1 to 2 to 3 to 4, but it's not enough to ionize it, so when the energy falls down, when it emits that energy, that's the color.. when it falls down to a lower state, it's emitting energy

31 **I:** 09:58 So, what would that color look like?

32 **S:** Um [trails off …] well If it's absorbing all the colors, or all the energy… so if it's absorbing all of the wavelengths except for blue, and blue is being transmitted… but the energy that it emits is a mixture of all those wavelengths…

33 **I:** 11:51 Is there any amount of energy that wouldn't light the bulb?

34 **S:** I want to say like if it's lower than the IE, but that's not necessarily true… electron are still going to be doing something at that energy… even if its very small energy… I would say anything below the lowest electron configuration jump, anything lower than from n=1 to the next energy

35 **I:** Can you draw an energy level diagram of Hydrogen? (hand piece of paper with table)

36 **S:** 13:17 drawing I'm drawing an arrow that is going up in energy, and on the arrow I have different energy states, of n=1, n=2, n=3 and next to it I have the energy provided in the table, the kJ/mol.

37 **I:** And what do those represent?

38 **S:** those represent… Well n=1 is the ionization energy, and…

39 **I:** and why is that the IE?

40 **S:** because that's how much energy it takes for the electron to come off, so the n=1….. that's all I memorized from class… and the differences between n=1 and n=2, for example if you take 1312 – 328 that's how much energy it takes to excite the electron from n=1 to n=2 I believe..

41 **I:** 16:08 Is this different from an emission spectra?

42 **S:** Yea, the emission spectra would be.. I think this is the spectra with the probabilities of the electrons being ejected, I think, It's kinda coming back to me…

43 **I:** What if I asked you the absorption spectra and emission spectra? What would the absorption spectra be?

44 **S:** the absorption would.. like you have a color line, like ROYGBIV, the absorption what wavelengths were absorbed and where there is a dip or where the absorption is very low, those are the colors that you actually see, because it's absorbing all the other colors, and emission is just the inverse of that

45 **I:** What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

46 **S:** 17:47 It will ionize the electron and the resulting energy would be KE.

47 **I:** 17:58 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

48 **S:** 500? It would excite… it wouldn't do anything. Because it's not enough energy to move the electron to a different energy level.

49 **I:** 18:28 984?

50 **S:** Yes, because it will absorb that amount of energy and that is enough energy to move it from n=1 to n=2

51 **I:** 18:46 990?

52 **S:** If it was 990 – then it would, yeah it would excite it from n=1 to n=2 and the excess is not enough to really do anything else, so there would be a little bit of KE left over. So it would just excite it to the next energy level. That little bit of extra energy, I know it's conserved, but it's not enough to really make a difference, like it's not significantly more to keep it traveling up the energy levels

53 **I:** but it would still move from 1 to 2?

54 **S:** yeah

Student No: 15

	Evidence	Code
Probabalist/ Determinist	1s orbital - Well it's where the electron will be most probably to be I guess present. Shaped like a circle. It's more probable to be in that location.	1
Discrete/ Continuous	cause there are like specific levels with specific quantities or like numbers that has to be it. (990 kJ) um, I'm tempted to say one of 2 things. (laughs) the first thing I was going to say was that it will still go from 1 to 2 except it would only be up to 984 and hte remaining energy would just be absorbed. I'm also tempted to say nothing will happen cause it's not at a specific energy	2
Interpreting Spectra Code	(990 kJ) um, I'm tempted to say one of 2 things. (laughs) the first thing I was going to say was that it will still go from 1 to 2 except it would only be up to 984 and hte remaining energy would just be absorbed. I'm also tempted to say nothing will happen cause it's not at a specific energy	1
Energy/Force Code	08:03 with an absorption spectra, an electron is moving up to a different orbital, as opposed to an emission spectra where it's going down, I guess when I illustrate it the arrows going down are the emission spectra, absorption is going up 08:37 (draws) so up is absorbing and down is emitting 07:28 then the remaining light will be transmitted as KE. I don't really know (what that means)	1

Line No.		Transcript
1	I:	03:50 Describe how you visualize the hydrogen atom
2	S:	well it has a relatively high IE, sorry just going back into the whole midterm zone.. it has one electron, if light shines on it and does meet that certain IE, then the electron won't be ejected.
3	I:	where is the electron in H? which orbital?
4	S:	1s
5	I:	what does that mean to you?
6	S:	Well it's where the electron will be most probably to be I guess present.
7	I:	If you were to draw the 1s for me, how would you draw it?
8	S:	well, it's Shaped like a circle, so this would be 1s I guess [draws circle]
9	I:	so what does that circle represent?.
10	S:	It's more probable to be in that location.
11	I:	05:05 How would you describe oxygen?
12	S:	Should I write the electron configuration? Or?
13	I:	Mm-hmm
14	S:	ok, all right so this and then I'll admit that I can't illustrate the p's.
15	I:	how about the 2s?
16	S:	I'm assuming it's another circle, but I'm not too sure
17	I:	05:52 Describe how you visualize light
18	S:	I think of all the different wavelengths right now. Certain light being absorbed, and others being reflected, transmitted things like that, so think about it in terms of absorption and transmittance
19	I:	in lecture, they kinda talked about this wave model and this particle model if you remember, so how do those models kinda explain different things about light?
20	S:	06:14 I don't completely remember the wave model that much. I remember them mentioning the number of nodes. As far as the particle model goes, I don't remember too much of that either.

21 **I:** 06:57 Here we have the first 4 energy levels of H. Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table] chart those out on an arrow

22 **S:** 07:06 this one's the easiest to plot. [1312]

23 **I:** Why is that 1312?

24 **S:** That's how much energy is required to eject the electron

25 **I:** so what if I shine more than 1312 on this atom?

26 **S:** Then the remaining light will be transmitted as KE

27 **I:** what does that mean?

28 **S:** I don't really know

29 **I:** 07:50 So hydrogen has one electron bu there are 4 levels here - so what does that mean, or how come.. What do these 4 things represent

30 **S:** I don't know either, I'm sorry

31 **I:** 08:00 my other question is what is an absorption spectrum, and what is an emission spectrum? just describe it to me

32 **S:** oh, well with an absorption spectra, electrons, an electron is moving up to a different orbital, as opposed to an emission spectrum where it's going down. I guess when I illustrate it like the arrows going down with the emission spectrum, and the absorption is going up

33 **I:** can you draw me just a quick line n=1234 and show me what does going up and going down mean?

34 **S:** so this would be emission and the opposite way would be absorbance

35 **I:** so why do you think up is absorbing and down is emitting?

36 **S:** I think because it's going to a more excited state

37 **I:** what does that mean to you?

38 **S:** um, I'm guess there's more energy and the electron is just moving to a different orbital so..

39 **I:** can it be in between 1 or 2?

40 **S:** um, no cause there's like specific levels and specific quantities or like numbers it has to be at

41 **I:** So for these numbers, how much energy does it take to get from 1 to 2?

42 **S:** um, [calculates] 984

43 **I:** 09:51 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

44 **S:** it would move from the first one to the second one, something like that that.

45 **I:** What if I shine a little less, like 980

46 **S:** nothing will happen, it won't move to the other orbital…

47 **I:** when you were learning that, was that confusing?

48 **S:** Kinda what I think was more confusing was that even though H has one electron it has all these existing orbitals, even though technically the electron configuration doesn't include all of that

49 **I:** so how do you understand that now?

50 **S:** it's still somewhat confusing...

51 **I:** 10:51 So let's say now I shine more, I shine 990 kJ, what happens then? Or does anything happen?

52 **S:** um, I'm tempted to say one of 2 things.

53 **I:** what are they?

54 **S:** [laughs] well the first thing I was going to say was that it will still go from 1 to 2 except it would only be up to 984 and likt the remaining energy would just be absorbed.whereas I'm also tempted to say nothing will happen cause it's not at a specific energy

Student No: 16

	Evidence	Code
Probabalist/ Determinist	So it's not just orbiting around like there's that possibility of it being found in this, the outer layer 03:35 (what is an orbital?) isn't an orbital like um a possible place to find the electron so yeah	3
Discrete/ Continuous	13:33 (500?) then it wouldn't succeed in ejecting it. Although I don't know what it would do to the atom itself if it doesn't eject it, cause I always thought that it just absorbs it but that might be wrong (would it move up in these energy levels for 500?) possibly? (984?) well since you have different energy levels i guess it might possibly move to like a higher energy it just won't eject. (more energy 1 to 3 than 1 to 2) yeah. I think so. (1 to in between 2 and 3?) i don't think so, I really don't know why. (what would happen?) wouldn't it just stay at n=2? I'm not really sure	2
Interpreting Spectra Code	13:33 (500?) then it wouldn't succeed in ejecting it. Although I don't know what it would do to the atom itself if it doesn't eject it, cause I always thought that it just absorbs it but that might be wrong (would it move up in these energy levels for 500?) possibly? (984?) well since you have different energy levels i guess it might possibly move to like a higher energy it just won't eject. (more energy 1 to 3 than 1 to 2) yeah. I think so. (1 to in between 2 and 3?) i don't think so, I really don't know why. (what would happen?) wouldn't it just stay at n=2? I'm not really sure	2
Energy/Force Code	for different elements? because some of these electron feel like a greater effective nuclear charge or like greater attraction to the nucleus depending on their position. if they are really far from it it might be easier or like the IE could be lower so that energy needed to eject it wouldn't be that high whereas if it's closer you will need something higher, so the energy would be high	4

Line No. **Transcript**

1 **I:** Describe how you visualize the atom

2 **S:** 00:20 like according to the Bohr model, there is a nucleus surrounded by a cloud of electron and these electron are organized into different shells and depending on the atomic number it dictates how many shells there will be. Like Hydrogen there'd just be one and one electron in that shell whereas oxygen, I don't really remember the number, number 8, so it's gonna be like a 2 shell, so it's going to reach like there

3 **I:** 01:10 how do you imagine shells?

4 **S:** spherical.

5 **I:** Can you draw it?

6 **S:** nucleus, one shell... s's...

7 **I:** what doyou mean by shells?

8 **S:** they said that it can like move from the lower energy state to the higher, like the excitation. depending on if you add certain energy to it. So it's not just orbiting around like there's that possibility of it being found in this, the outer layer

9 **I:** how about 2p?

10 **S:** it's like, like different shapes, like that, one like that.

11 **I:** how do these compare?

12 **S:** I don't know. I usually just think of them separate, because when I think about this and like to this I don't really know how that [2p] would look like in here [2s]. It gets confusing when you look at it like [gestures combined]
03:08 it just shows that it's different from the s orbitals in what it looks like. the d looks different too, has a certian number of nodes

13 **I:** 03:35 what is an orbital?

14 **S:** isn't an orbital like um a possible place to find the electron so yeah

15 **I:** Describe how you visualize light

16 **S:** 03:56 there's like the particle aspect to it and then there's the wave aspect of it, so it's not just like a simple beam, there's photons and stuff in it.

17 **I:** what does that mean?

18 **S:** It has different components to it and those components can affect other things like breaking bonds or something or the photoelectric effect and intensity and stuff like that

19 **I:** What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

20 **S:** 04:50 then it ejects the electron. Doesn't it remove it from like.. The first IE would be from the outer shell, and the 2nd from here. So when they eject it, it's like gone

21 **I:** What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

22 **S:** 05:28 well, then the electron wouldn't be ejected, right? So it doesn't necessarily have an effect, it would just be absorbed. Well it still has a lot of energy just not enough to eject it so maybe something else happens within that atom that yeah, besides getting ejecting

23 **I:** what happens to the energy that gets absorbed?

24 **S:** well possible I think it might cause an electron to be excited to the next orbital

25 **I:** if it doesn't excite it?

26 **S:** I guess nothing happens

27 **I:** is the energy still absorbed?

28 **S:** probably not.

29 **I:** 06:53When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

30 **S:** it's when the electron move to a higher energy state and then they move down it's like the emission of the light

31 **I:** Why are Ne and He tubes different colors

32 **S:** they have different electron configurations even though I mean they are very similar because they are in the same group and they have noble gas config but I guess the other one is a bigger atom, it has more electron to it whereas He just has one

33 **I:** if both He and Ne 1s to 2s, would it be the same color?

34 **S:** He doesn't have 2s right so it would be the same color

35 **I:** or how about Ne and another big noble gas

36 **S:** if you put it that way, it might. I can't explain how they are actually really different. all I know is different elements emit different types, different colors of light

37 **I:** why certain energies?

38 **S:** for different elements? because some of these electron feel like a greater effective nuclear charge or like greater attraction to the nucleus depending on their position. if they are really far from it it might be easier or like the IE could be lower so that energy needed to eject it wouldn't be that high whereas if it's closer you will need something higher, so the energy would be high

39 **I:** 09:47 Over time, would the tubes change color?

40 **S:** probably not because if it's going up and into a lower one it's happening all again and again

41 **I:** 10:12 Is there any amount of energy that wouldn’t light the bulb?

42 **S:** probably.. I'm not really sure
43 **I:** Can you draw an energy level diagram of Hydrogen? hand piece of paper with table
44 **I:** 11:11 so n=4?
45 **S:** that would be -82 kJ/mol
46 **I:** what is the diagram telling you?
47 **S:** that the n=4 energy level is the highest among these and n=1 would be the lowest

48 **I:** How much energy is needed to ionize Hydrogen?
49 **S:** 11:37 1312 kJ
50 **I:** Can you draw the absorption spectrum of Hydrogen?
51 **S:** 11:53 isn't it just like you just go like up like that, starting from it's lowest energy state
52 **I:** what would be peaks on spectra?
53 **S:** I don't know..
54 **I:** why 1 to 4 1 to 3?
55 **S:** absorption is when the electron moves from the lower energy state to the higher ones and I know they have to start from the lowest , like in emission they can start from the highest, like going down they can go from here to here
56 **I:** How is this different from an emission spectra?
57 **S:** 12:51 emission? It would be like here going down to 3 to 2 to 1 or from 3 to 2 to 1, or from 2 to 1. you have like a lot of possibilities you don't have to start from the highest only. As long as it's higher than the lowest one.
58 **I:** What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
59 **S:** 13:20 since ionization is 1312, and 1512 is higher then that would eject the electron
60 **I:** 13:33 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?
61 **S:** then it wouldn't succeed in ejecting it. Although I don't know what it would do to the atom itself if it doesn't eject it, cause I always thought that it just absorbs it but that might be wrong
62 **I:** would it move up in these energy levels for 500?
63 **S:** possibly?
64 **I:** 984?
65 **S:** well since you have different energy levels i guess it might possibly move to like a higher energy it just won't eject.
66 **I:** more energy 1 to 3 than 1 to 2
67 **S:** yeah. I think so.
68 **I:** 1 to in between 2 and 3?
69 **S:** i don't think so, I really don't know why.
70 **I:** what would happen?
71 **S:** wouldn't it just stay at n=2? I'm not really sure

Student No: 17

	Evidence	Code
Probabalist/ Determinist	so you can't say where the electron is at any given time cause then it could be somewhere else, so the cloud is just like an area of probability of where the electron will be like some % of the time like 99% of the time , it would be in that cloud, one of the points . If you look a the diagram, you have the nucleus in the center, and a bunch of tiny little points all around it could be any one of those dots	3
Discrete/ Continuous	um, my GSI really harped on us and said that it has to be that exact amount of energy if it's absorbed. If not, it's not absorbed at all. But there was a question like that on the test , and it said the light was transmitted, so I guess the light just goes right through the atom or it doesn't have any effect on it	3
Interpreting Spectra Code	so if you subtract 1312-328 that gives you how much energy requires to move it to the n=2 orbital (so 984) so it's 984 (what does the 984 represent to you?) the 984 means that if you put 984 kJ into this atom, this little e-, you have the proton and you have the e-, it's in the n=1 orbital, that's going to kick it up to the n=2 orbital, so that's what that means. and then it will release light of a certain wavelength as it comes back down from the n=2 orbital to the n=1 orbital	3
Energy/Force Code	so you are requiring more and more energy to move it up to higher energy levels, cause it's farther away from the nucleus, and the attraction between the electron and the proton, you would have to move it farther away, it would require more energy to separate them, the PE, so	4

Line No. **Transcript**

1 **I:** 01:08 Describe how you visualize the atom

2 **S:** visualize the atom? Schrodinger model?

3 **I:** How would you describe an atom

4 **S:** for me to visualize it and for me to conceptualize it I just think of like the ball and the ball moving around. I just like that's how I've always thought about it and that's like the stylized pictures in the textbook, cartoons, like that's how I think about it. But if you actually like get really into the material like actually think about the closest possible approximation you can get like if you condense it down into a 2D picture it would be like a nucleus in the center and the cloud around it, the area where the electron could possible be

5 **I:** 01:54 what do you mean by cloud?

6 **S:** because the electron are moving at the speed of light, at any one time, once you try to pinpoint its location it's already going to be somewhere else, so you can't say where the electron is at any given time cause then it could be somewhere else, so the cloud is just like an area of probability of where the electron will be like some % of the time like 99% of the time , it would be in that cloud, one of the points . If you look a the diagram, you have the nucleus in the center, and a bunch of tiny little points all around it could be any one of those dots

7 **I:** 02:28 can a electron move around within orbitals?

8 **S:** I'm visualizing they are moving around in one. um, they can go up to the higher orbitals, but if it's just in a ground state it's just moving around in one

9 **I:** why?

10 **S:** because stuff in nature wants to be at the level where it uses the least amount of energy, and since it only has one electron it's just gonna be at the lowest energy level. putting it to another energy level requires it putting energy into the system

11 **I:** 03:05 How about oxygen? Can go to lower levels?

12 **S:** the lower levels are full so they can't go to the lower levels cause like you can't fit more electron in the lower levels cause it's full. Like it will..the energy differentials don't work, they can go to higher levels if you put more energy in ..if an orbital is full with 2electron you can't try to shove more in

13 **I:** why these levels?

14 **S:** the energy levels help to explain why atoms behave the way they do. when you put the electron in the energy levels it allows you to like better understand and explain like why atoms will bond in certain ways or why they react in ways that they do. so if you just look at it and throw all the electron in there, the properties that you measured won't match with the model that you have. so the orbitals are just the best approximation of trying to predict y'know as many times as you can y'know x amount of times, how the atom is going to react in that situation

15 **I:** 04:15 Describe how you visualize light

16 **S:** light it's both a particle and a wave, like it has properties of both. So you can think of it as just like a wave of energy, like you always see like sine waves or cosine waves, y'know the light, y'know hitting things. The short wavelength and the long wavelength and all this kinda thing. But it can also kinda be, they call it "packets", like packets of energy, photons, so it can be..it has characteristics of both a particle and a wave depending on which property you are looking at. Like for example if you are talking about light energy hitting atoms and knocking electron into higher energy levels, that's more directly explained by looking at it as a photon, it's like a particle. But if you are looking at like radio waves, it's easier to think of it as like a wave cause it's continuous it's not tiny particles

17 **I:** 05:15 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

18 **S:** ok, the IE is the energy required to knock the e-, like completely get it away from the atom, like once the atom is ionized that means it's completely lost or gained an electron, so if you put a photon in that has more than the IE you're gonna take that... like it takes the exact amt, like it has to be right on the nose of inized. if you take that exact amount and you hit the atom the electron is ejected but you still have this energy left over, energy is conserved, it can't just vanish, so you put the energy in the electron and it's just leftover KE, so it's going faster

19 **I:** 05:50 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

20 **S:** if light hits with less than the IE, because it requires that exact amt, nothing is going to happen, an electron isn't going to jump, nothing's going to happen, it's just gonna, like you said, go through

21 **I:** 06:07 tell me about that jump, what does that mean?

22 **S:** it means that you are putting energy into the atom so because there is excess energy, the electron has to go to a higher energy level cause it has more energy. Like I guess higher energy electrons go to higher energy levels because it has more energy it has to go to that higher level

23 **I:** will the entire amount of energy be absorbed somehow?

24 **S:** um, my GSI really harped on us and said that it has to be that exact amount of energy if it's absorbed. If not, it's not absorbed at all. But there was a question like that on the test , and it said the light was transmitted, so I guess the light just goes right through the atom or it doesn't have any effect on it, cause I was a little bit.. I thought that was written in stone, and I was a little bit unclear about that when I took the MT. She had been completely adamant, that if it's not that exact energy absolutely nothing is ever going to happen. transmitted?

25 **S:** that's one of the questions on the MT, so I don't know..I guess it would make sense if light was just going through everything, cause then you would have light shining through...I guess that makes sense, transmitted is.. it doesn't interact with the atom in any way, it just goes through it, like it doesn't bounce off, I mean like the billiard ball model that we saw in lecture y'know stuff just doesn't bounce off of the atom, so...

26 **I:** 07:43 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

27 **S:** ok, so um what happens is you are putting… it goes back to putting the energy in the atom. So, you put the energy in, and when you put the excess energy in, enough to kick one of the electron up to a higher energy level, then it goes to the higher energy level but it doesn't want to stay there, y'know it's not going to stay there indefinitely, it releases the energy as a photon of a certain color, or like a certain wavelength rather. So, because yknow, so the photons coming off the the electron as it's going back down to the ground state, as the atom goes back to the state that requires the least amount of energy to maintain, this photon that gets kicked out is a specific wavelength of light and we see the different colors because the photon that is released happens to be like in that specific wavelength of light. I mean depending on which energy level the electron moves to, it releases light of a whole bunch of different wavelengths, but the visible wavelengths are the only ones we can see, so the color is just the amount that is released in the visible spectrum, there is also IR and UV

28 **I:** 08:55 Over time, would the tubes change color?

29 **S:** you wouldn't think so. I mean that's a good question, one which I hadn't thought about, cause you seem to be able to pick questions that I haven't considered. um, I've never really seen Neon signs get old, I don't know if they replace Neon signs or they put more neon in there to replenish the fuel, but you wouldn't think that they'd do anything. I mean if honestly you are just throwing this energy in the atom, the e= move up it's going back down, it seems like it can do that indefinitely as long as you have energy are the electron kicked out? no, cause it's not the IE. the light that is released is just the amount of energy required to move the electron to a higher energy level. it's not enough to completely ionize it

30 **I:** 09:50 Is there any amount of energy that wouldn't light the bulb?

31 **S:** well if it's... if you don't put enough energy to move the electron up to a different energy level, then nothing is going to happen, so there are some energies that won't light the bulb

32 **I:** Can you draw an energy level diagram of Hydrogen? hand piece of paper with table

33 **S:** 10:16 sure, nothing would make me happier right now than to draw an energy level diagram… so you have 1312, 328, 146.. So put a zero… is this the energy level diagram?

34 **I:** sure

35 **S:** cause I can't remember if the energy level diagram is one of those [draws horizontal] or if it's one of these ones [draws short lines vertically] with the little tiny lines like

36 **I:** stick with this one...

37 **S:** I started out very confidently drawing a spectrum and drawing like the different little lines at the different amts of energy you need to put in.. but now I'm starting to think I should draw one of the ones with the... that makes sense

38 **I:** 11:58 so what is it telling you?

39 **S:** it's telling you the amount of energy that's required to...so all these values here, this is the amount that.. so 1312 kJ/mol is the IE for H

40 **I:** how do you know that?

41 **S:** I memorized it, they are always talking about 1312, 1312, 1312, it's really important, so I know - so 1312 kJ/mol is the amount of energy required to ionize the electron on H. H has one proton and one electron and to kick it off you need exactly 1312 kJ/mol, no more, no less.. these are all negative so...so these are all the amts of energy you need to put in to move.. well these amts aren't, but this tells you how much energy you need to put in to move the electron to all these different energy levels

42 **I:** so how do you figure out how much it takes to move it?

43 **S:** you take 1312, and you subtract all of these from 1312, so if i subtract 1312 from 1312, I get zero, and that's because it's already in the n=1 orbital, and that makes sense. so if you subtract 1312-328 that gives you how much energy requires to move it to the n=2 orbital

44 **I:** so 984

45 **S:** so it's 984

46 **I:** what does the 984 represent to you?

47 **S:** the 984 means that if you put 984 kJ into this atom, this little electron, you have the proton and you have the electron, it's in the n=1 orbital, that's going to kick it up to the n=2 orbital, so that's what that means. and then it will release light of a certain wavelength as it comes back down from the n=2 orbital to the n=1 orbital

48 **I:** 14:22 why in relation to 1312?

49 **S:** because 1312 is the IE. and once... I mean, these numbers get smaller and smaller, so you are subtracting less and less from 1312 and the IE would be minus zero, or you would need all 1312 kJ to completely ionize the electron, so you are requiring more and more energy to move it up to higher energy levels, cause it's farther away from the nucleus, and the attraction between the electron and the proton, you would have to move it farther away, it would require more energy to separate them, the PE, so

50 **I:** 15:10 How is this different from an emission spectra?

51 **S:** the two are like cutouts from each other, like if you have a spectrum, like you have gamma rays down here and radio waves here and you have the spectrum and the emission spectrum will show you the wavelengths at which light is emitted like is transmitted out. and the absorption spectrum will show you which wavelengths of light is absorbed, so for any given object the 2 should be the opposite of each other. if you have the planet Neptune, neptune is blue, it's really like deep really pretty blue, so you have a blue planet, so that means the absorption spectrum, if you have the visual spectrum you are going from 420nm to 700nm, red over here and blue over here, so it's because it's blue that means it's transmitting it's emitting blue light, so then the emission spectrum will be really high in the blue and it would be very low for red cause it's not emitting red, maybe high in the IR cause it's emitting heat but that's not what we are talking about...but if you look at the absorption spectrum it would be the opposite because it's absorbing a whole lot of red and not absorbing blue at all because blue is what is transmitted, so they are not opposite in sign they are just kinda like flip-flopped

52 **I:** 16:49 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

53 **S:** ok, you put 1512 in, the IE is 1312, so you can subtract that and you are left with 200 kJ/mol, so you take this out, that ionized the e-, the electron is in space it's free floating, and then it's got 200 kJ/mol excess energy goes into KE of the e-

54 **I:** 17:12 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

55 **S:** if it's 500 kJ, then it won't do anything, because you need 984 to kick it up to the next energy level, and you need 1312 to ionize it, so if you just put 500 kJ in, it's not enough to do anything, so nothing is going to happen

56 **I:** 17:44 how about 984?

57 **S:** If its 984 because energy is quantized in atoms you have to have this exact amount then if you put 984 kJ of energy into the atom the electron will go up to the n=2 level and it would release light of a certain wavelength that you could measure

58 **I:** 18:05 what is quantized?

59 **S:** my understanding of the word quantized, besides that it sounds fancy is that quantized means that you have to have the exact number , like you can't be close, you can't be… unless it's really the IE, cause if it's the IE you can have more, cause you'll just cut it off the top and put it into the KE of the e-

60 **S:** 19:04 the quantization energy allows you to distinguish elements by looking at their spectrums because the lines are in particular places for particular elements, because it requires a certain amount of energy, and it's unique to each element, so you are gonna get a different spectrum of lines for each element, so you can use it to identify different compounds...

Student No: 19

	Evidence	Code
Probabalist/ Determinist	orbitals are the highest probability of the place you have the highest probability of finding e- developed these pictures basically wherever the electron is, there's a dot there, it will show you the most probable places	3
Discrete/ Continuous	20:23 (984?) it would absorb from n1 to n2 (985?) it's just transmitted (so it can't go a little bit above and stay on 2) not necessarily	3
Interpreting Spectra Code	18:04 n1 to n2? 984? (calculates) I think that's right	3
Energy/Force Code	they are different energy levels, because of the attraction of the nucleus, the proton, closer to the nucleus has less energy than further from the nucleus which explains why it's easier to remove a valence shell electron than an inner shell electron cause the closer ones have a greater attraction to the middle so more energy to get it out I think it has to do with the nucleus, the protons will pull electron closer to itself if it has more mass, plus there are less electron in the atom, there will be less shielding so the overall radius will be more compact, because that's how easily the electron can move	4

Line No.		Transcript
1	**I:**	01:09 Describe how you visualize the atom
2	**S:**	apparently according to the models there are orbitals that are named 1234, and we thought there were just 2 electrons in the first 2, no sorry 2 electrons in the first one the other ones would have 8, sometimes 4 orbitals s,p,d,f, I think s stands for sigma and p stands for pi but I'm not sure of that
3	**S:**	01:50 orbitals are the highest probability of the place you have the highest probability of finding electron, for some reason, I don't think they really covered it, there are basically spheres where electron have very little probability of being there
4	**I:**	02:20 How would you describe oxygen?
5	**S:**	and then for O which has 8 electron, there's 2 in the 1s and 2 in the 2s and that's four in the 2p
6	**I:**	so where are the electrons?
7	**S:**	I'm not sure, like some of them basically took lots of pictures of finding 1 electron and developed this cloud model, developed these pictures basically wherever the electron is, there's a dot there, it will show you the most probable places
8	**I:**	03:32 can you draw the 2p orbital?
9	**S:**	within the spheres it's going around crazy,
10	**I:**	is it around the edges?
11	**S:**	I want to say it's going around in here in a path we cannot predict. 2s would defiitely be here, a sphere, bigger than the 1s, the 1s would be inside of that, with a node on the surface of the 1s, I guess maybe cause if you kinda like pushed them together, but if you moved it one atom with 1 electron-...
12	**I:**	is it overlapping?
13	**S:**	doesn't make sense if they are not overlapping so like that
14	**I:**	is it different between orbitals?

15 **S:** they are different energy levels, because of the attraction of the nucleus, the proton, closer to the nucleus has less energy than further from the nucleus which explains why it's easier to remove a valence shell electron than an inner shell electron cause the closer ones have a greater attraction to the middle so more energy to get it out

16 **I:** 06:15what is the importance of energy levels?

17 **S:** if you talk about emission and absorbance, defined, I guess that's not what we use...discrete energy, it would move the electron from one orbital to the higher orbital which would be called absorption, and in a manner of I guess we would call in nanoseconds, the electron would fall back into its original state which releases the energy that it first absorbed and this is emitted as sometimes its light, sometimes its UV, no not UV, sometimes visible, that explains why some metals glow when you heat them in a fire

18 **I:** is it any energy?

19 **S:** you can get from 1s to 3 p, but it would take, but you can't go one orbital ove, which doesn't make sense to me because how would it make sense that whole numbers , not 0.0

20 **I:** how does it make sense exact energies?

21 **S:** No, it makes sense to me why exact energies, but it seems to me we kinda got lucky it's not 273.

22 **I:** 07:59 Describe how you visualize light

23 **S:** particle model proposed by Einstein, wave model proposed by Newton, um, the particle explains why on the macro scale shadows look very distinct not with fuzziness, the wave explains why… and the particle also explains why you can't see around a corner because it doesn't bend as much as a wave does, as much as you think a wave would... a wave explains why light can be induced... electricity, magnetism can induce current...

24 **I:** 09:07 is one better?

25 **S:** no, cause they are both not complete, and one of the pictures they give us, one of the descriptions they give us is that if you have a particle model, paticles shouldn't deviate from a straight line like this but in actuality you see.. would kinda explain the waves, cause waves go like this and kinda spread out and diffuse

26 **I:** 10:00What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

27 **S:** it will ionize the atom, ionize the electron and give that electron the excess energy, energy of the light minus..

28 **I:** what do you mean ionize?

29 **S:** shoot it off. Particle model, the photon which is the particle of light hit the electron and shoot it off and then in the wave model I think electron clouds are as waves then they have certain amplitudes if the wavelength of the light matches the amplitude of the electron that will also shoot it off

30 **I:** 11:01 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

31 **S:** it depends. It could, electron sould absorb the light and the move back but it has to be at a certain level, or it just gets transmitted, it goes straight through

32 **I:** 11:23 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

33 **S:** emission. Certain wavelenths of light.. [inaudible]

34 **I:** Why are Ne and He tubes different colors?

35 **S:** 11:41 ok, so this is 1s, and this is 2s. So if electron here get a certain wavelength of light it can either go up to here, or it could go all the way up to here or further, imagine there is only 3… um and then from here, 2p, it can fall down to the 2s I guess and emit a certain wavelength of light a photon or it could fall all the way down to the next one and emit a certain wavelength of light, this is usually, or we were taught this is usually visible spectrum so you can like see it but it could be like red or green for a He atom or Ne atom. Since the distances between the shells are different for each atom, electrons will absorb different energies of light which means they will emit different energies of light

36 **I:** 12:45 why energy levels different in different atoms?

37 **S:** I think it has to do with the nucleus, the protons will pull electron closer to itself if it has more mass, plus there are less electron in the atom, there will be less shielding so the overall radius will be more compact, because that's how easily the electron can move

38 **I:** 13:10 Over time, would the tubes change color?

39 **S:** not supposed to, no. if it breaks...

40 **I:** why would it?

41 **S:** um, in theory it should go on forever if you have the electron current, but the gas could leak out

42 **I:** 14:13 Is there any amount of energy that wouldn't light the bulb?

43 **S:** if it doesn't hit a certain discrete step, yeah.

44 **I:** why discrete?

45 **S:** I don't really know, it just kinda happens

46 **I:** 16:01 Can you draw an energy level diagram of Hydrogen? hand piece of paper with table what does this tell you?

47 **S:** the energy levels.

48 **I:** and why?

49 **S:** the different shells of the H atom, and the distance between them

50 **I:** 18:04 Can you draw the absorption spectrum of Hydrogen?

51 **S:** n1 to n2? 984? [calculates] I think that's right

52 **I:** why starting at 1?

53 **S:** In theory when you get an electron to n2, and then send a photon in to get it from n2 to n3, it's really really really fast..[inaudible]

54 **I:** 16:21 How much energy is needed to ionize Hydrogen?

55 **S:** 1312 kJ/mol - because you have to.. If you get an electron to infinity which is up here, n=infinity is up here, um it takes this much energy to get to the level -1312 - [-328] and then it takes more energy to get to n=3, and more energy to get to n=4 , and it takes 1312 to get to infinity which is the IE, is exactly 1312.. but they explained it if you have over the IE, the electron is ejected and just kinda stays there with no KE, which doesn't really make sense, the electron is just there.. so I guess it's not a complete description, it's a model for it

56 **I:** 19:23 How is this different from an emission spectra?

57 **S:** emission spectra would emit from n4 to n3, n4 to n2, n4 to n1, 3 to 2, 3 to 1, 2 to 1

58 **I:** 19:46What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

59 **S:** it would eject the electron with 200 kJ/mol of KE

60 **I:** What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

61 **S:** nothing. Cause it's defined to be discrete levels of absorbing which means that because it doesn't fit any of the transitions between orbitals that it's not going to do anything it would just be transmitted

62 **I:** 20:23 how about 984?

63 **S:** it would absorb from n1 to n2

64 **I:** how about 985?
65 **S:** it's just transmitted
66 **I:** so it can't go a little bit above and stay on 2
67 **S:** not necessarily

Student No: 20

	Evidence	Code
Probabalist/ Determinist	there are certain areas within the atom that the electron can frequent more and they are found in these orbs as they are dubbed. (H) falls within the 1s orb, and since it's one it just floats around in its orbital.	**3**
Discrete/ Continuous	(if light > than IE) It depends. I struggled with this for 10 minutes on the midterm. Either, yes, it does affect the electron and pushes it up and then there is extra energy that could increase the temperature or could increase some movement around and not actually fully excite an electron or that electron into the next orbital. Or it could just pass through because it doesn't properly fit the wavelength it doesn't properly fit the electron and it doesn't hit it. On the MT, I decided 50/50! I decided specifically to put that it moves the electron there is still some left over, because I thought it made more sense. It makes sense when you are heating something, even if you don't have the right wavelength it still gets more excited still has more temp increase. instead of just passing through, it made more sense overall. If there is not enough enough energy, it just passes through and doesn't affect it. and if there is too much energy the exact same thing happens. if it's inbetween the amount of IE, the amount of energy required to move electron between orbs, then it sorta glosses over it, it still goes through there is open space, it doesn't hit electron it doesn't hit what's going on, so you only need specific amts of energy in order to move the electron into the next orbital.	**2**
Interpreting Spectra Code	**mistakes IE for absorption... 16:04 it will take 1312 kJ to get excited. Starts off at n=1 so it will go to n=2. I said that it would excite it and there will be some left over and do something, but no - if it doesn't have that right amount, especially when we are talking about wavelength, then it doens't do anything, it just passes through, the electron is there, but it doesn't hit it. (then for 1313?) it would not hit it it would not excite it.	**1**
Energy/Force Code	no that makes sense, n=1 is closer to the proton so there is more energy involved in taking away because opposites attract. That makes sense.	**4**

Line No.		Transcript
1	**I:**	01:06 Describe how you visualize the atom
2	**S:**	well when you say unit 4 I think orbitals and p-orbs and such. And so um before I'd been thinking of electrons in electron clouds just around the atom. But based on what we talked about in unit 4 there are certain areas within the atom that the electron can frequent more and they are found in these orbs as they are dubbed.
3	**I:**	how about Hydrogen?
4	**S:**	falls within the 1s orb, and since it's one it just floats around in its orbital. 1s is the lower type of orbital, say the nucleus is here, it would be the closest to the nucleus. say it's in a 2s orb or a 2p orb, which is further away
5	**I:**	02:26 How would you describe oxygen?
6	**S:**	oxygen has a different type of orbital,. It has 8 electron and so that fills p the 1s orb which can take 2 e-, 2s orb ,2e-, and the 2p orb which takes 6 e-. So it fills up all the 3 separate different orbs. No! It's doesn't fill up the 2p orb, it fills up 4 out of th 6 aailable spots, and the first 2 spots, there are 2 different electron with up and down spin, in the second 2 spots in the 2p orb, there are only one electron , both up spin.
7	**I:**	How would you compare 1s and 2s?

8 **S:** 03:49 educated guess I guess, [draws 1s/2s] I think it's more linear, 1s 2s, and then from what I sorta half remember, then the 2p orbs are in opposite direction. well they are like here.instead there are like areas within the molecule or around the molecule that the e-s inhabit, because of course there are neg charges, they are repelling each other it's not the best situation. 2s, again, I can't say specifically where it is, is one of these and so it confines itself to that, of course the electron are all spinning around, and it's trying to avoid them, so it's somewhere within that region

9 **I:** 05:48 Describe how you visualize light

10 **S:** it's a wave, I've sort of always visualized it that way since physics, which was an awful class!

11 **I:** Explain wave versus particle

12 **S:** photons hit electron and they excite the electron they push them onto higher orbital states depending on if it is the right wavelength or not

13 **I:** what's a photon?

14 **S:** it's a wave light energy. it's energy.

15 **I:** what do you mean by excite?

16 **S:** it can increase the energy of a lower electron orbitals and push electron into a higher orb.

17 **I:** Can you explain, why?

18 **S:** there's space in between the atom, there's the nucleus and there are these electron moving in certain areas, and the wave just moves in, there is space for it to move it. it sort of pushes it to the next orbital, the IE, if it has enough.

19 **I:** 08:23 what if light hits the atom with an energy equal to the IE?

20 **S:** then it pushes it up one, from the 1s level to the 2s level

21 **I:** ow is this different from ionization?

22 **S:** it's the different between one orbital level to the next orb level.

23 **I:** What happens if light hits the atom with an energy less than the IE?

24 **S:** It depends. I struggled with this for 10 minutes on the midterm. Either, yes, it does affect the electron and pushes it up and then there is extra energy that could increase the temperature or could increase some movement around and not actually fully excite an electron or that electron into the next orbital. Or it could just pass through because it doesn't properly fit the wavelength it doesn't properly fit the electron and it doesn't hit it. On the MT, I decided 50/50! I decided specifically to put that it moves the electron there is still some left over, because I thought it made more sense. It makes sense when you are heating something, even if you don't have the right wavelength it still gets more excited still has more temp increase. instead of just passing through, it made more sense overall.

25 **I:** 12:22 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

26 **S:** I thought n=1 goes at the bottom, but looking at that it seems like n=4 should be at the bottom because there is less IE, is that IE? Energy levels, there is less energy levels, because further away, no that makes sense, n=1 is closer to the proton so there is more energy involved in taking away because opposites attract. That makes sense.

27 **I:** 13:39 What does it mean by n=1234?

28 **S:** that talks specifically about the orbitals, like when you are looking at the.. if you take 3-1=2, that's, uh, what is that? it refers specifically to that energy level

29 **I:** 14:20 How much energy is needed to ionize Hydrogen?

30 **S:** to ionize it, you add all of that up, it's pretty much taking it from the ground state and bringing it past n4

31 **I:** What do you mean by ground state?

32 **S:** there is no energy hitting it, it's just stable and there and the way we think of it at most points, just as a hydrogen atom

33 **S:** 15:12 [calcs] greater than 163??

34 **I:** 16:04 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

35 **S:** it will take 1312 kJ to get excited. Starts off at n=1 so it will go to n=2. I said that it would excite it and there will be some left over and do something, but no - if it doesn't have that right amount, especially when we are talking about wavelength, then it doens't do anything, it just passes through, the electron is there, but it doesn't hit it.

36 **I:** then for 1313?

37 **S:** it would not hit it it would not excite it.

38 **I:** How would you explain orbitals to non-chemistry person?

39 **S:** there is an atom, and the atom has electron in certain areas on the atom which we call orbs, right, cool. and when energy is passing through this electron it can or cannot excite the electron it depends on how much energy is there. for different atoms, there is certain amts of energy that excite the electron into the next orb into the next area within the electron which of course makes it move faster when that happens. If there is not enough enough energy, it just passes through and doesn't affect it. and if there is too much energy the exact same thing happens. if it's inbetween the amount of IE, the amount of energy required to move electron between orbs, then it sorta glosses over it, it still goes through there is open space, it doesn't hit electron it doesn't hit what's going on, so you only need specific amts of energy in order to move the electron into the next orbital.

40 **I:** 19:16 What's the difference between absorption and emission?

41 **S:** absorption is when there is. I guess it's best to think of it in colors. So when we look at this, we see blue, but that's not the color of light that's hitting it. Every single type of light is hitting this, light is hitting this, more than blue light, and this is absorbing some of it, that means light is going through and some light that is going through is not coming out the other end., so we can say the main light that is not being absorbed is blue. [points at blue stapler] we could say that some of the light that is being absorbed is red, cause we're not seeing very many reds with that., we don't see oranges, we don't see yellows. there could be some green

42 **I:** 20:52 how about for H?

43 **S:** there is an equation, I did not memorize the equation because I knew it would be on the cheat sheet

44 **I:** 21:40 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

45 **S:** when the electron are excited to certain levels, the light that is coming out glows, it's emitting. When they are excited I guess they vibrate with a certain amount of zeal, with this amount of constant voltage, would stay constant. So they emit a certain way, that's not a good explanation!

46 **I:** 22:28 Why does it emit a certain way?

47 **S:** um, well vs. another element, they have different amts of electron. at a given voltage for each one, say that it's constant for both same number it would be different because there are different electron jumping from different orbs they are jumping around, they may be ionized. and because there are different numbers of electron initally, they aer different ionization energies of electron that are jumping. I assume that it has to do with these electron that are jumping and how many of them and what they are jumping to, vs. another element which is a completely different situation

48 **I:** 23:37 what causes the color?

49 **S:** I have a guess. i assume when it jumps to the next orb or level, it sorta leaves behind a trace, we sorta see it but we don't really see it , when we see it in the form of light, because there is energy in there and something has to happen. it gets hot and emits light

Student No: 21

	Evidence	Code
Probabalist/ Determinist	An orbital is the space where you can find the electrons (for H?) it looks like a ball. (go outside?) if it has enough energy	2
Discrete/ Continuous	12:38 (984?) goes up to n=2 (980?) don't go anywhere, basically photon passes through (990?) still photon passes through. It has to absorb discrete energy to go to other energy levels.	3
Interpreting Spectra Code	12:38 (984?) goes up to n=2 (980?) don't go anywhere, basically photon passes through (990?) still photon passes through. It has to absorb discrete energy to go to other energy levels. so this is basically that - if the photon doesn't have the energy that the atom asks for, it doesn't matter. (increase intensity at 980?) still wouldn't	3
Energy/Force Code	(why?) cause it absorbs a certain amount of energy to get to another energy level, when it comes back it goes to a more stable state and releases energy. 17:04 they have different energies, Ne because they are different. Ne is a noble gas, Neon is on a different orbital. The valence e-, so for neon we are exciting the outer shell e-, which is pretty far away from He which is a 1s orbital, the 1s electron takes more energy to excite than a Ne, it's IE goes up when you go that way	2

Line No.		Transcript
1	**I:**	00:18 Describe how you visualize the atom
2	**S:**	a ball, now we have the orbital diagram. An orbital is the space where you can find the electrons
3	**I:**	how about for H?
4	**S:**	it looks like a ball.
5	**I:**	can it go outside the ball?
6	**S:**	if it has enough energy
7	**I:**	00:50 How would you describe oxygen?
8	**S:**	so it's a 2p orbital, that woud be . It has this ball, and it has a kinda infinity sign, but it's 3D. So p-orbital, H has 4 electron in the p orbital. I don't really know how to draw that I only know the p orbital looks like this, it overlaps with the s orb. 1 s inside, 2s outside.
9	**I:**	How do they relate?
10	**S:**	2:09 when I saw in the lecture slide it looks like this with 1 and 2 and a space in between, the space between orbitals basically within this space, the electron can be anywhere, i guess it just tells us where the electron can be, they call it the probability. if like for example we learn about moleucular orb overlapping, two atoms comes together then we would have a sigma bond... 1s you are more likely to find it here, 2s you are more likely to find it here, i think they have nodes, that's the region you don't find electron
11	**I:**	04:10 Describe how you visualize light
12	**S:**	particles. I picture it more like particles because you learn about the energy that a photon can carry
13	**I:**	what do you mean by photon?
14	**S:**	light particles that carry energy. It's really hard to represent them with distinct energy levels, wave packet expression.
15	**I:**	why is it useful to think of as a wave?
16	**S:**	when 2 light waves come together they don't don't bounce off, easier to explain in a wave model. if they are particles you would expect them to hit

17 **I:** 05:06 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

18 **S:** depends on the energy of the photons you are shining on to. If there is enough energy to excite it to the next energy level, need discrete energies

19 **I:** Explain what you mean by excite.

20 **S:** for example if we have 2 levels, 1312 kJ, if you put in 1312 kJ it will go up there, but if you put 1300, you put in 1400 it wouldn't go, but here's the IE. If we put energy over the IE then it would go, anywhere over basically then it would eject the electron instead of just exciting it to the next energy level

21 **I:** can the electron be in between energy levels?

22 **S:** No.

23 **I:** What's the difference between excite and eject?

24 **S:** ejecting means the electron goes off, but exciting... there are 2 ways to make matter produce light. if you excite an electron the electron goes off and produces light, I mean if you eject the electron, the electron goes off and produces light. when you excite the electron to another energy level, when the electron comes back, it emits light

25 **I:** why?

26 **S:** cause it absorbs a certain amount of energy to get to another energy level, when it comes back it goes to a more stable state and releases energy.

27 **I:** why is a low one more stable?

28 **S:** it's where it should be
07:38 if the electron is excited from 1 to 2.

29 **I:** 08:13 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

30 **S:** then it would still go off. Extra energy goes to KE. The speed,how fast the electron moves when it is ejected from the atoms depends on the energy excess from the photon

31 **I:** how about 1350?

32 **S:** then the difference will become the KE

33 **I:** 09:37 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

34 **S:** this is zero. [draws]

35 **S:** 10:18 n= infinitiy, zero. Basically over that point, the electron would already be ejected. N= infinity basically means ionized. The atom would get a plus sign and the electron would go.

36 **I:** 10:46How much energy is needed to ionize Hydrogen?

37 **S:** 1312. the electron exist in n=1 so you can tell from the diagram n=1 to 0 you need to put in 1312 to ionize

38 **I:** 12:38 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

39 **S:** goes up to n=2

40 **I:** how about 980?

41 **S:** don't go anywhere, basically photon passes through

42 **I:** how about 990?

43 **S:** still photon passes through. It has to absorb discrete energy to go to other energy levels. They showed us the model. Computer graphic thing, shows us how the light interact, shows the photon. the photon carries energy that hits the atom and excites the electron, so that explains you have more photons, still only one photon is hitting the atom. so this is basically that - if the photon doesn't have the energy that the atom asks for, it doesn't matter.

44 **I:** what happens if you increase intensity at 980?

45 **S:** still wouldn't
46 **I:** 13:40 Can you draw the absorption spectrum of Hydrogen?
47 **S:** [calcs] 1312-328…
48 **S:** 14:23 I get confused with those, so many spectra, is it this one? Say this is 1000 here, then it would have .. 984 here, past 1312 al black, all would be absorbed
49 **I:** 15:25 How is this different from an emission spectra?
50 **S:** same thing as these, and know it can go from 3 to 2 and emits about 162… [draws arrows] n4 to n3 n4 to n2, n4 to n1, n3 to n2… 6 lines.
51 **I:** Can it emit in ground state?
52 **S:** if it's excited. You have to shine light or heat them up to get an emission spectra
53 **I:** 16:50 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?
54 **S:** because I guess it's the color that emits when it goes from a certain energy level to a different level
55 **I:** Why are Ne and He tubes different colors?
56 **S:** 17:04 they have different energies, Ne because they are different. Ne is a noble gas, Neon is on a different orbital. The valence electron, so for neon we are exciting the outer shell electron, which is pretty far away from He which is a 1s orbital, the 1s electron takes more energy to excite than a Ne, it's IE goes up when you go that way
57 **I:** 18:34 Over time, would the tubes change color?
58 **S:** probably because sometimes you put in too much energy, and basically the gas is ionized. if same energy, why not. you don't want Ionization in light then it would reduce it's life. No, I don't think so, I don't know why. if you are putting the same amount of energy it goes up and comes back. the energy matches the wavelength and that won't change
59 **I:** Is there any amount of energy that wouldn't light the bulb?
60 **S:** 19:56 too low. anything lower than 984, that's the minimum requirement of exciting an electron

Student No: 22

	Evidence	Code
Probabalist/ Determinist	02:38 um, so more like you have a nucleus and you have like rings or like a cloud of probability of electron around the thing and there's different orbitals and different probability of where the electron will be. So you have like the s-orbs and like the shape of the atom will be a determined probability of where the electron will be but it's um...	3
Discrete/ Continuous	15:37 (500) then it wouldn't be quite enough, it would be the right energy to change it from one thing to another, It just passes through, it's not able to really interact with the electron (984?) then it would move the electron from n=1 to n=2 (985?) wouldn't do anything	3
Interpreting Spectra Code	um so this is the n=1 and it takes 1312 to ionize it so from the n=1 level to take that electron right there, and then this is like the different between these 2, like the different amount of energy is like 1000, and then this is the different between these two (why are different important) um because if you, it's the different that energy that is needed to move from one energy level to the next	3
Energy/Force Code	So say in the H atom, the electron is more tightly bound because there is only one electron and one proton and so you have the electron has just enough energy to be at that like place where it is just inherently but say it absorbs a photon it gains more energy than the forces between then with the added energy it has the ability to go farther away into different orbitals 05:53 (would 1s on O have same energy as 1s on H?) I think it would be slightly different because you have different forces acting upon each of them because thy are completely different atoms 09:32 then if it's the exactly right amount it will allow the electron to overcome the forces of the orbital and go to another, but if it's not enough then it will just like not interact with the electron	4

Line No.		Transcript
1	**I:**	02:38 Describe how you visualize the atom
2	**S:**	um, so more like you have a nucleus and you have like rings or like a cloud of probability of electron around the thing and there's different orbitals and different probability of where the electron will be. So you have like the s-orbs and like the shape of the atom will be a determined probability of where the electron will be but it's um...
3	**I:**	03:22 how about 2p?
4	**S:**	[draws] so you have kinda like that, the probability of where the 6 if electron would be
5	**I:**	how about 1s in relation?
6	**S:**	it would be kinda like in the midst of it
7	**I:**	where are the electrons located?
8	**S:**	I think it's like floating like going from one little lobe to another, cause there are different forces with the electron itself and the other electron and the nucleus all pulling on it and the probability is like it's gonna be at this place
9	**I:**	04:45 can it go from 1s to 2p and back?
10	**S:**	no because it's costs more energy. cause if it has more energy then it can go to the higher energy levels and more probability of being over there and if it doesn't have as much energy it's restricted to the energy level or area that it's normally at
11	**I:**	05:05 why is energy important?

12 **S:** because if it doesn't have enough energy, then the electron won't have enough energy to get away far away the nucleus. So say in the H atom, the electron is more tightly bound because there is only one electron and one proton and so you have the electron has just enough energy to be at that like place where it is just inherently but say it absorbs a photon it gains more energy than the forces between then with the added energy it has the ability to go farther away into different orbitals

13 **I:** 05:53 Would the 1s orbital on Oxygen havethe same energy as 1s on Hydrogen?

14 **S:** I think it would be slightly different because you have different forces acting upon each of them because thy are completely different atoms

15 **I:** can they be at any energy?

16 **S:** No, cause you have to have like, to be in the certain areas you have to have just the right energy to keep it in place. cause if you don't have enough it will be at a lower energy because that's what it can sustain itself at, but if you have like just the right energy, it will go to a different energy level however if it has too much energy then that will be like stable enough to like bump it up to the next one

17 **I:** 06:45 Describe how you visualize light

18 **S:** um it's like a wave of different particles, of photons. Um it's like just a constant stream almost. Particle in like each ittle piece of light has energy of it's own like entity, and like one particle could be absorbed while another particle maybe couldn't or interacts with one thing while another one would interact with something else. But then if you had a wave, it's like an entire string of particles so say like a normal wave holds a string of particles together. It's two ways to think about it

19 **I:** 08:03 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

20 **S:** um so then it has enough energy so that the electron is completely freed from the forces of the atom, so if it's just the right IE, like if it just has the energy to leave the atom it kinda hangs there. But if you have the extra energy it goes to giving the electron KE

21 **S:** 08:48 since the photon is massless then it can absorb it without affecting it's mass so it will take it in as energy and make it a part of itself and be able to use that energy to leave the atom and then it might emit off extra energy as photons of light. I feel like there is a lot of photons coming in but each electron only has the ability to absorb one at a time, interact with them one at a time

22 **I:** 09:32What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

23 **S:** then if it's the exactly right amount it will allow the electron to overcome the forces of the orbital and go to another, but if it's not enough then it will just like not interact with the electron

24 **I:** 09:55 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

25 **S:** um it's when the electric current give each electron more energy so then since they, provided that it's to the right energy levels, then the electron go up a certain energy level and then like after a millisecond or nanosecond or something then like emit a photon and then cascade down to another energy level, so then the light that's coming from it is the certain wavelength of photon

26 **I:** 10:32 Why are Ne and He tubes different colors?

27 **S:** cause each orbital has a different energy associated with it for each atom, so then it would be emitting different photons for each one

28 **I:** Over time, would the tubes change color

29 **S:** no, cause every same Ne atom is essentially the same, you might have some weird thing out there, but essentially it's a Ne atom, you have the proton, etc, so it's all gonna be essentially the same for every Ne atom in the history of the universe

30 **I:** 11:17 Is there any amount of energy that wouldn’t light the bulb?
31 **S:** if it's not quite enough or if it's at the wrong... it's not enough to ionize it or it's not enough to send it up to another energy level
32 **I:** 12:02 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
33 **S:** like a line or chart or picture of H atom?
34 **I:** Chart or energy level diagram
35 **S:** um so this is the n=1 and it takes 1312 to ionize it so from the n=1 level to take that electron right there, and then this is like the different between these 2, like the different amount of energy is like 1000, and then this is the different between these two
36 **I:** why are differences important?
37 **S:** um because if you, it's the different that energy that is needed to move from one energy level to the next
38 **I:** 13:40 How much energy is needed to ionize Hydrogen?
39 **S:** 1312 kJ
40 **I:** 13:55 Can you draw the absorption spectrum of Hydrogen?
41 **S:** either you have 1312 which will ionize it or you will have 98.. Or the different between these two or 1 to 3 or 1 to 4, but normally unless you are rapidly absorbing multiple photons it's normally gonna go from one levels to another levels. However it could go from like n=2 to n=3 if it has just absorbed a photon and then immediately before it has a chance to emit that photon and cascade down
42 **I:** 14:45 is this the same as emission spectra?
43 **S:** no. cause the absorption spectra is what wavelengths are absorbed from the light that's coming in. but the emission spectra is if you have just if you are looking at the light, the photons emitted from each energy level.
44 **I:** 15:08 what are possible emission lines?
45 **S:** practically anything. from like n=4 to n=3 32 21 32 41 42 or anything
46 **I:** 15:25 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
47 **S:** um then it would ionize the atom and give it extra KE after it leaves
48 **I:** 15:37 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?
49 **S:** then it wouldn't be quite enough, it would be the right energy to change it from one thing to another, It just passes through, it's not able to really interact with the electron
50 **I:** 984?
51 **S:** then it would move the electron from n=1 to n=2
52 **I:** 985?
53 **S:** wouldn't do anything

Student No: 24

	Evidence	Code
Probabalist/ Determinist	00:44 um well basically there is a nucleus with protons and neutrons in it and there is electron just like whizzing around them and basically the subshells are kinda just general areas where you can find the electron it's not necessarily in like a perfect sphere	3
Discrete/ Continuous	13:30 (985) then it wouldn't be able to go to the next subshell because it's not the correct energy (why not a little bit more?) because then it wouldn't be in an orbital I guess	3
Interpreting Spectra Code	10:55 well I guess I would need to know what wavelength is corresponding to 1312 kJ/mol. If I know what wavelength is 1312 kJ/mol then that's what would absorbed and everything else would be emitted. (possible jumps an electron can make?) it can go from n1 to n2; n1 to n3; n1 to n4 or it can ionize	3
Energy/Force Code	02:22 (how does energy play into this?) well, each orbital has a certain energy associated with it so if you add more energy it can go to higher and higher level orbitals like s-orb is the lowest energy and then there is p and then d and f. 05:45 um the energy is turned into speed so it determines how fast the electron goes 06:30 when you put energy into an electron like Ne or He then it has enough energy to cause an electron to go to a different orb and then once it goes back to its low energy state it emits a photon particle	2

Line No.		Transcript
1	**I:**	00:44 Describe how you visualize the atom
2	**S:**	um well basically there is a nucleus with protons and neutrons in it and there is electron just like whizzing around them and basically the subshells are kinda just general areas where you can find the electron it's not necessarily in like a perfect sphere
3	**I:**	01:15 can you draw the 2p?
4	**S:**	the nucleus and the 2p orb is just like that that. so basically the electron... this is the probability around where you can find most
5	**I:**	how about 1s?
6	**S:**	the 1s, well if you are looking at the hybrid orbital, basically it's in this general area
7	**I:**	01:54 what is the electron doing?
8	**S:**	well this is just the general area where you can find it. it can jump to different orbitals if you add energy and stuff like that.
9	**I:**	02:22 how does energy play into this?
10	**S:**	well, each orbital has a certain energy associated with it so if you add more energy it can go to higher and higher level orbitals like s-orb is the lowest energy and then there is p and then d and f. they're named just to have a way to reference them. but the s's are shaped around the nucleus in like a like it goes around it and then the p is shaped like that and then the d is like another shape, a dumbell thing
11	**I:**	why are there set energy levels?
12	**S:**	well the ideal is to be at low energy which makes it stable so each energy level is just a ref point again to show what kind of energy the atom has, so if it's at a s level its at lower energy, more stability
13	**I:**	would Oxygen and Nitrogen have same energy for 1s orbital?
14	**S:**	I guess so, yes, if you're just looking at the s-orb

15 **I:** Is there a set energy for 1s?

16 **S:** yeah.

17 **I:** 04:20 Describe how you visualize light

18 **S:** so light it's.. I don't really know what it looks like but it acts like a particle and it acts like a wave so when you are looking at its behavior and the way it interacts with atoms and just substances you look at it like a wave or a particle

19 **S:** 04:50 well the wave particle helps you see how light interacts when it's going through substances or I remember during lecture they had the hole when you're looking up if there's a hole in the ceiling then ilght comes through , it doesn't just go straight through it kinda disperses because of the wave and for the particle it helps with when you are looking at how light interacts with an electron if it like if you are shining light sometimes it gives energy to make the electron go up and down like a particle like you can ionize the electron

20 **I:** 05:45What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

21 **S:** um the energy is turned into speed so it determines how fast the electron goes

22 **I:** 05:59What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

23 **S:** if it's less then it just stays there. Well it I guess it can have it jump to a different orb if another orb is open but if it's not enough energy then it just goes through the atom

24 **I:** 06:30 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

25 **S:** when you put energy into an electron like Ne or He then it has enough energy to cause an electron to go to a different orb and then once it goes back to its low energy state it emits a photon particle

26 **I:** Why are Ne and He tubes different colors?

27 **S:** the electron that's going to a different orbital is at a different energy, like He is going from an s shell to p, and Neon is p to d I think so there is different energy associated with different orbs, so when it jumps back it emits a different wavelength

28 **I:** what if it was 1s to 2s for both He and Ne, would it be the same color?

29 **S:** I think so but I'm not sure, if you are looking at just one.. I think that if the other orbs are full I don't know how you would be able to jump from 1s to 2

30 **I:** 08:27 Over time, would the tubes change color?

31 **S:** I don't think so, because after you put the energy through, the electron jumps back to where it used to be so every time the current goes through it would just go back to the same

32 **I:** 08:46 Is there any amount of energy that wouldn't light the bulb?

33 **S:** if it's not enough energy to get it to the orbor if it's too much then it would ionize the electron

34 **I:** 10:14 Can you draw an energy level diagram of Hydrogen? hand piece of paper with table

35 **S:** each energy level that's how much energy it would take to ionize an electron.

36 **S:** 10:29 to ionize the , if there's only one in the n1 it would take 1312 kJ/mol

37 **I:** 10:55 Can you draw the absorption spectrum of Hydrogen?

38 **S:** well I guess I would need to know what wavelength is corresponding to 1312 kJ/mol. If I know what wavelength is 1312 kJ/mol then that's what would absorbed and everything else would be emitted.

39 **I:** what are the possible jumps an electron can make?

40 **S:** it can go from n1 to n2; n1 to n3; n1 to n4 or it can ionize

41 **I:** why not 2 to 3?

42 **S:** cause there is no electron in the n=2 shell.

43 **I:** 12:07 if went from 1 to 4, then what are possible emissions?

44 **S:** then it go from 4 to 3 to 2 to 1. or 4 to 2 to 1, like any combination.

45 **I:** 12:22 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

46 **S:** then the electron is ionized

47 **I:** 12:31 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

48 **S:** then it would… well it's not enough energy to get it to a subshell so I think that it.. Well it doesn't do nothing but I think that it, hum I'm not really sure

49 **I:** can it move to between n=1 and n=2?

50 **S:** no. so it has to have the exact energy.

51 **I:** 13:30 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

52 **S:** then it goes to the 2nd subshell

53 **I:** how about 985?

54 **S:** then it wouldn't be able to go to the next subshell because it's not the correct energy

55 **I:** why not a little bit more?

56 **S:** because then it wouldn't be in an orbital I guess

Student No: 25

	Evidence	Code
Probabalist/ Determinist	00:57 for H, it's in the s orbital (what does it look like?) I'm not completely sure *but the shell is like these invisible rings around the nucleus and only so many electron can exist in each shell	1
Discrete/ Continuous	15:49 (would it absorb anything less than 1312?) it would move, vibrate, but it wouldn't eject... It would hit the atom, the electron would move around more but it wouldn't actually leave. (what happens when it gets excited?) I don't know exactly... 19:09 it would move from here to here 16:16 (985?) it would move still to the second one	1
Interpreting Spectra Code	(struggled a lot)	1
Energy/Force Code	09:44 the light moves it cause the energy is transferred and so it affects the atom giving off light and electron are ejected	2

Line No.		**Transcript**
1	**I:**	00:20 Describe how you visualize the atom
2	**S:**	a H atom has one electron and its in an orbital, so first we looked at shells and now it's in like the different compond kinda, and since it only has one electron it's in the first orbital 00:57 for H, it's in the s orbital
3	**I:**	So, what does it look like?
4	**S:**	I'm not completely sure
5	**I:**	01:13 How would you describe oxygen?
6	**S:**	it has 6 valence electron, and with the orbitals, I don't really understand like how to, when you're given an atom, how to… I remember going it over vaguely in lecture, the table how it's configured and then I really didn't have a good understanding of it so I went back to the textbook and I couldn't really find anything on it..
7	**S:**	02:29 I don't really understand how to follow it, cause the segment on the fall left are the s's on the far right are the d... the electrons are filling orbitals as they go up C maybe 1s11s2and then...
8	**I:**	05:28 how is 2s different from 1s?
9	**S:**	the first orbital only holds 2 electron, 2s2 can only fill 2 electrons
10	**I:**	06:13 what is an orbital?
11	**S:**	I think I'm confusing orbitals with shells, and I don't understand really how the electrons are counted because it's related to energies rather than how many in each shell
12	**I:**	06:27 what is a shell?
13	**S:**	I'm not completely sure, the chemistry foundation that I have is really basic so I don't really know about orbitals, but the shell is like these invisible rings around the nucleus and only so many electron can exist in each shell
14	**I:**	07:39 Describe how you visualize light
15	**S:**	at first when we learned about absorbance and transmission that was a little more about how I thought about light.
16	**I:**	What's the difference between absorption and transmission?
17	**S:**	how waves are perceived and determined by their wavelength and filters
18	**I:**	how about absorbance?

19 **S:** Absorbance is like there is an object and when you hit it with light, it's the light you don't see because it's absorbed, and whatver is reflected or transmitted is what you do
20 **I:** 08:40 how about wave and particle nature of light?
21 **S:** I don't really know the difference.. particles is less like one thing, waves are more continuous particles are more kinda like if it hits something it can go everywhere , where the wave would be one line.
22 **I:** can you describe it?
23 **S:** a photon is a little packet of energy and when I think of it I mostly think of photosynthesis
24 **I:** 09:44 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
25 **S:** the light moves it cause the energy is transferred and so it affects the atom giving off light and electron are ejected
26 **I:** 10:33 how about more than IE?
27 **S:** first it has to reach the IE and after that that's when the electron can be ejected and then the rest of it is converted to KE
28 **I:** what does that mean?
29 **S:** I'm not completely sure,
30 **I:** what is KE?
31 **S:** KE is energy to move things.
32 **I:** can you guess what it means that it is converted to KE?
33 **S:** the electron or the whole atom? the one that's ejected? moves more?
34 **I:** 11:37 Here is a table with the first 4 energy levels of hydrogen. Take a look - what do you think n=1,2,3,4 means?
35 **S:** these are the shells and like the ones closest to the nucleus and they go out
36 **I:** can you draw an energy level diagram?
37 **S:** not really
38 **I:** where would the lowest energy be?
39 **S:** the lowest energy is n4
40 **I:** can you draw me a horizintal line with n4? now draw n3 - is it above or below?
41 **S:** below
42 **S:** because it's neg, a larger neg number, like y-axis
43 **I:** how about the others?
44 **S:** yeah, put the other 2, like y-axis
45 **I:** 14:28 How much energy is needed to ionize Hydrogen?
46 **S:** 1312 kJ, is it negative -1312?
47 **I:** yes, you put in positive energy to ionize
48 **S:** so the ionization energy is 1312, that's how much it takes, so one electron is removed.
49 **I:** how about 1512?
50 **S:** it would be ejected and would have KE
51 **I:** 15:49 would it absorb anything less than 1312?
52 **S:** it would move, vibrate, but it wouldn't eject... It would hit the atom, the electron would move around more but it wouldn't actually leave.
53 **I:** what happens when it gets excited?
54 **S:** I don't know exactly...
55 **I:** 16:35 how come 4 levels in H?
56 **S:** I think these wouldn't be in the H atom, like these, an atom had 4 shells it would have the valence electron would be in the 4th shell, not in Hydrogen.
57 **I:** 17:10 Can you draw the absorption spectrum of Hydrogen?

58 **S:** absorption is when I feel like, when light goes in, but doesn't go out physically. Emission is when the light goes out

59 **I:** what causes light to come out?

60 **S:** in lecture we were talking about how they move from one shell to another, when photons aof light are emitted when they jump back.

61 **I:** 18:36 how much energy does it take to move from 1 to 2?

62 **S:** it takes the difference?

63 **S:** [calculates]

64 **S:** is it 984?

65 **I:** 19:09 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

66 **S:** it would move from here to here

67 **I:** 16:16 985?

68 **S:** it would move still to the second one

69 **I:** 19:32 983?

70 **S:** I don't think it would go because it's not enough, the light is not absorbed

71 **I:** 20:00 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

72 **S:** I don't know. I know Ne has a full valence. The current could be exciting electron?

Student No: 27

	Evidence	Code
Probabalist/ Determinist	I guess they move around a lot but I guess if you think if you account for where each electron was over a long period of time then most of the time they will be within those shapes, I think it's like 90% of the time	3
Discrete/ Continuous	16:08 (500?) well, I don't think it would actually do anything cause it doesn't correspond to a difference... then it would be able to, like move between n1 to n2, (a little more?) if it's between 1 and 3, it wouldn't do anything either it has to be exact	3
Interpreting Spectra Code	16:08 (500?) well, I don't think it would actually do anything cause it doesn't correspond to a difference (corspond to a difff?) then it would be able to, like move between n1 to n2, (a little more?) if it's between 1 and 3, it wouldn't do anything either it has to be exact	3
Energy/Force Code	cause I think it's cause when it's closer to the nucleus it's a lower orbital it's PE is lower and then it goes to a higher orbital so given the PE you will have to add in energy (why?) um I'm not completely sure but I think it's because once you add more electron and more protons, the electronegativity of the nucleus increases , so the electron feel a harder pull to the nucleus which would change the energies	4

Line No.		Transcript
1	**I:**	00:55 Describe how you visualize the atom
2	**S:**	um well I guess the last unit I guess there is like I kinda think of different ways to visualize it depending on what I'm trying to figure out about it. Usually I visualize it more like the Lewis Dot Structure, but then if it's a question about like light emission and stuff then it's more like the model where there is, I guess the Bohr model with different orbitals and electron kinda fall back and forth and then also if I think about the orbitals specifically then there is different shapes
3	**I:**	what are these orbitals or shapes?
4	**S:**	I guess it's where the electron usually end up being , for like the H there is like the 1s orbital, a spherical orbital, 2s there is like a bigger orbital and then there is different shapes to p's and d's
5	**I:**	what are the electrons doing?
6	**S:**	I guess they move around a lot but I guess if you think if you account for where each electron was over a long period of time then most of the time they will be within those shapes, I think it's like 90% of the time
7	**I:**	do they stay in their shapes?
8	**S:**	I guess when it gets enough energy through light or something it can jump up to a higher energy orbital but then it will come down
9	**I:**	why does it need energy to jump to different orbitals?
10	**S:**	cause I think it's cause when it's closer to the nucleus it's a lower orbital it's PE is lower and then it goes to a higher orbital so given the PE you will have to add in energy
11	**I:**	03:45 Describe how you visualize light
12	**S:**	ok, I guess um two main ways would be like a group of photons moving , and like depending…[inaudible] but then also like a wave, so I guess depending on the question you would use one of those. I guess they kinda show you like… I guess none of them are exactly what , none of them are complete but together they give you the properties of light, the observed

13 **I:** 04:55 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

14 **S:** um, so the light has energy, so it wouldn't be enough to ionize the atom, so it would get transmitted , the light passes through

15 **I:** 05:22 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

16 **S:** then it would be absorbed and it would ionize the electron

17 **I:** 05:38 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

18 **S:** so I guess electric current is the energy that is kinda like provides the atoms with energy so that their electron can move to a higher orbital and then as those electron come down from a higher orbital they will emit the light , the light that you see

19 **I:** 06:18 Why are Ne and He tubes different colors?

20 **S:** it's cause they have different like the energy levels are different with Ne and He so the gap the different between the 2 energies is also different so when the light comes down they move from one to the other so the light being transmitted will be different , different wavlngth so our eyes will see diff.

21 **I:** why?

22 **S:** um I'm not completely sure but I think it's because once you add more electron and more protons, the electronegativity of the nucleus increases , so the electron feel a harder pull to the nucleus which would change the energies

23 **I:** for every Ne atom, are the levels the same?

24 **S:** I guess if it's in the ground state, they should be the same

25 **I:** 07:37 Over time, would the tubes change color?

26 **S:** so if you have the exact same current going through? um, I don't think so.

27 **I:** can you change the colors of the tubes?

28 **S:** um, well I guess if you had a different energy current, I'm not sure but you might be able to move the electron to an even higher energy level, which would cause the drop to be different

29 **I:** can they be ionized?

30 **S:** not sure?

31 **I:** 08:58 Is there any amount of energy that wouldn't light the bulb?

32 **S:** um, I guess if it's less than the IE, it wouldn't light the bulb. um, because if it is less than the IE, nothing will happen to the atom, there's not enough to move the electron so it wouldn't be any emission of light.

33 **I:** what is the ionization energy?

34 **S:** the least amount of energy needed to eject the electron. so I guess the outermost electron would have the , they would be easiest to remove. so if there's not enough energy to remove those, there wouldn't be enough. One of the electron in the outer core will drop back to a lower energy state

35 **I:** 12:39 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

36 **S:** so the different energy levels in H are spaced out like this so the first level is 1312 kJ/mol which is negative to negative so its way below zero and as the energy level moves up the PE increases towards zero

37 **I:** 13:15 How much energy is needed to ionize Hydrogen?

38 **S:** if it's H in it's ground state then that much, 1312.

39 **I:** 13:54 Can you draw the absorption spectrum of Hydrogen?

40 **S:** absorption spectra… absorption would be from here to here 1 to 2 or 1 to 3 or 1 to 4 and the difference would be of those lines

41 **I:** how about from 2 to 3?
42 **S:** I don't think so?
43 **I:** 15:10 How is this different from an emission spectra?
44 **S:** um, so emission is when it falls down 4 to 1 or 3 to 1, but then I think for emission spectra you can go from 4 to 2 or 3 to 1, don't have to go all the way to one
45 **I:** 15:40 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
46 **S:** um, it would ionize it so the electron would be off
47 **I:** 16:08 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

48 **S:** well, I don't think it would actually do anything cause it doesn't correspond to a difference
49 **I:** what do you mean correspond to a difference?
50 **S:** then it would be able to, like move between n1 to n2,
51 **I:** how about a little more?
52 **S:** if it's between 1 and 3, it wouldn't do anything either it has to be exact

Student No: 29

	Evidence	Code
Probabalist/ Determinist	atom there is electron moving incredibly quicly but they don't move in like a circular motion they move well it depends sometimes they do move in circular motion but more of it's like since the electron is so small it's really hard to tell where it is so basically you use a probability to say 'ok these electron are proabably going to be here' so it's kinda like a cloud around it and then there's areas within that cloud where you are gonna have electron or very likely to find electron and there's areas in that cloud where you're not going to find electron	3
Discrete/ Continuous	no, they have to be, energy is like quantized so it has to be at specific levels, so they have to be at certain levels, but basically they have to be in that shell, they can't just be floating around, so they have to be at a specific energy level (985?) no, it wouldn't absorb it (why not?) it's at the wrong level and so the electron is just going to transmit it , because it's too much energy it's more than the n=2 level so it has to remain at one of these levels and energy has to be quantized	3
Interpreting Spectra Code	14:53 that's the horizontal one, right? (draws) 1312-328 = 984; 1312-146 = 66, 1312 - 82 = 1230 328 -146 (so what are those telling you?) Do you put in 328-146, I don't know… I don't think so. Those are telling you, 1312 is like the baseline. (what are these telling you?) the energy that would be absorbed at different transitions. i think basically this tells you yeah to move from yea to move from the n=1 shell to the n=2 shell it takes 984 kJ/mol.	3
Energy/Force Code	04:15 (different energies?) yeah, the levels closer to the atom definitely have higher energies and as you get further out.. I mean they have energies in that it takes energy to remove them and it also takes energy to say move something from the 1s to the 2s or the 2p or something it takes energy to transfer electron between orbitals in order for the charge from the proton the force from the proton is gonna have to travel a further distance through more electron to reach the outside electron so it's gonna have a weaker attractiveness or detractiveness to... bond with nucleus The electron is entirely not affected by the proton anymore, the nucleus anymore well, i think it depends on how many protons there are because protons are going to have a different pull towards it so that will affect the energy required to but if they are at the same 1s level and the same # of protons are the same I think it would be the same color	4

Line No. **Transcript**

1 **I:** 00:44 Describe how you visualize the atom

2 **S:** well H I view as there's gonna be a proton, a nucleus at the very center with a single proton and there's going to be an area of higher mass because a proton is basically the biggest part of the atom along with the neutrons but there's no neutrons in H.. anyway it's a very high density part of the atom and then around the atom there is electron moving incredibly quicly but they don't move in like a circular motion they move well it depends sometimes they do move in circular motion but more of it's like since the electron is so small it's really hard to tell where it is so basically you use a probability to say 'ok these electron are proabably going to be here' so it's kinda like a cloud around it and then there's areas within that cloud where you are gonna have electron or very likely to find electron and there's areas in that cloud where you're not going to find electron

3 **I:** 02:00 What do the clouds look like for Oxygen?

4 **S:** well, oxygen has 6 valence electron, right, so it's gonna have 4 electron in the p orbital so the s orbs , the cloud of the s looks kinda like a sphere for the 1s , and then for the 2s it just looks like a bigger sphere and then then there is a sphere inside that other sphere for the 2s and then for the 2p since O has 6 4 valence in the 2p then it's kinda in a dumbell shape cloud on top of it and

5 **I:** Can you draw the 2porbital? how does it fit in with the 1s?

6 **S:** Yeah, I've actually asked other people about this question because I was kinda confused by it, but I believe is that the 2s is in the center and overlap at the nucleus, so my thinking is that the nucleus is gonna be at the center of that so then in order for them to be centered around the nucleus they have to be centered like that. I think that's right

7 **I:** 03:46 so what is the difference here, if it's farther away?

8 **S:** yeah, sure, so if it's farther away there's more probability that it's gonna be deflected by other electron in between... in order for the charge from the proton the force from the proton is gonna have to travel a further distance through more electron to reach the outside electron so it's gonna have a weaker attractiveness or detractiveness to... bond with nucleus

9 **I:** 04:15 how about different energies?

10 **S:** yeah, the levels closer to the atom definitely have higher energies and as you get further out.. I mean they have energies in that it takes energy to remove them and it also takes energy to say move something from the 1s to the 2s or the 2p or something it takes energy to transfer electron between orbitals

11 **I:** 04:51 The electron in the 2p orbital - what is it doing?

12 **S:** well it's like a cloud, basically like an area where the electron could be in at any time so it's just moving really fast in there

13 **I:** how about outside the cloud?

14 **S:** maybe if it does it has a low probability, the highest probability is in the cloud

15 **I:** do electrons in different levels have different energies?

16 **S:** yes, I guess depending on the distance from the nucleus and yeah I think the distance from the nucleus is the biggest source of difference in energy levels

17 **I:** can it be any energy?

18 **S:** no, they have to be, energy is like quantized so it has to be at specific levels, so they have to be at certain levels, but basically they have to be in that shell, they can't just be floating around, so they have to be at a specific energy level

19 **S:** 06:32 yeah, my ideas about 'quantized' is just basically energy is only… has certain values that it can attain, so like for example, energy can be "1" or it can be "2", but it can't be like "1.5" I mean obviously it's not correct, I'm just saying like for this situation, it has to be at this level or it can't be released or it can't be absorbed or anything like that it just has to be in these like sections

20 **I:** 07:09 Describe how you visualize light

21 **S:** yeah, um, so I mean it is there's EM nature to it and it's two waves that are interacting with each other , it's EM and then um yeah it's these two waves that are at 90 deg to each other that can travel through a vacuum, but then it acts like a particle sometimes when it comes into contact with matter or when it interacts with matter. there's not like any model that really explains how it is, how it can be both particle and a wave , but it exhibits characteristics of both, it's like energy. where it also has mass to it

22 **I:** 08:18 is one model better than the other?

23 **S:** I think the EM model applies more, but I don't know I think you have to have both models to fully understand it

24 **I:** 08:32 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

25 **S:** um, when it's bigger than the IE, the electron is thrown free of the atom itself and so it basically breaks, I mean it's not in any of its quantized levels, it's above all those levels, so the energy.. The electron is just thrown off of the.. The electron is entirely not affected by the proton anymore, the nucleus anymore

26 **I:** does the light zoom in?

27 **S:** the energy? no it has to collide with the electron to like send it off of the atom

28 **I:** 09:30 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

29 **S:** if it's less than the IE, if it's in one of the energy levels that would move the electron up to different n level, 1,2,3,4,5, basically an electron level in the atom, then it would be absorbed, and if it's not it's just it passes right through, and is not absorbed, it's transmitted

30 **I:** What does that mean?

31 **S:** basically the electron catches it and then sends it right along, it just goes away

32 **I:** why? can't it grab one, then wait for another one...

33 **S:** it just.. i just don't understand, when you get to this level quantum chemistry doesn't really make logical sense, I don't know why it does that , I'm confused

34 **I:** 10:53 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

35 **S:** well the electricity has to be at a specific level or energy to ionize the electron and basically you move it up to a different subshell, and that's not stable , so once the electron stops or once the energy is passed on , the electron falls back down and releases that energy as a photon, light of a specific frequency , and depending on what the molecule is and which level it's at, then that transition is going to send off a photon of different wavelength

36 **I:** What do you mean by passes on? transmitted?

37 **S:** no, sorry the energy is absorbed by the electron it jumps up to a different level because overall energy has to be conserved and as it falls back down the energy.. I mean the energy is conserved because as the electron moves up the electron is in a higher energy level, but then as it falls back down it has to release the energy, basically the same energy goes in as goes out

38 **I:** 12:12 Why are Ne and He tubes different colors?

39 **S:** I think the main thing is that it's the different valence electron because they're the ones that are most likely to be ionized so because they are at different levels, He Ne, the electron n He are much closer to the center of the nucleus so as they jump off it's going to take a different energy to excite them and as they fall back down that different energy is going to emit a different color.. I don't know I was just thinking, I wonder if He+ releases the same color as H?

40 **I:** is every 1s to 2s transition the same color? is the 2s of every atom the same energy?

41 **S:** well, i think it depends on how many protons there are because protons are going to have a different pull towards it so that will affect the energy required to but if they are at the same 1s level and the same # of protons are the same I think it would be the same color

42 **I:** so He and Ne have different # of protons so would it be different?

43 **S:** yeah, 1s levels of He? yeah yeah

44 **I:** 13:42 Over time, would the tubes change color?

45 **S:** I think that assuming you don't have any incredible highly charged particles that are knocking electron off the atom fully, I don't think it would change color cause they can just continually go back and fall down until

46 **I:** like forever?

47 **S:** yeah, I think..

48 **I:** 14:13 Is there any amount of energy that wouldn't light the bulb?

49 **S:** yeah, if the energy level is not within those packets within those set energy levels, say electron will jump from n=1 to n=2 or n=1 to 3 or something like that , any of those possibiliites, then it's not going to do it

50 **I:** 14:53 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

51 **S:** that's the horizontal one, right? [draws] 1312-328 = 984; 1312-146 = 66, 1312 -82 = 1230 328 -146

52 **I:** so what are those telling you?

53 **S:** Do you put in 328-146, I don't know… I don't think so. Those are telling you, 1312 is like the baseline.

54 **I:** what are these telling you?

55 **S:** the energy that would be absorbed at different transitions. i think basically this tells you yeah to move from yea to move from the n=1 shell to the n=2 shell it takes 984 kJ/mol.

56 **I:** 17:38 How much energy is needed to ionize Hydrogen?

57 **S:** um more than, 1312 or more, well I think 1313, well if it's in an exact level, I don't think it's ejected , is it? Wow. Yeah it just falls back down to its exact level, but yeah 1312

58 **I:** 18:07 How is this different from an emission spectra?

59 **S:** An emission spectra is going to have more lines because it's going to have, it has more possibiliites , so it can fall from say 4 to 3, that's gonna release different energies and then from y'know 4 to 2 4 to 1 3 to 2, 3 to 1

60 **I:** would it still have all of these?

61 **S:** yeah, i think it would have all of these, yeah. It should have all of those plus a few more

62 **I:** 18:33 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

63 **S:** 1512? The electron is ionized

64 **I:** What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

65 **S:** well it depends, if the energy..500..it's probably not gonna be, yeah it's not absorbed, because there is no level between the two that's 500

66 **I:** 18:54 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

67 **S:** yeah, it's gonna be absorbed

68 **I:** what would happen then?

69 **S:** it's.. Well if there are electron in the n=1 level, then they'll be bumped up to the n=2 level

70 **I:** how about 985?

71 **S:** no, it wouldn't absorb it

72 **I:** why not?

73 **S:** it's at the wrong level and so the electron is just going to transmit it , because it's too much energy it's more than the n=2 level so it has to remain at one of these levels and energy has to be quantized

Student No: 30

	Evidence	Code
Probabalist/ Determinist	01:34 (orbital v e-cloud?) An orbital it's more in shells or layers, and the cloud it's more free circling, and then the way we see it, we don't really see it layered in orbtals, but we see it like more of a cloud	3
Discrete/ Continuous	but to excite it you need exactly the amount to get it to different shells, I think it's like 9000 something to get it to the second one, but if you have not exactly that, the light will just pass through, transmit 09:16 (980?) well it doesn't have enough so the light will just transmit. Like all energy is conserved, the Hydrogen doesn't absorb that energy, so the light just passes through 09:33 (990?) same thing, it has to be exactly the amount to get it to n=2, so same case it would just transmit the light (why not n=2?) Um, well as far as I learned, it just has to be exactly n=2. the concept was easy, but the theory i really didnt understand	3
Interpreting Spectra Code	06:44 (draws) so Its n=1, n=2, n=3. n=4, n= infintity, this is -1312, this is -328, so this will be 984, 146, 182… and then this is 82	3
Energy/Force Code	05:15when you excite it it goes to a higher shell and it becomes really unstable so when it comes back down it will emit light. (describe for H 1s to 2s) well you don't really see it pass through here, it will go from here to here, but when it comes back here it will emit light. (why release light?) cause it's releasing photons, not too sure The core electron are empty, so it's just a valence electron and the protons are trying to pull it back	3

Line No.		Transcript
1	**I:**	00:25Describe how you visualize the atom
2	**S:**	I still see like the nucleus and the little cloud of electrons around it, and then from the fourth unit the whole orbital thing, I mean I feel like that's such at a small level you don't really account for it, and the way that the electron jumps between shells, it's not like a way you can physically diagram, or so I still see it as an electron cloud
3	**I:**	What's an orbital?
4	**S:**	00:54 An orbital is like a grouping of electrons, a pairing, and each energy shell has x number of orbitals, and that determines the shape and some of the behavior properties of the atom.
5	**I:**	01:15 how about for H?
6	**S:**	1s orbital, the 1 comes from the shell number, and then it's an s orbital, which is like the first 2 electrons. It's spherical and it doesn't really have any nodes, yeah no nodes
7	**I:**	01:34 What an orbital vs an electron-cloud?
8	**S:**	An orbital it's more in shells or layers, and the cloud it's more free circling, and then the way we see it, we don't really see it layered in orbitals, but we see it like more of a cloud
9	**I:**	02:00 How would you describe oxygen?
10	**S:**	Oxygen has 6, 1s22s22p4 [draws] the 1s is like that, the 2s it has a spherical node, so it's like that, there is no electron density in the white space
11	**I:**	does the 2s go inner to the white space?
12	**S:**	No it's outside. The 2p is dumbell shaped, so it's like that. anywhere within here a chance you'll find it

13 **I:** can it move from one side to another in the 2p?
14 **S:** yeah.
15 **I:** 03:17 Describe how you visualize light
16 **S:** the way they described it with the photoelectric effect is that it's energy and it's particles, photon particles. Packets of light energy, and the way we observed it, light is used to excite electron by using it's photon packets, and the strength of the light, the intensity doesn't really matter, its more on the Wavelength of light to eject electrons.
17 **I:** What do you mean?
18 **S:** 04:01 There is different classficiations of the wavelengths, the length determines it. the xrays can be used to eject electrons, depending on the wavelength, they can either excite electron or eject
19 **I:** 04:28What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
20 **S:** If you shine light on hydrogen, it's got one in the n1 orbital, you can excite it or you can emit it, the emission energy is like 1312 kJ, so if you shine that much or more, the electron will get emitted, and whatever extra light beyond 1312 kJ that will be KE, but to excite it you need exactly the amount to get it to different shells, I think it's like 9000 something to get it to the second one, but if you have not exactly that, the light will just pass through, transmit
21 **I:** 05:03 so what's the difference between emit and excite?
22 **S:** emitting is getting it out of the orbital or I guess like theoretically putting it in like n=infinity, exciting is just putting it in a higher energy shell
23 **S:** 05:15when you excite it it goes to a higher shell and it becomes really unstable so when it comes back down it will emit light.
24 **I:** Describe for H exciting from 1s to 2s
25 **S:** well you don't really see it pass through here, it will go from here to here, but when it comes back here it will emit light.
26 **I:** why release light?
27 **S:** cause it's releasing photons, not too sure
28 **I:** 06:07 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?
29 **S:** it depends, some of the wavelengths have a certain amount of energy, the lower the wavelength, the more energy it has
30 **I:** 06:44 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
31 **S:** [draws] so Its n=1, n=2, n=3. n=4, n= infinity, this is -1312, this is -328, so this will be 984, 146, 182… and then this is 82
32 **I:** what does n= infinity mean?
33 **S:** 08:02 n= infinity means it's not in an orbital anymore, it's been ejected
34 **I:** 08:15 How much energy is needed to ionize Hydrogen?
35 **S:** 1312 or more. Because when you are ionizing it you are basically turning it into an ion so when you eject you get H+ which is an ion, so to get it to n=infinitiy or to get the, you need enough energy to get the electron out, and that's how much it costs right there
36 **I:** 08:41 why is it at n=1?
37 **S:** because, I forgot the name of the principle but they fill up from the lowest energy levels, and n=1 is lower than the other ones. The other levels still exist even if the electron is not in there, the levels can be excited to there, they still exist
38 **I:** 09:09 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

39 **S:** then it will get excited to the second shell, and will come back down eventually, and emit light

40 **I:** 09:16 What happens if you shine light on hydrogen with an energy of 980 kJ/mol?

41 **S:** well it doesn't have enough so the light will just transmit. Like all energy is conserved, the Hydrogen doesn't absorb that energy, so the light just passes through

42 **I:** 09:33 how about 990?

43 **S:** same thing, it has to be exactly the amount to get it to n=2, so same case it would just transmit the light

44 **I:** why won't it go to n=2?

45 **S:** Um, well as far as I learned, it just has to be exactly n=2. the concept was easy, but the theory i really didnt understand

46 **I:** 10:35 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

47 **S:** in theory it will emit, and the extra energy will be KE of the electron

48 **I:** 10:42 What energies of light does hydrogen absorb?

49 **S:** it absorbs I think, well, it absorbs xrays, like lower frequencies, I think it will absorb … I'm not too sure. When it absorbs light, it will move an electron up or it will emit an e-. The electron get the energy and become excited. Well it will absorb 1312, 984, 1066 from n=1 to n=3.

50 **I:** why not n=2 to 3?

51 **S:** generally when it's at 2 it's pretty unstable so it will just come right back down.

52 **I:** why is it unstable at n=2?

53 **S:** The core electrons are empty, so it's just a valence electron and the protons are trying to pull it back

54 **I:** 12:34 How is this different from emission?

55 **S:** emission is when, well you have an ionization energy so you are emitting an electron; and the spectra it diagrams the probability of the electron to be emitted, and that's represented by the height of the peak, and then it shows at what energies. There is a spectrometer, shoot in xrays and then you can measure the KE of the electron... they know the IE, whatver KE it has, they just subtract that

56 **I:** 13:45 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

57 **S:** it's caused by the average wvlgth of ight that's reflected, like if the color is red, then the average wvlght of light is 700ish, so it depends on the the average energy of light that passed through it.

58 **S:** 14:21 Neon absorbs certain colors, and whatever colors it doesn't absorb it reflects and that's the colors we see.

59 **I:** 14:33 Over time, would the tubes change color?

60 **S:** No, I don't think it would. I think it depends on how much energy you are putting it. What you are doing is exciting electron and having them come back down, I don't see how that process could change. You would have to either emit stronger light, the intensity of the light doesn't matter, you would have to emit a different wavelenth or a different energy of light

61 **I:** Is there any amount of energy that wouldn’t light the bulb?

62 **S:** you have to get it to n=2 or past the gap, so anything below n1 to n2

63 **I:** Why are Ne and He tubes different colors?

64 **S:** Ne it absorbs a different spectra and when it's got more levels too, you can emit different colors I think. He has only got n=1 filled, and Ne has got more.

Student No: 31

	Evidence	Code
Probabalist/ Determinist	then you have electron that are just kinda not necessarily like orbiting like planets orbiting the sun, but it's like areas of probability so it's like more like a cloud but then like at one point it's here and then here and then here so um, I mean it's kinda hard to visualize because again, because of Schrodinger or something you don't know where it's gonna be at any given point in time but you know like the probability of the electron	3
Discrete/ Continuous	The photon of light would hit the electron and the electron would vibrate a little or shake a little bit off it's previous position Anyways, so it goes from one subshell to maybe like the next subshell or a little bit out, and then it goes back and relaxes or something, then it emits a photon of that energy 14:00 (can any energy photon be absorbed in that way?) yes? I'm going to say yes...	1
Interpreting Spectra Code	30:36 (500?) then it would be excited to the.. It would be excited and then turn back.. These are negative numbers so huh… so it would be somewhere in this region for sure (between 1 and 2?) yeah. (984?) so first of all I'm going to point out that's the difference between the 2, based on that observation, I believe it would go the n2 subshell, because from that point, it would take 328 to be ejected.	2
Energy/Force Code	so, um, well, I'm trying to link the idea of energy levels we learned in class, like it takes a certain amount of energy to jump from a lower one to a higher one. it takes more energy to get the electron closest to the nucleus, cause there is more like an attractive charge and then it takes a lot less to get to the next one and so forth... (why?) I guess like I said because of the effective charge, because of the proton has a positive charge and electron are neg charged so it's kinda like a magnet, so if you think of it like a magnet, if it's closer to the magnet, then stronger pull and then the valence electron by contrast would have a lot less of the pull on them because they are farther away from the nucleus	4

Line No.		Transcript
1	**I:**	01:09 Describe how you visualize the atom
2	**S:**	ok so the atom.. You have the nucleus which consists of some protons and maybe some neutrons depending on the identity of the atom and then you have electron that are just kinda not necessarily like orbiting like planets orbiting the sun, but it's like areas of probability so it's like more like a cloud but then like at one point it's here and then here and then here so um, I mean it's kinda hard to visualize because again, because of Schrodinger or something you don't know where it's gonna be at any given point in time but you know like the probability of the electron
3	**I:**	01:57 what do you mean by probability?

4 **S:** so it depends on the, what's it called, the energy level? I forgot.. s and p and d and something, oh, it's the energy subshell. So depending on the energy subshell there is shape could be just like around the.. the s I remember is like a spherical type thing ,so the electron is... there aren't any "nodes" or areas where it couldn't be so it just could be like almost equal probability anywhere around a certain radius around the proton , I guess.. and then in terms of S, P, P-orbs have one planar node or something like that, so it's shaped kinda like a, I think of it as a bowtie, or a figure 8, I think they use dumbell, but I like the bowtie thing, a cartoon bowtie... anyways so when it's like.. it could be in two of these big lobe things but not in the center and there is d-orbs which are, they have both a radial node and a planar node

5 **I:** 03:45 why is energy important?

6 **S:** ok so it takes a certain amount of energy to eject an electron, or not eject, to make an electron vibrate or something, but I don't think.. can you rephrase your questions?

7 **I:** how do you link energy with spdf?

8 **S:** so, um, well, I'm trying to link the idea of energy levels we learned in class, like it takes a certain amount of energy to jump from a lower one to a higher one. it takes more energy to get the electron closest to the nucleus, cause there is more like an attractive charge and then it takes a lot less to get to the next one and so forth...

9 **I:** why?

10 **S:** I guess like I said because of the effective charge, because of the proton has a positive charge and electron are neg charged so it's kinda like a magnet, so if you think of it like a magnet, if it's closer to the magnet, then stronger pull and then the valence electron by contrast would have a lot less of the pull on them because they are farther away from the nucleus

11 **I:** 06:08 are Hydrogen's and Oxygen's 2p energy levels the same?

12 **S:** no, the energy levels for I think all the elements, I want to say all the elements, but I'm sure some of them are very similar. But what we learned in lecture are that energy levels are "chemical fingerprint" or something like that, they are very discrete and they are very particular to each element.

13 **I:** why?

14 **S:** well it's because IE's, which is.. we learned about periodic trends right, i feel like IE varies depending on where you are in the Periodic Table so there are a bunch of different factors works, so there is the distance from the nucleus or the size of the atom, then there is also Z effective charge, so Zeff is pretty much moving up as you go across the periodic table and there's also number of electron as you go across the periodic table, and there's something as you are going down a group too, oh, that was the distance from the nucleus, cause you are on the same "subshell" but there are more electron , there's like more layers of electron

15 **I:** 08:13 Describe how you visualize light

16 **S:** ok, so, well light is a wave first of all with sometimes particlelectronlike behavior, at the macroscopic level it is a particle I think, at the microscopic level it is a wave… so that means that if… I'm thinking of the examples from lecture where if you shine a...so light... they are like particles or photons, but they travel in a wavelectronlike fashion

17 **I:**   why are there different models?

18 **S:** cause light has a bunch of different indications like color and things like that and energy and so it's helpful to understand how it works out, cause i think that's how the wave part of it is, implications for the wave part of it so you can calculate wavelength and frequency and all that stuff to determine different energies of light

19 **I:** 11:00 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

20 **S:** when that happens, the photons in the light have a particular energy, right, so the IE is converted into energy that ejects the electron and any leftover energy is converted into KE that determines how far the electron goes

21 **I:** any ideas how?

22 **S:** well, I guess I always kinda think of it as a pool-ball kinda thing, but I guess that's more like a particle version rather than wave which is kinda problematic

23 **I:** 12:24 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

24 **S:** then nothing happens, well at least the electron is definitely not ionized. I'm not really sure what happens to the photon of light because I mean I would assume that it's energy still like… oh ok! The photon of light would hit the electron and the electron would vibrate a little or shake a little bit off it's previous position which is kinda problematic cause I was just describing the atom as like "you don't know where it's going to be!" anyway, well maybe not, it's going from on subshell to another so it's like one configuration to like the next thing, so maybe it's not completely inconsistent. Anyways, so it goes from one subshell to maybe like the next subshell or a little bit out, and then it goes back and relaxes or something, then it emits a photon of that energy

25 **I:** 14:00 can any energy photon be absorbed in that way?

26 **S:** yes? I'm going to say yes...

27 **I:** 15:31 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

28 **S:** ok so, the excited gas from like the electricity or something, the current, that is providing the energy that I was talking about, like energy that excited the electron and they kinda like go "woo!" and then when they relax again they emit photons of a certain wvlngth, that travel in a certain wavelength that is within our visible light spectrum that corresponds to whatever light we see

29 **I:** 16:14 Why are Ne and He tubes different colors?

30 **S:** well that has to do with the different energy of the light I guess because longer wavelength or smaller frequency is both corresponding to lower energy, so something that is like red is more energy than blue...

31 **I:** what about He makes in that color?

32 **S:** I think it probably has to do with the number of electron versus the ffective charge, He has fewer subshells that are filled vs Neon which has more layers or more rings if you want to use that model of the atom, so Ne would theoeretically take less energy for the electron to get excited than He even though they are both hard cause they are noble gases

33 **I:** 19:14 Over time, would the tubes change color?

34 **S:** um, assuming like the electricity is still going?

35 **I:** yeah

36 **S:** I don't think so, my first reaction is no, that's my first thought

37 **I:** how could it change color?

38 **S:** maybe radioactive decay? does that count? ...presumably then the two new elements would have different energies...

39 **I:** 20:50 Is there any amount of energy that wouldn't light the bulb?
40 **S:** yes, so I guess that means earlier my response was wrong about the whole - can any amount of energy excite the electron - anyway, I'm just going to go on this new path - anyway, yeah, for sure, there has to be a certain level of, like once you get above a certain wvlngth, threshold, then anything above it will excite it, any amplitude of light, any lightness or darkness will excite that, but then if you are below that threshold regardless of how high that energy is then it won't cause that electron to be excited
41 **I:** 23:15 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table] what is the table telling you?
42 **S:** it's telling me the ionization energies of particular electron at different levels.
43 **I:** don't worry about subshells
44 **S:** this represents the different amts of energy to move the electron away from the nucleus, or actually to eject the electron from the nucleus, at different energy..uh shells. So even though there is only one electron for H, these are still like relevant, because the electron can technically be anywhere, because like the Schrod things it's probability, it's doesn't just go from 1 to 2 or something like that. So also from this you can also figure out the amount of energy that's released when it relaxes. So if it's not necessarily 1312 kJ/mol of energy that hits , then it won't be ejected, it will just be "oh!"
45 **I:** 25:16 How much energy is needed to ionize Hydrogen?
46 **S:** 1312 kJ
47 **I:** 25:25 Can you draw the absorption spectrum of Hydrogen?
48 **S:** maybe. So absorption… it should be the energy, and this should be.. Energy input.. But 1312 is.. It would absorb everything but 1312 which is where it would be.. a red object will absorb everything but red which it reflects back, and I feel like for this.. cause these are discrete or something like that, right?
49 **I:** what do you mean by discrete?
50 **S:** we mentioned earlier that there are specific energy inputs for it to be... and if you put in less or put in more, it's not ionized... only specific energies can be...
51 **I:** what can be absorbed?
52 **S:** 1312 would. anything between 1 and 2; and 2 and 3; and 3 and 4; would be absorbed cause other than that it would actually cause the thing to move out. So that means that it's like squiggly, squiggly and then a gap here.
53 **I:** 29:33 How is this different from an emission spectra?
54 **S:** emission would look like the… assuming there is only 1 electron it takes 1312 kJ/mol to cause it to eject, and even though there are these other energies, they don't really factor in the emission spectrum
55 **I:** 30:14 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
56 **S:** so since it takes 1312 kJ/mol to ionize it, it would cause it to separate from the energy level, the 200 kJ/mol is converted to KE
57 **I:** 30:36 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?
58 **S:** then it would be excited to the.. It would be excited and then turn back.. These are negative numbers so huh… so it would be somewhere in this region for sure
59 **I:** between 1 and 2?
60 **S:** yeah.
61 **I:** how about 984?
62 **S:** so first of all I'm going to point out that's the difference between the 2, based on that observation, I believe it would go the n2 subshell, because from that point, it would take 328 to be ejected.

Student No: 32

	Evidence	Code
Probabalist/ Determinist	02:19 the sphere is basically, as I said it's a probability for the electron to be, it is much probably to somewhere inside the sphere but not necessarily within the sphere 02:34 There are certain areas that might be more probable and less probably, and looking at schrod model there will be more densely shaded parts and less densely shaded parts and that will denote... The electron is around the protn and where it is more shaded it is more likely to be, not necessarily means that it has to be there	3
Discrete/ Continuous	It makes more sense to use the Bohr model, the electron has certain orbitals and like Stacy described it as using a ladder, you have to be on a step, you can't be in between. 12:59 (982?) then it's not enough energy to get to the second energy level, so nothing happens, light is transmitted 13:12 (986?) still it wouldn't be, because the energy that is required to move it up to another orbital has to be precisely. (why not n=2?) the energy is greater than n=2	3
Interpreting Spectra Code	Excited means like lets say that a photon of light that has 1312-328 comes in then it will go to the second energy level and then fall back down (calculates) 984	3
Energy/Force Code	For ionization, the extra energy is converted to KE, but in this case if you are only exciting it to a certain energy level, then where would the remaining energy go? and that kinda makes sense that it wouldn't do anything, otherwise conservation of energy would be broken and that would give us bigger problems! 10:14 If the photon is at a high enough energy, if it's bigger than 1312 kJ, then the electron will be basically, it will be kicked off. If we denote the distance between the proton and neutron as "R", as long as within a certain R there will be an attraction towards it. When R is infinite or basically there is no attraction, that is the energy required to move from ground state to that level because you will have a different effective nuclear charge, if there is more protons than another. becase while there is shielding, more protons, greater nuclear charge and greater attraction	4

Line No.		Transcript
1	**I:**	00:16 Describe how you visualize the atom
2	**S:**	um, still kinda thinking about it like 3 separate models for it, um probably the most basic and probably the most incorrect is the billiard ball model, or Dalton's Model which is basically that these atoms are indivisible parts, and that isn't correct because that would mean light would just bounce off of them it wouldn't be absorbed. then you have the plum pudding model with the electron around but still it doens't explain it very well; then you start getting into more accurate models, the bohr model, which there is one proton and it's surrounded by different orbitals and electron exist in orbitals, orbitals basically just different energy levels; and then there is the Schrodinger's Model, and that it shows you more, it shows you the 3dimensional shape of orbitals and [inaudible] the probability where the electron will be at a certain time.
3	**I:**	01:26 what's an orbital?
4	**S:**	An orbital is basically an area at which the electron can be at a certain energy.
5	**I:**	01:52 Compare the Bohr and Schrodinger models

6 **S:** Bohr model tells you the orbitals but doesn't give you the shape of the orbitals, Schrod model will give you the shape of the orbitals and that explains pi and sigma bonds

7 **I:** 02:11 how about in the H-atom?

8 **S:** 1s shell, it's a sphere surrounding the proton and it's a relatively small sphere compared to higher energy levels

9 **S:** 02:19 the sphere is basically, as I said it's a probability for the electron to be, it is much probably to somewhere inside the sphere but not necessarily within the sphere

10 **S:** 02:34 There are certain areas that might be more probable and less probably, and looking at schrod model there will be more densely shaded parts and less densely shaded parts and that will denote the electron is around the proton and where it is more shaded it is more likely to be, not necessarily means that it has to be there

11 **I:** 03:30 How would you describe oxygen?

12 **S:** 2 electrons in th 1s shell 2 electrons in the 2s shell 4 electrons in the 2p shell, [draws 1s and 2s] they are kinda distinct regions, and youre gonna see radial nodes also in 2s. The shaded areas are separated by a region of relatively low probability. 2p is… because there are 3 sub p-orbs xyz, and the loops are basically the areas of most probable, along x y z direction. i mean there probably will be some overlap [between 2s and 2p]

13 **I:** 07:14 Describe how you visualize light

14 **S:** it's both a particle and a wave. Like the way a water droplet, there is amplitude and wavelength and freq, and there is also particle properties to it. I really don't picture it. Light is light - there are properties of light. If you are talking about absorption or transmission, the wave model is really useful, it will tell how how the wavelgnth changes as the energy of the light is gonna change, cause energy is directly related to wvlgth or freq. Particle model just tells you how light travels and wave model can tell you that too, bt yeah. it's kinda like the ray model. basically just like if there is a source of light it goes in all directions, but that's not really true, because if you have a really small opening....

15 **I:** 09:31 what is particle of light called?

16 **S:** quanta...um...i forgot these things after the midterm. packet of light, photon. photons you see them to excite electrons

17 **I:** 10:14 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

18 **S:** If the photon is at a high enough energy, if it's bigger than 1312 kJ, then the electron will be basically, it will be kicked off. If we denote the distance between the proton and neutron as "R", as long as within a certain R there will be an attraction towards it. When R is infinite or basically there is no attraction, that is the energy required to move from ground state to that level

19 **I:** 11:07 what if you shine light lower than 1312?

20 **S:** Nothing will happen.

21 **I:** 1512 kJ?

22 **S:** it will be kicked off and the remaining energy will be converted to KE

23 **I:** 12:15 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

24 **S:** [draws]

25 **I:** why 4 levels?

26 **S:** usually the electron is in n=1, but it can be excited to n=2,n=3,n=4. n=1 is the most stable. Excited means like lets say that a photon of light that has 1312-328 comes in then it will go to the second energy level and then fall back down [calculates] 984

27 **I:** 12:59 What happens if you shine light on hydrogen with an energy of 982?

28 **S:** then it's not enough energy to get to the second energy level, so nothing happens, light is transmitted

29 **I:** 13:12 986?

30 **S:** still it wouldn't be, because the energy that is required to move it up to another orbital has to be precisely.

31 **I:** why not n=2?

32 **S:** the energy is greater than n=2. For ionization, the extra energy is converted to KE, but in this case if you are only exciting it to a certain energy level, then where would the remaining energy go? and that kinda makes sense that it wouldn't do anything, otherwise conservation of energy would be broken and that would give us bigger problems!

33 **I:** would it absorb 984?

34 **S:** yes.

35 **I:** 14:10 Can you draw the absorption spectrum of Hydrogen?

36 **S:** probably not! Probably higher energies will get absorbed.

37 **I:** what exact energies?

38 **S:** you will have 984… etc anything greater than 1312. because it will be converted to KE..

39 **I:** how about in between?

40 **S:** no, the electron can't be in between n=1 and n=2. It makes more sense to use the Bohr model, the electron has certain orbitals and like Stacy described it as using a ladder, you have to be on a step, you can't be in between.

41 **I:** is n=4 physically farther from the nucleus?

42 **S:** Yes.

43 **I:** 16:21 what if you shine 984?

44 **S:** it will go to n=2 and then go back to n=1, n=1 is more stable. when it falls back down, releases 984 kJ of light

45 **I:** 17:29 How is this different from an emission spectra?

46 **S:** it's gonna be basically it's gonna be more than this, it can fall from n=4 to n=1 to n=3 ,etc… H is in the ground state won't emit, it's only when there is a change in PE when it falls from a higher level to a lower level

47 **I:** 18:28 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

48 **S:** because the fall between the energy levels is an energy level that corresponds to a wavelength of light of orange.

49 **I:** Why are Ne and He tubes different colors?

50 **S:** Because the difference between energy levels are gonna be different, and it's the difference which is emitted, the different corresponds to the wavelength which is emitted, because you will have a different effective nuclear charge, if there is more protons than another. becase while there is shielding, more protons, greater nuclear charge and greater attraction

51 **I:** 20:30 Over time, would the tubes change color?

52 **S:** theoretically no, but I'm gonna say yes. these bulbs do burn out, it would make sense they would change colors but I don't know why they would. I don't see why they would. the electron going higher, and release as they fall down, they are just getting excited and falling excited falling. when the electron falls from a higher energy level to a lower energy level, corresponds to emission. different gas would give different color, would have different spectra

53 **I:** Is there any amount of energy that wouldn't light the bulb?

54 **S:** 22:17 yeah, if reduce too much not enough energy to get to higher energy states, then you will not see that fall. For H, like 983..

Student No: 33

	Evidence	Code
Probabalist/ Determinist	But the electron instead of moving around in circles like the Bohr Model or just standing there like some of the other models, instead it forms a cloud ,that's the probability density of the electron gonna be there, the more dense the cloud, the more likely it will be there..	3
Discrete/ Continuous	07:24 discrete amount of energy, essentilly it means, when you have some sort of phenomena, like a photon or fire, the light that is coming off is in particles, tiny little pieces, tiny balls of light, each ball has a specific energy that is related to it.	3
Interpreting Spectra Code	15:30 absorption spectra, there would be one at 984, n2-n1, there is one at like .. N3-n1, the lines mean the specific energy levels of light that would be absorbed,	3
Energy/Force Code	09:10 if the energy is enough to move it n=1,2 it will bump it up, past n=4 usually it's enough to ionize it completely. pull it away from the core. Exciting it and giving it energy. When it goes back down to ground it will release energy. 10:11 when light hits the e-, it's giving it enough energy to change it's signature change it's quantum properties, like shining light gives it more energy to work with and it's characterized as a higher energy level... when an electron goes back down to ground state, it releases energy because it becomes more stable, so how much energy it releases depends on how much it took to move it out, related to electron shielding... 09:10 if the energy is enough to move it n=1,2 it will bump it up, past n=4 usually it's enough to ionize it completely. pull it away from the core releases energy because it becomes more stable, so how much energy it releases depends on how much it took to move it out, related to electron shielding...	4

Line No. **Transcript**

1 **I:** 00:35 Describe how you visualize the atom

2 **S:** Ok, well I guess by that question if you mean describe the model, then the one we learned the latest - the Schrodinger Wave one, basically the idea that the atom is composed of a core has the nucleus with neutrons in the center. But the electron instead of moving around in circles like the Bohr Model or just standing there like some of the other models, instead it forms a cloud ,that's the probability density of the electron gonna be there, the more dense the cloud, the more likely it will be there.. the model will imply a dense core and around it however many electrons flying around in a random pattern. Because of the shell patterns, flying around randomly but more likely to be in certain areas

3 **I:** What are shells?

4 **S:** 01:48 the shells are a model for us to understand the energy levels, also have principal quantum numbers 1,2,3,4.. so 1 would be the lowest, 2 would be the second, with 2, start getting p orbitals, d's then f's... the shell model helps to explain electron becoming excited

5 **I:** How are s shells different from p shells?

6 **S:** 02:48 S is a spherical shell, electron are in spherical pattern, p orbitals have x,y,z,, like a figure 8, p-orbitals are higher in energy than s. s and p can overlap - why there is hybridization, sp orbs.. in one atom, s and p are separate, because S shields P

7 **I:** 04:51 How would you describe oxygen?

8 **S:** there is 6 valence, 2 in 1s, 2 in 2s and 4 in 2p, core electron are held closer to electron core, not directly involved in chem reactions or bonding, has to do with atomic radius. 2s and 2p are in the same shell, p is somewhat farther away, because at higher energy, more likely to come off electron first

9 **I:** 06:14 Describe how you visualize light

10 **S:** not sure -there is a wave/particle model, sometimes looks like both. Wave model explains light diffraction, wavelength, double slit exp, and the particle model - energy can be quantized, won't go around corners,

11 **I:** 07:24 What do you mean by quantized?

12 **S:** discrete amount of energy, essentilly it means, when you have some sort of phenomena, like a photon or fire, the light that is coming off is in particles, tiny little pieces, tiny balls of light, each ball has a specific energy that is related to it.

13 **I:** 09:10 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

14 **S:** if the energy is enough to move it n=1,2 it will bump it up, past n=4 usually it's enough to ionize it completely. pull it away from the core. Exciting it and giving it energy. When it goes back down to ground it will release energy.

15 **I:** Why does this happen?

16 **S:** 10:11 when light hits the electron, it's giving it enough energy to change it's signature change it's quantum properties, like shining light gives it more energy to work with and it's characterized as a higher energy level...

17 **I:** 09:56 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

18 **S:** it will come off and the electron will have KE

19 **I:** 11:10 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color? Why are Ne and He tubes different colors?

20 **S:** the electric current is providing energy for electron to move to higher level, when it comes back down it emits light, it will release a specific signature of neon, like spectroscopy is characteristic of each atom. Ne an He have different energy properties, have to do with nuclear charges. when an electron goes back down to ground state, it releases energy because it becomes more stable, so how much energy it releases depends on how much it took to move it out, related to electron shielding...

21 **I:** Is there any amount of energy that wouldn't light the bulb?

22 **S:** 12:54, yes if you didn't have enough energy to move it from the first level to the next one, then it wouldn't light.

23 **I:** Over time, would the tubes change color?

24 **S:** Over time, i don't think the color should change. because if you are just shooting current through neon, there shouldn't be any chemical reactions...

25 **I:** 14:15 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

26 **S:** y-axis is kJ/mol, zero point would be ionization point, electron has no KE, not attracted to atom, n=.. Says how much energy is required to ionize the atom at that specific energy at that level. In the inert state, at n=1

27 **I:** 15:30 Can you draw the absorption spectrum of Hydrogen?

28 **S:** absorption spectra, there would be one at 984, n2-n1, there is one at like .. N3-n1, the lines mean the specific energy levels of light that would be absorbed,

29 **I:** 18:10 How is this different from an emission spectra?

30 **S:** emission spectra is the wavelengths that are emitted, I believe there are 6 different lines

I: How much energy is needed to ionize Hydrogen?
S: 1312 kJ
I: What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
S: would eject the electron, extra would be KE
I: What happens if you shine light on hydrogen with an energy of 500 kJ/mol?
S: nothing would happen at 500kJ, doesn't match difference

Student No: 34

	Evidence	Code
Probabalist/ Determinist	but it's really, the best way to say it is it's a probability where you're gonna see the electron and um I mean it's just a space filling model but it's more like a density of probabilities of where the electron is gonna be or where we would predict it to be	3
Discrete/ Continuous	09:53 use the step model, I mean if you think of stairs, you can't really step in a place between stairs and there's certain levels of the stairs, so I guess this would quantization model would work the same way, there are certain levels, orbitals, energy levels and um light can make or provide just the right amount of energy and that would be analagous to providing the right step	3
Interpreting Spectra Code	so I'm just drawing what would happen if it absorbed light and interacted and I think the differences between these is what matches up (so the different between -1312, -328) yeah	3
Energy/Force Code	and there are certain freq, that the photon has, and the frequency corresponds to some energy, and that energy if it's the right amount that can push that electron up I guess if these are the energy levels and you have the diffs would give enough energy to move it up one leve so I think yeah I think the diffs would do something. It would just, that would be enough energy to say move it up from n=1 to n=2 , so it's pretty much exciting the electron from one orbital to the next it's always moving around randomly and it's still attracted to the nucleus well, I guess energy has to do with certain PE how well the electron are attracted to the nucleus so I guess there are certain levels of PE where the electron kinda rests at that level I mean earier going back to the attraction with the nucleus, different elements have different number of protons that will change the attraction	4

Line No. **Transcript**

1 **I:** 01:21 Describe how you visualize the atom

2 **S:** well we've gone over a few models in class, I mean from different intro chem classes in HS was always the classical model which is you have with hydrogen you would have the nucleus in the middle and you would have electron circling it in orbits. So as I went into higher level chem classes, that all changed, so know instead of electron orbiting, we know its there's no clear cut model that shows where the electron will be but we have the electron orbitals and that comes from the schrodinger wave eqn

3 **I:** what do imagine those orbitals to be?

4 **S:** it's more like, I mean we see them as shapes and we give them names, but it's really, the best way to say it is it's a probability where you're gonna see the electron and um I mean it's just a space filling model but it's more like a density of probabilities of where the electron is gonna be or where we would predict it to be

5 **I:** 02:58 now, what do you picture the electron doing?

6 **S:** it's still moving around it's not like in a circle, it's, I don't know, the electron would be... it's always moving around randomly and it's still attracted to the nucleus, but really it's just.. you can't really pinpoint where exactly

7 **I:** would it stay in 1 shape?

8 **S:** well again the shape is kinda, the shape is really a probability, I guess the electron is always moving, so you can't really tell where it is, the schrodinger wave eqn you can't really tell the same place and time where the electron could be

9 **I:** 05:51 for oxygen in the 2p orbital -is it staying in that space or go to 2s?
10 **S:** I haven't really thought about it that way, I thought it would stay in that shape.
11 **I:** why?
12 **S:** I think the model.. Say you have 2 electron in the s and they stay there so the electron in the p-orb they can't really go into the s orb, it's already filled
13 **I:** 06:58 Describe how you visualize light
14 **S:** light, so we learned about the wave and particle models, so light is really a mixture of those two and I mean it has properties that shows that it is a EM wave and it's can also be a photon.
15 **I:** what do those 2 models tell you?
16 **S:** I guess it tells me a lot about what it can do. In terms of waves the whole experiments they have diffraction gratings, if it was a beam of light it would just go through, but it just just has that wave property.. there's that , and there's the photoelectric effect , i guess light can think of them as photons, so packets of energy that cause the electron, if it gets enough energy [inaudible], so that
17 **I:** 08:48 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?
18 **S:** so if it's the IE it will rip it off so I guess if it's greater than the difference between the ionization energy and how much energy is in that photon, that energy is converted into the KE of the electron
19 **I:** 09:18 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
20 **S:** then it depends. You go under the IE, we have complication, and it has to have a certain level of energy to move the electron to other orbital and yeah.
21 **I:** 09:53 What do you mean by certain level?
22 **S:** use the step model, I mean if you think of stairs, you can't really step in a place between stairs and there's certain levels of the stairs, so I guess this would quantization model would work the same way, there are certain levels, orbitals, energy levels and um light can make or provide just the right amount of energy and that would be analagous to providing the right step
23 **I:** 10:55 why at certain energy levels?
24 **S:** well, I guess energy has to do with certain PE how well the electron are attracted to the nucleus so I guess there are certain levels of PE where the electron kinda rests at that level, that orbital
25 **I:** how is light interacting?
26 **S:** I guess the light the photons, I can think of them as particles...cause we also go back to the wave model and there are certain freq, that the photon has, and the frequency corresponds to some energy, and that energy if it's the right amount that can push that electron up
27 **I:** 13:00 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What aauses this color?
28 **S:** I guess you can go back to the waves again, certain frequency have different colors and so running an electric current through say He would I guess the electron, for He I guess it's the n=1 orbital, it would provide enough energy to excite the electron to a higher level and when they fall back down, the frequency of the light emitted corresponds to some color, that's why you see colors for He, Ne, the energy difference between the orbitals are different for each

29 **I:** why?

30 **S:** I mean earier going back to the attraction with the nucleus, different elements have different number of protons that will change the attraction

31 **I:** 14:20 Over time, would the tubes change color?

32 **S:** I wouldn't.. I guess not, if you have the current flowing, then there's not leak, I think it would stay the same color

33 **I:** if you increase the energy to tube, would you see color change?

34 **S:** possibly? I think you need to specifiy how much energy is, especially if it's current...

35 **I:** 16:40 Is there any amount of energy that wouldn't light the bulb?

36 **S:** yeah I guess if you, because it's all quantized, if you don't put in the right amount I think the light would just pass through.. it wouldn't really light up

37 **I:** what do you mean by pass through?

38 **S:** if the energy would, since it's not the right amt, it would just kinda pass through the atom, and it wouldn't really do anything

39 **I:** 18:00 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

40 **S:** so energy level you would have the energy on the y-axis and since we think about this In terms of PE, it's kinda all negative… I guess we start at zero, and basically just fill in where the energy levels are… so I guess this would be 1312, -328 and so and that would be the same as 1234

41 **I:** 18:49 Can you draw the absorption spectrum of Hydrogen?

42 **S:** so absorption spectra is I guess the light in absorption and it would also be energy, so I guess it would be matching.. Cause the absorption say for n=1, it would absorb a certain amount of light and… so I'm just drawing what would happen if it absorbed light and interacted and I think the differences between these is what matches up

43 **I:** so the difference between -1312, -328 ?

44 **S:** yeah

45 **I:** how about 2 to 3?

46 **S:** I'm not quite sure. my feeling for that is that it's a H-atom, and on the test was He I think, you wouldn't see an absorption spectra for something that starts at n=2 because all of the electron are in the ground state. So for H I guess you wouldn't. For atoms with electron in those energy levels, yeah

47 **I:** 21:17 How is this different from an emission spectra?

48 **S:** emission spectra would be the other way around, arrows would be pointing down,

49 **I:** would it be the same peaks?

50 **S:** for the most part, I think so, except with emission I think it would go like 4 to 3, you would have more

51 **I:** 21:59 How much energy is needed to ionize Hydrogen?

52 **S:** probably 1312

53 **I:** 22:08 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

54 **S:** that would, the 1312 would be enough to ionize it and the rest of that would be go into KE of the electron

55 **I:** 22:28 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

56 **S:** then it wouldn't be enough to ionize

57 **I:** how about 928?

58 **S:** it wouldn't do anything,

59 **I:** at one of these differences would anything happen?

60 **S:** I trying to think because.. I guess if these are the energy levels and you have the diffs would give enough energy to move it up one leve so I think yeah I think the diffs would do something. It would just, that would be enough energy to say move it up from n=1 to n=2 , so it's pretty much exciting the electron from one orbital to the next

Student No: 35

	Evidence	Code
Probabalist/ Determinist	there was this diagram which had a bunch of dots which was like the probability so it was just like it's possible for it to be in like a little bit out but it's highly improbable	3
Discrete/ Continuous	07:28 (not match?) the light would be transmitted. the light would pass through it wouldn't move it to the next shell but to me if it's there it would have to do something to it , like it would have to at least make it spin a different direction or a little bit faster , it would do something but not enough to move it to the next shell 18:04 (what energies of light would H absorb) it would absorb the energies that would send it to a different orb shell. Like if you put in 82 kJ, it would absorb 82 but it wouldn't absorb 83 or 81	2
Interpreting Spectra Code	17:13 the abs spectrum is the specific wvlgnths that an atom or anything would absorb. H would absorb these specific energies of light (why?) because this is the energy that it takes for … so 82 kJ/mol is the energy that it takes from the n4 to shoot the n4 energy level... 18:04 (what energies of light would H absorb) it would absorb the energies that would send it to a different orb shell. Like if you put in 82 kJ, it would absorb 82 but it wouldn't absorb 83 or 81 19:38 (82 kJ/mole?) then it would send the electron to one from the it would send it from the ground state to the first shell. I mean from the first shell which is 1s to the second shell which is 2s	2
Energy/Force Code	06:50 (how do 1s and 2s compare?) one of them has no nodes, one of them has 1 node in the middle, and they represent different things because if an electron were to be on the 2s it would be easier to ionize it because it's further away from the protons and the nucleus which would make the attraction between the electron and the proton less so it would take less energy to ionize 11:26 I couldn't say exactly but it would have to do something with the energy, well they have the same current so the electron in the Ne atom are further away the valence electron are further away the nucleus than the He electron are away from its nucleus, so it would take more energy... the Ne would be a higher frequncy, lower wvlgth because it's more energy - no it's the opposite way - because the protons in the nucleus are further away from the electron so it's not at much attraction so it would be a little easier to push it one more out in Ne. so then Ne would be a higher wavelength color as opposed to He. the energy emitted would be greater for He.	4

Line No. **Transcript**

1 **I:** 00:37 Describe how you visualize the atom

2 **S:** It's just like a protona and an electron and shhhh.. Basically would be on the 1s orbital and it would be so it would be like it would have it would be in the dumbell or like in the 8 it would be in that area

3 **I:** What's an orbital?

4 **S:** it's like the probability of the electron being in a specific area around the proton. or around the nucleus

5 **I:** Can you describe the 1s orbital?

6 **S:** 1s I guess it means the orbital or area or space that's closest to the nucleus .

7 **I:** can it be anywhere?

8 **S:** there was this diagram which had a bunch of dots which was like the probability so it was just like it's possible for it to be in like a little bit out but it's highly improbable

9 **I:** 02:03 How would you describe oxygen?

10 **S:** so it has like 6 valence so then it would be 1s2s2p so it would be on the 2p orbital and it would orbit further away, it would be orbiting further away from the, I mean the valence electron would be orbiting further away from the nucleus than the H atom

11 **I:** 02:51 Can you describe 2s and 2p?

12 **S:** 2s is a spherical orb 2p is a dumbell shaped orbital.

13 **I:** Do they overlap?

14 **S:** they overlap and then depending on how they overlap they create nodes. A node is an area where the electron is really not likely to be because of the electron repulsion the proton repulsion I think... I don't know if the proton has anything to do with the nodes but I'm pretty sure the electron do

15 **I:** 03:39 How is the electron in 2p orbiting?

16 **S:** depends on how many e or it can be orbiting in the x or y or z, it's kinda like an axis. opposite spinning electron are orbiting 2 at a time, 2 in the x y z.

17 **I:** why is it like that?

18 **S:** so the electron are as far away from each other because they repel

19 **I:** 04:31 Describe how you visualize light

20 **S:** I'm still thinking about it actually. I'm still trying to grasp the idea of it not being matter but it being able to change and move and like travel and have distance, like how can it have distance if it's not matter. It's just kinda strange like I know it's like packets of energy, like photons are packets of energy that hit the electron and like make the electron can ionize it if it has enough energy or if not excite it

21 **I:** What do you mean by excite?

22 **S:** it means it moves, it's not ionized, it's not shot off the atom but moves to a different orbital, shell.

23 **I:** Do different shells have different energies?

24 **S:** yes they do, they have energies and like how I was referring to how much energy it takes for the electron to be shot off to a certain level, like it takes a certain amount of energy to be shot from the 1s to the 2s, and then from the 2s to the 2p, specific amount yeah

25 **I:** 06:01 What happens if light shines on the atom that matches that certain energy?

26 **S:** then it will jump to the next orbital so like if it's on the 1s and you shine enough it will go to the 2s, and for a little bit of time, that's the electron being excited. The 2s orbital is really just the space where it could be. just because an electron in the 1s doesn't have an electron in the 2s doesn't mean the 2s orbital doesn't exist. or it's just like a space where if it were there, it would act differently

27 **I:** 06:50 how do 1s and 2s compare?

28 **S:** one of them has no nodes, one of them has 1 node in the middle, and they represent different things because if an electron were to be on the 2s it would be easier to ionize it because it's further away from the protons and the nucleus which would make the attraction between the electron and the proton less so it would take less energy to ionize

29 **I:** 07:28 what if the light does not match?

30 **S:** the light would be transmitted. the light would pass through it wouldn't move it to the next shell but to me if it's there it would have to do something to it , like it would have to at least make it spin a different direction or a little bit faster , it would do something but not enough to move it to the next shell

31 **I:** 08:05 Can you zoom in, and describe what happens?

32 **S:** the energy or the KE of the photon like the speed it's travelling at, like the energy in general of the photon will be transferred to the electron making it spin faster or ionize

33 **I:** 08:51 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

34 **S:** so when the electron are excited in the Ne atoms, they have 8 valence have a complete octet, they jump to like different orbs, higher orbs and then fall back down. So when they fall back down, the energy they fall back down with… like say they are in the 2p and go to the 3s or the 3d, when they come back down, they emit light

35 **I:** how does this match with the color?

36 **S:** well depending on the energy would be the color. I don't really know if it's direct relationship between lower wvlgth and lwer energy orbital , like moving frm a higher one to a lower one than a much higher one to a middle orbital. I don't really know how that works but I knw it does vary.

37 **I:** 10:20 if you have 2 levels close together or 2 far apart, which one would emit a higher energy photon?

38 **S:** so if it's further away, then it takes more energy to put the electron in that orbital because they are like close together close together close together and then they start getting further apart from each other, so then it would take more energy to throw an electron up to a higher orbital , which means that the energy that it emits would be higher energy which means high frequency so it would be in the purple area as opposed to like red

39 **I:** Why are Ne and He tubes different colors?

40 **S:** 11:26 I couldn't say exactly but it would have to do something with the energy, well they have the same current so the electron in the Ne atom are further away the valence electron are further away the nucleus than the He electron are away from its nucleus, so it would take more energy... the Ne would be a higher frequncy, lower wvlgth because it's more energy - no it's the opposite way - because the protons in the nucleus are further away from the electron so it's not at much attraction so it would be a little easier to push it one more out in Ne. so then Ne would be a higher wavelength color as opposed to He. the energy emitted would be greater for He.

41 **I:** 13:29 Over time, would the tubes change color?

42 **S:** huh, I'll probably go home and try it right now - um, if the current is constant, I don't think they would change color because the atoms would still be inside of the tube unless they were like diffusing out , and if all the atoms of the gas were still in there then as long as you keep shining photons, packets of energy to the electron it would keep shooting them out and back down emitting light I don't think it would change color

43 **I:** what would need to happen in order for the color to change?

44 **S:** it would need to be more energy in the current to send it to a different orbitals so when it would come back down it would emit a different energy of light , yeah it would be that, that's one thing

45 **I:** 14:54 Is there any amount of energy that wouldn't light the bulb?

46 **S:** yeah if it was not enough to send it from the 1s to the 2s of He what happens? then I think it would just like transmit

47 **I:** 15:52 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

48 **S:** so this would be like energy and this would be like here they would be closer together and here further apart

49 **S:** 23:00 n1 is most stable. The negative is the energy that's put in, and the positive of that is the energy…

50 **I:** 16:56 How much energy is needed to ionize Hydrogen?

51 **S:** this is IE [points to diagram]

52 **I:** 17:13 Can you draw the absorption spectrum of Hydrogen?

53 **S:** the absorption spectrum is the specific wavelengths that an atom or anything would absorb. H would absorb these specific energies of light

54 **I:** why?

55 **S:** because this is the energy that it takes for … so 82 kJ/mol is the energy that it takes from the n4 to shoot the n4 energy level...

56 **I:** 18:04 what energies of light would H absorb?

57 **S:** it would absorb the energies that would send it to a different orb shell. Like if you put in 82 kJ, it would absorb 82 but it wouldn't absorb 83 or 81

58 **I:** 18:42 what is energy in ground state?

59 **S:** the energy of the electron is 1312 kJ/mol in its n1 ground state

60 **I:** 18:58 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

61 **S:** um the electron would be shot out because it's past the IE it's past the threshold so it would just be like shot out of the nucleus

62 **I:** 19:12 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

63 **S:** then light of 500 kJ/mol would pass through the atom it would just like pass through the atom

64 **I:** 19:38 82 kJ/mol?

65 **S:** then it would send the electron to one from the it would send it from the ground state to the first shell. I mean from the first shell which is 1s to the second shell which is 2s

66 **I:** 20:21 how much energy needed to go from n=1 to n=2?

67 **S:** it's 1312 - 328, so 984

68 **I:** What if you shine 984?

69 **S:** the electron would move from the n1 to the n2

70 **I:** 20:55 How is this different from an emission spectra?

71 **S:** an emission spectrum is kinda the opposite of the absorption spectrum as in where if you were to have an emission of an absorption spectra that would absorb here and not absorb here, the emission spectra would be it's absorbing this so it would be emitting here and not emitting here, it's kinda like the opposite, like when it absorbs, it doesn't emit, and when it doesn't absorb it emits

72 **I:** 21:21 Does H in ground state emit light?

73 **S:** H in its ground state would not emit i think any light because it doesn't have any light in it so there is no electron being like dropping to a lower energy level

74 **I:** 25:13 So, what is the electron doing when it emits 984?

75 **S:** it's coming down from here to here

Student No: 37

	Evidence	Code
Probabalist/ Determinist	cloud area were the electron is somehow floating around it	3
Discrete/ Continuous	06:13 They explained it with the stairs, you can take a step up or down, but you can't go in between	3
Interpreting Spectra Code	11:12 yes, it's enough to ionize it, it would absorb it and shoot the electron off… to get to n=2 it's the difference between n=1 and n=2 so whatever 984 kJ. It would absorb 984 kJ and move it to n=2. 1166 would take it to n=3, 1238 you would see 4 lines, and you would see 4 + 4... not these but you would only see the 4 lines 13:25 would not see 82, 146, 328, 1312 are just what the energies are, not how much energy is required...	3
Energy/Force Code	03:40 it puts more energy into it, and it can't stay at that lowere energy state so it knocks it up, but then it can't maintain it so it jumps back down and releases light, releases the same amount of energy that got put into it 06:25 the energy shells or orbitals are different, so the energy that is released when they drop down from one shell to the next is different... don't know why the shells are different	2

Line No.		Transcript
1	**I:**	0:56 Describe how you visualize the atom
2	**S:**	tiny little nucleus, cloud area were the electron is somehow floating around it
3	**I:**	01:08 How would you describe oxygen?
4	**S:**	eight electrons, 8 protons, 8 neutrons, radius is a bit bigger but basically the same structure, just on a larger scale, there are different shells of electrons
5	**I:**	What are these shells?
6	**S:**	01:36 there are different orbitals there is the s orbital, then s2 and p2, increasing levels of energy I guess.. the more electrons the more energy you have, it just moves it up to a different orbital..
7	**I:**	what is an orbital?
8	**S:**	is where an electron floats around, like a shell, I guess... In oxygen, 2 electron in the s1, 2 in the s2 and 4 in the p2
9	**I:**	02:50 Describe how you visualize light
10	**S:**	little photons they are sorta particles but waves at the same time… it's not a particle and not a wave, but its both at the same time
11	**I:**	03:22 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
12	**S:**	it depends on how much the energy of the photon is, if its above the threshold energy then it will knock that electron either, depending on the energy it is, to the next energy level or if it's enough it will knock it completely off the atom
13	**I:**	why?
14	**S:**	03:40 it puts more energy into it, and it can't stay at that lowere energy state so it knocks it up, but then it can't maintain it so it jumps back down and releases light, releases the same amount of energy that got put into it
15	**I:**	04:19 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?
16	**S:**	the electron is knocked out, has greater KE, moves faster
17	**I:**	05:04 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

18 **S:** when the electric current goes through it and it raises the electron of the Ne gas to a certain energy level, and when it drops down it emits a photon of a specific energy, an energy corresponding to the wavelength of light

19 **S:** 05:40 If it got raised to 3 it can drop down to 2 and from 2 to 1, but it can't drop down to between 2 and 1

20 **I:** why?

21 **S:** 06:13 it's not allowed to, I guess... They explained it with the stairs, you can take a step up or down, but you can't go in between

22 **I:** Why are Ne and He tubes different colors?

23 **S:** 06:25 the energy shells or orbitals are different, so the energy that is released when they drop down from one shell to the next is different... don't know why the shells are different

24 **I:** Over time, would the tubes change color?

25 **S:** 07:01 wouldn't change color... because it's constantly raising the electron to a certain level and dropping them down. If there was some decay

26 **I:** Is there any amount of energy that wouldn't light the bulb?

27 **S:** 07:36 maybe if there is too much energy it would ionize... if it doesn't have enough energy to raise it to the next level it won't emit.. it's not going to move back down and emit

28 **I:** 08:40 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

29 **S:** [drawing] n=1234 represent the different energy levels, the different shells, I guess

30 **I:** 09:18 How much energy is needed to ionize Hydrogen?

31 **S:** 1312 kJ because that's the amount of energy it will take to remove the electron from the shells

32 **I:** 09:39 Can you draw the absorption spectrum of Hydrogen?

33 **S:** I don't remember exactly how to draw it, you will have the energy and the absorption spectra at like 1312, 82, 146… If the energy is different than one of these its not going to affect the electron.

34 **I:** 11:00 What happens if you shine light on hydrogen with an energy of 900 kJ/mol?

35 **S:** 900kJ won't be absorbed

36 **I:** 11:12 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

37 **S:** yes, it's enough to ionize it, it would absorb it and shoot the electron off… to get to n=2 it's the difference between n=1 and n=2 so whatever 984 kJ. It would absorb 984 kJ and move it to n=2. 1166 would take it to n=3, 1238 you would see 4 lines, and you would see 4 + 4... not these but you would only see the 4 lines

38 **I:** would you see these values? [points to diagram]

39 **S:** 13:25 would not see 82, 146, 328, 1312 are just what the energies are, not how much energy is required...

40 **I:** 13:44 How is this different from an emission spectra?

41 **S:** after the electron is absorbed it drops back down and emits. You would see the same things because they are dropping down the same amounts. It can drop down from 2-1 from 4-2 from 3-1 or from the top all the way to the bottom. They would be a little bit different

Student No: 38

	Evidence	Code
Probabalist/ Determinist	The electron are distributed mainly around the edge in an orbital. Found there most of the time. 1 e-, 1 pro, 1 neu. 01:21 the electron are found mainly near the edge of the orbital	2
Discrete/ Continuous	05:15 if not perfect amount of energy, electron is not excited and the light I believe is transmitted, it just goes through 04:31 a very very specific wavelength of light would excite an electron to a different orbital and as it would come down in would emit light. 13:32 - there is no orbital at that halfway pt, there are only distinct levels or places where it can be 14:26 at 990kJ , nothing happens again. It has to go to that step and that has to be it	3
Interpreting Spectra Code	09:34 the energies of n=2, n=3 represent the IE of the different orbitals 09:42 the electron can be excited to other energy levels. got it... so if you put in the amount of light, if you give it the difference between 1 and 2, and 1-3 10:17 (does quick calcs) first one is 984 from n=1 to 2. 182 is from n=2 to n=3 if already at n=2, from 1-3 would be the sum of these 2 differences, same with n=4, if in standard state will absorb from n=1 to n=4	3
Energy/Force Code	The electron are coming to a more neg PE, it's losing energy so that's why it emits light. 06:25 1312 kJ/mol, because this is the PE of this orbital, in order to excite it you need to put in at least that amount of energy to break the attraction to the nucleus 17:26 have different charges on their nucleus, the electron are closer in He than in Ne, so it would be harder to remove He electron and excite electron from He	4

Line No.		Transcript
1	**I:**	0:38 Describe how you visualize the atom
2	**S:**	very small nucleus, electrons dispersed around in a cloud-like thing in a spherical shape. The electron are distributed mainly around the edge in an orbital. Found there most of the time. 1 e-, 1 pro, 1 neu.
3	**I:**	Where are the electrons?
4	**S:**	01:21 the electron are found mainly near the edge of the orbital
5	**I:**	01:24 How would you describe oxygen?
6	**S:**	O has 6 electrons, they are in the cloud form in distributed among 3 different orbs - 1s [gestures closer to nucleus], 2s. 2p farther away [draws 2s and 2p]. The 2p is higher in energy and holds more electrons , it's a different shape and can be on 3 different planes. [draws cloud picture of 2s and 2p] 2s and 2p have areas of overlap.
7	**I:**	03:58 Describe how you visualize light
8	**S:**	thinking much more about how light interacts with molecules, fuels reactions, our own bodies, in terms if heat.
9	**I:**	04:31 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
10	**S:**	a very very specific wavelength of light would excite an electron to a different orbital and as it would come down in would emit light.
11	**I:**	04:40 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?
12	**S:**	or it could excite it to the point which exits the atom. If above this, would get KE

13 **S:** 05:15 if not perfect amount of energy, electron is not excited and the light I believe is transmitted, it just goes through

14 **I:** 06:03 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

15 **S:** 06:48 [draws diagram] the 0 is the point where the electron and the nucleus are infinite distance apart. it is a ref point. you need to put in energy to get to here [zero] - i can't really explain it…

16 **I:** 06:25 How much energy is needed to ionize Hydrogen?

17 **S:** 1312 kJ/mol, because this is the PE of this orbital, in order to excite it you need to put in at least that amount of energy to break the attraction to the nucleus

18 **I:** 07:49 Can you draw the absorption spectrum of Hydrogen?

19 **S:** H only has an electron in the n=1, so it would only absorb 1312, the electron is emitted.

20 **I:** How about below 1312?

21 **S:** 09:09 everything under 1312 is transmitted

22 **I:** why?

23 **S:** 09:19 if you shine any other kind of light on it it wouldn't do anything

24 **I:** what do these levels represent?

25 **S:** 09:34 the energies of n=2, n=3 represent the IE of the different orbitals

26 **I:** can it move there?

27 **S:** 09:42 the electron can be excited to other energy levels. got it... so if you put in the amount of light, if you give it the difference between 1 and 2, and 1-3

28 **S:** 10:17 [does quick calcs] first one is 984 from n=1 to 2. 182 is from n=2 to n=3 if already at n=2, from 1-3 would be the sum of these 2 differences, same with n=4, if in standard state will absorb from n=1 to n=4

29 **I:** 08:24 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

30 **S:** emitted with KE. Electron will escape with a velocity

31 **I:** 13:24 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

32 **S:** nothing happens, it's not enough to excite to any of the levels and it can't go halfway, it has to go to the discrete steps

33 **I:** why?

34 **S:** 13:32 - there is no orbital at that halfway pt, there are only distinct levels or places where it can be

35 **I:** can you explain?

36 **S:** 13:55 Stacy used a step ladder - it was very clear. she has to put energy into her foot to get it up the stairs

37 **I:** 14:26 What happens if you shine light on hydrogen with an energy of 990 kJ/mol?

38 **S:** at 990kJ , nothing happens again. It has to go to that step and that has to be it

39 **I:** 14:54 How is this different from an emission spectra?

40 **S:** that shows the wavelengths of light that the electron would emit when the electron come back down to ground state. The electron are coming to a more neg PE, it's losing energy so that's why it emits light.

41 **I:** how about for hydrogen?

42 **S:** 15:45 for H - [draw emissions] from 4-1, 3-1… you would see 6 peaks

43 **I:** would you see an emission spectra from the ground state?

44 **S:** 16:19 no you would not

45 **I:** 16:47 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

46 **S:** when you run a current through it you are exciting the electron in the gas, and when they are excited they are moved up in energy levels. And then the light the emit when they come back to ground state is the light that we see

47 **I:** Why are Ne and He tubes different colors?

48 **S:** 17:02 Ne and He have different energies per level, different for every atom, have different energies for n=1, because different energies, difff frequencies, emit different wavelengths

49 **I:** why?

50 **S:** 17:26 have different charges on their nucleus, the electron are closer in He than in Ne, so it would be harder to remove He electron and excite electron from He

51 **I:** Over time, would the tubes change color?

52 **S:** 17:53 over time would not change color. the would only be emitting those discrete energies

53 **I:** Is there any amount of energy that wouldn't light the bulb?

54 **S:** 18:28 if there was not enough energy to excite the electron at all it would not light the bulb. If we put an energy of 100, it wouldn't be enough to do anything. would need to put a minimum of 984, then the next smallest is 1184...

Student No: 34

	Evidence	Code
Probabalist/ Determinist	No, not necessarily. I mean that's just like an area where it most likely will be	**3**
Discrete/ Continuous	13:52 it just means like a certain package of energy it's not like you can gradually go up steps it's like here's a chunk jump down to the next rung, or ladder, here's a chunk go to the next rung here's a chunk (so like if I had enough energy for 1.5 steps where do I fall, all the way down or to step 1?) well, to the one below it, right below it, you wouldn't fall all the way down (1313?) then it would be able to.. again it has to have enough energy to make it to the next level, so it would stay at the first energy level until it gets enough energy to reach 328 then it would be able to reach to that next level (so again, 1315?) nothing it would stay within itself, stay at n=1 (go to first?) well it would, it would stay within this, and then once you have anough to pass this 328 then it would go to the next one, cause they move in quantized amounts of energy, they don't just go in between	**1**
Interpreting Spectra Code	11:28 so if you're dealing with, so so these would be the different wavelengths the energy like you would be able to well if I do that so pretend it would be this, so it would adjust according to these peaks so 1312, so it would peaking there and at 82 83 so they absorb at these energies (1313?) then it would be able to.. again it has to have enough energy to make it to the next level, so it would stay at the first energy level until it gets enough energy to reach 328 then it would be able to reach to that next level (so again, 1315?) nothing it would stay within itself, stay at n=1 (go to first?) well it would, it would stay within this, and then once you have anough to pass this 328 then it would go to the next one, cause they move in quantized amounts of energy, they don't just go in between	**3**
Energy/Force Code	cause the more energy they have the more they can push away from the positive nucleus. They do move around in every which way but to move away further from the nucleus they need more energy When th energy is shot through it basically kinda interacts with the electron and the electron will get excited um and then it will push the electron to leave and go outside well it all depends on the nuclear charge and the amount of energy it takes for the electron to be able to move away from the nucleus so there are more protons in a nucleus that has a higher atomic number so the effective nuclear charge is going to be stronger	**4**

Line No. **Transcript**

1 **I:** 00:57 Describe how you visualize the atom

2 **S:** ok, so H I kinda picture in a 3D sense, like a nucleus and I picture this cloud of electron around them. It helps me kinda get a sense of relative size cause y'know H is a lot smaller than Oxygen and then automatically I started thinking of the valence electron [inaudible]

3 **I:** 01:23 so what are those electrons doing?

4 **S:** They are on the outermost shell so they can interact with other atoms or molecules and they are also most likely to be lost or gained, etc.

5 **I:** what's a shell?

6 **S:** so, each atom has different energy levels where they.. this is the way that chemists [inaudible] have been able to picture and give some sort of shape to an atom and it's, they separated it so that the electron are most likely to be found according to their energy in certain shell levels. So the higher shell, the higher the energy, again these are not distinct things which are actually in an atom, these are just something that chemists have used to kind of visualize how they interact and the type of orbitals, just locations where the electron are most likely to be found

7 **I:** 02:30 so does an electron stay in its orbital?
8 **S:** No, not necessarily. I mean that's just like an area where it most likely will be
9 **I:** for the most part, are they just going everywhere?
10 **S:** yes.
11 **I:** 02:45 different energy levels, what does that mean to you?
12 **S:** well, so you have the electron going around and every which way possible in the orbitals, if they receive some sort of outside forceto excite them they can move with a little more KE and by doing that they can move up a level to.. and that just basically means that they are spreading outward, away from the center of the cell, cause the more energy they have the more they can push away from the positive nucleus. They do move around in every which way but to move away further from the nucleus they need more energy
13 **I:** 03:40 Can you draw the 2p orbital for oxygen?
14 **S:** so p-orbs look like figure eights, and the nucleus would be in the center and this is the area where they would most likely be found, and then of course it has .. This is gonna be vertical, there you go..
15 **I:** how about the 2s?
16 **S:** well like, ok, so there is this and there would be spherical orbitals in between so that would be the 1s and this would be the 2s a little bit larger. it's pretty similar to that of the 2p and then withink and if it starts to like bind with another atom we learned about hybrid orbitals and they would kind of use constructive and destructive interference to form different shapes so if you wanted to make an sp orbital you would have a shape where the circular portion kinda mixed with the p's...
17 **I:** are they on their own or are they overlapping?
18 **S:** yeah.
19 **I:** 05:50 Describe how you visualize light
20 **S:** well I think of it in waves still. I also learned to think of it as photons, and one thing that is a little bit different than before is when I think of the intensity of light now not only do I see larger amplitudes but I also see more photons or particles which is something that I didn't before.
21 **I:** how do photons fit within the wave picture?
22 **S:** well you can either take... there are 2 models from looking at light, you can either take wave model or you can take the particle model , and the particle model is looking at these packets of energy, these photons being shot through certain energies and then you have the wave model which is thinking of it as a traveling wave and the wavelength dictates the amount of energy
23 **I:** is one model better than another?
24 **S:** no, they are useful in explaining different things so dealing with absorbance is easier to think of using the wave and sometimes thinking of intensity of light its easier to look at photons
25 **I:** 07:08 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

26 **S:** so first off it will excite one of the electron, one of the electron will be emitted because it will be excited to a point where it exceeds the threshold energy and then once it exceeds that it can leave the atom. When th energy is shot through it basically kinda interacts with the electron and the electron will get excited um and then it will push the electron to leave and go outside

27 **I:** 07:40 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

28 **S:** nothing will happen

29 **I:** any cases where it would?

30 **S:** no.

31 **I:** 08:06 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

32 **S:** so gas discharge tube, so you are exciting the electron so I guess in this case you would have an electron that's excited but not emitted so it's excited to a certain point so that it's moving to a higher energy level, and when it moves back down to its ground state so the normal energy level that it would be at that change of energy is equal to the amount of energy put in and that would produce the light

33 **I:** 08:27 Why are Ne and He tubes different colors?

34 **S:** because each atom will have different energies and the amount of energy corresponds to the color

35 **I:** would 1s of He be different than Ne?

36 **S:** yes

37 **I:** why?

38 **S:** well it all depends on the nuclear charge and the amount of energy it takes for the electron to be able to move away from the nucleus so there are more protons in a nucleus that has a higher atomic number so the effective nuclear charge is going to be stronger

39 **I:** 09:10 Over time, would the tubes change color?

40 **S:** over time? no, I don't think so.

41 **I:** why not?

42 **S:** well if you are using the same atom it's still going to have the same attraction, it's not going to be reduced unless something comes in the way and there's a fusion or the atoms change

43 **I:** 09:39 Is there any amount of energy that wouldn't light the bulb?

44 **S:** anything that isn't enough to exceed the energy different between the levels, so if there is something that's like below that energy nothing will happen. It has to be enough energy to move it to a different level

45 **I:** 10:10 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

46 **S:** so if you make this zero and make this 1312 , the difference from here to here will be 328 and the different from here to here would be 146, and 82 so the initial difference is larger and then it gets smaller

47 **I:** so why are you worried about the differences?

48 **S:** um well between each one there are different energy like we were saying as we progress outward the n correlates to a different energy level so the higher you get the more you get out the more energy it has so from zero to 1312 there's.. that how much energy between the nucleus and the first energy level , and when you get to 328 that's the difference between n2 and n1 and 146 is the different between n3 and n2 and 82 is the different between n4 and n3

49 **I:** 11:13 How much energy is needed to ionize Hydrogen?

50 **S:** altogether it would be 1312 +.. You add them all together, it would end up being them all

51 **I:** 11:28vCan you draw the absorption spectrum of Hydrogen?

52 **S:** so if you're dealing with, so so these would be the different wavelengths the energy like you would be able to well if I do that so pretend it would be this, so it would adjust according to these peaks so 1312, so it would peaking there and at 82 83 so they absorb at these energies

53 **I:** 12:06 How is this different from an emission spectra?

54 **S:** it's the opposite so instead of looking like this it woud look the exact opposite

55 **I:** 12:23 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

56 **S:** 1512? It would excite it to a certain point but it wouldn't be able to ionize

57 **I:** 12:40 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

58 **S:** nothing would happen. Because it wasn't able to have enough energy t o reach the first energy level, so it has to be at least past this for it to move anywhere

59 **I:** ok, what if 1312?

60 **S:** well if it meets it it would be able to go up to this point but it would just be there it would go to the first energy level and that's it

61 **I:** how about 1313?

62 **S:** then it would be able to.. again it has to have enough energy to make it to the next level, so it would stay at the first energy level until it gets enough energy to reach 328 then it would be able to reach to that next level

63 **I:** so again, 1315?

64 **S:** nothing it would stay within itself, stay at n=1

65 **I:** where would it go to first?

66 **S:** well it would, it would stay within this, and then once you have anough to pass this 328 then it would go to the next one, cause they move in quantized amounts of energy, they don't just go in between

67 **I:** 13:52 what does quantized mean to you?

68 **S:** it just means like a certain package of energy it's not like you can gradually go up steps it's like here's a chunk jump down to the next rung, or ladder, here's a chunk go to the next rung here's a chunk

69 **I:** so like if I had enough energy for 1.5 steps where do I fall, all the way down or to step 1?

70 **S:** well, to the one below it, right below it, you wouldn't fall all the way down

Student No: 41

	Evidence	Code
Probabalist/ Determinist	I know they are there somewhere in the shells, but I don't know where just somewhere	3
Discrete/ Continuous	(990?) no it's not going to do anything, it has to be exactly right, it can't be like a little but over the second subshell it has to be exactly on the second subshell, the light has to match up with the difference exactly, the electron can't really have KE in the shell because it's already there it can't really move	3
Interpreting Spectra Code	12:36 so all the bars are the same height.. This is the IE... (so what do these lines represent?) well this is the amount like if you shine light on H, it is the emission spectra, well if you shine light that is 12?? On it then it willjump up to the n=4 shell and then fall to the n=3 then n=2 n=1 shell, so when it falls it emits a specific wavelength of light but for some reason it's weird to look at it like that .. H doesn't fall 2 shells, falls one at a time 16:00 (500) it doesn't match up so it would shine right through, it would transmit, like that window, light is being transmitted, it doesn't interact with the e- 16:35 (984?) it is going to get absorbed and then re-emitted because the electron are going to go to the n=2 subshell and fall back and release energy of that same amount (990?) no it's not going to do anything, it has to be exactly right, it can't be like a little but over the second subshell it has to be exactly on the second subshell, the light has to match up with the difference exactly, the electron can't really have KE in the shell because it's already there it can't really move	2
Energy/Force Code	and as the electron falls back down levels it can either fall all the way back down once and release energy of that same wavelength or it can fall down in steps and release different energy light they all have their own same IE because of different elecronegativities, different pull on the electron so different amts of energy released because the PE is different for electron in each of their shells (why, what does this mean to you?) electron in their shells when you take them off, when they come back they release the same amount of light (so every 2p is at the same energy level?) no, because there is different protons in the nucleus so the energy levels gonna be different because there is going to be more just looking at coulombs law there is more magnetic forces pulling it together and they're shielded by electron and other stuff	3

Line No.		Transcript
1	**I:**	0:42 Describe how you visualize the atom
2	**S:**	positive electron moving in orbitals now.. Like intellectually I know there are orbitals, but I still sort of picture like discrete levels of atoms
3	**I:**	tell me about this discreteness
4	**S:**	like the rows n like the rows of the periodic table and each row is like another level like electron cloud thing
5	**I:**	what would prompt you to think about orbitals?
6	**S:**	like if I get a problem like.. like I think about orbitals and i think about that but if you tell me to visualize an atom my first instinct ... like I do think about orbitals but that's not my first instinct... like they are all models anyway so whatever the problem needs I just find the model that works, the simplest model that works
7	**I:**	02:27 what do picture the electron doing in these discrete...

8 **S:** I'm not picturing the electron, I know they are there somewhere in the shells, but I don't know where just somewhere

9 **I:** do they have to stay in the certain shells?

10 **S:** I mean like they are probably in a certain shell but they could jump but it's just not very likely

11 **I:** 02:57 Describe how you visualize light

12 **S:** oh gosh, you ask me this right now, I just saw this picture of this guy on a skateboard riding into a light wave, but I don't know if that's kind of how I visualize it like, like it's sort of a difficult question

13 **I:** what are the different ways you see it?

14 **S:** well if it were like straight lines going on forever becase that's the simple intuitive way to see, and if that doesn't work then go to thinking about it as a wave theory and then pretty much photons go in a straight path cause not usually, but in a lot of prblems you don't have to worry about that

15 **I:** 03:52 what are the different reasons for different ways?

16 **S:** light has properties that are wavelike and particle like and the ray theory works on big pictures , so you can't always think of light one way or another

17 **I:** 04:15 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

18 **S:** depends on the energy different between the levels of the electron in the atom. Well if it corresspons to an energy different between levels of electron in the atom , then it will jump up between the levels of light matches up with, so it would be absorbed by the atom , and as the electron falls back down levels it can either fall all the way back down once and release energy of that same wavelength or it can fall down in steps and release different energy light

19 **I:** 04:50What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

20 **S:** [inaudible] the electron comes off and. KE of the electron

21 **I:** 05:20 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

22 **S:** you are running electron through the tube and these free electron can fall can fall back to from outside the atom to inside the atom and when they do that its sort of like reverse ionization so the amount of light that is required to get it ionized is then released

23 **I:** 05:47 Why are Ne and He tubes different colors?

24 **S:** cause they have a different IE

25 **I:** why?

26 **S:** cause they have different orbitals, different electron like He is just has the one spherical whereas Ne has 1s22s23p3

27 **I:** what about Ne and Ar? Are they the same color?

28 **S:** they all have their own same IE because of different elecronegativities, different pull on the electron so different amts of energy released because the PE is different for electron in each of their shells

29 **I:** why, what does this mean to you?

30 **S:** electron in their shells when you take them off, when they come back they release the same amount of light

31 **I:** so every 2p is at the same energy level?

32 **S:** no, because there is different protons in the nucleus so the energy levels gonna be different because there is going to be more just looking at coulombs law there is more magnetic forces pulling it together and they're shielded by electron and other stuff

33 **I:** 07:46 why certain energies?

34 **S:** they have to be in the set they are, like in the model because they can't all be in the same area because electron are all going to be charged, so these energies have these quantum numbers and do a a lot of math and spits out these orbitals

35 **I:** 08:45 Over time, would the tubes change color?

36 **S:** um, I would guess so becaues all the shells... no, I don't think so - I get this feeling that the answer is no even though I don't know why - probably because there is electron being.. the current is running... the electron leave - honestly I don't know

37 **I:** could you change the color?

38 **S:** if all the orbitals, if you fill all those up with electron I guess the color might change

39 **I:** 10:08 Is there any amount of energy that wouldn’t light the bulb?

40 **S:** electricity is just the flow of electrons, so it's not necessarily, there is always going to be some light, but if it's really low you might not see it , like if you had 1 electron on one atom it would still make a tiny bit of light

41 **I:** 12:36 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

42 **S:** so all the bars are the same height.. This is the IE...

43 **I:** so what do these lines represent?

44 **S:** well this is the amount like if you shine light on H, it is the emission spectra, well if you shine light that is 12?? On it then it willjump up to the n=4 shell and then fall to the n=3 then n=2 n=1 shell, so when it falls it emits a specific wavelength of light but for some reason it's weird to look at it like that .. H doesn't fall 2 shells, falls one at a time

45 **I:** 14:29 Can you draw the absorption spectrum of Hydrogen?

46 **S:** it would absorb all wavelngths of light, it represents the same information, basically it's going to say that if it's not emitting that light it's gonna absorb that light, I don't remember, you can represent it like this but I don't think it is, it would absorb 1312 and past after 1312 it would be like this [darkens] because after 1312 it's just gonna shot the electron and absorb it

47 **I:** 15:43 How much energy is needed to ionize Hydrogen?

48 **S:** 1312

49 **I:** 15:48 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

50 **S:** It would send off electron with a KE of 200 kJ

51 **I:** 16:00 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

52 **S:** it doesn’t match up so it would shine right through, it would transmit, like that window, light is being transmitted, it doesn't interact with the electron

53 **I:** 16:35 how about 984?

54 **S:** it is going to get absorbed and then relectronemitted because the electron are going to go to the n=2 subshell and fall back and release energy of that same amount

55 **I:** how about 990?

56 **S:** no it's not going to do anything, it has to be exactly right, it can't be like a little but over the second subshell it has to be exactly on the second subshell, the light has to match up with the difference exactly, the electron can't really have KE in the shell because it's already there it can't really move

Student No: 42

	Evidence	Code
Probabalist/ Determinist	electron that go around so basically how they described it is like an electron cloud so it's not exactly going in a circle but a 3D shape there's like a relative cloud there are electron density	3
Discrete/ Continuous	09:53 (500) I think that just gets absorbed and and the electron don't really.. They might absorb the energy but they won't move 10:05 (984?) If it was originally in n=1, I think because that different is exact for this it would move from n=1 to n=2. (does it need an initial 1312, or only need that diff?) I think it only needs that difference. (how is that case different from 1512?) I think because this energy is so great it goes into the ionization and the KE but then because this isn't any of the exact amts except for the different it would just move up a shell	2
Interpreting Spectra Code	09:53 (500) I think that just gets absorbed and and the electron don't really.. They might absorb the energy but they won't move 10:05 (984?) If it was originally in n=1, I think because that different is exact for this it would move from n=1 to n=2. (does it need an initial 1312, or only need that diff?) I think it only needs that difference. (how is that case different from 1512?) I think because this energy is so great it goes into the ionization and the KE but then because this isn't any of the exact amts except for the different it would just move up a shell 08:42 (1512?) it would ionize it from n=1, but it doesn't have enough energy to jump it to the next level , so I think it just the electron breaks away from the first IE and the rest to KE (why not enough) so all the energy would go into 1312, and then the rest there is like 200 left (so what is the initial 1312 going into?) moving the electron out of the shell (where does it go?) I believe it just gets separated from the atom so then there just isn't any electron anymore	2
Energy/Force Code	04:40 this color is caused by I believe when an electron gets excited it jumps to different shell and then afterwards that energy calms down and it woud go back to it's original shell and so that drop in energy level will emit a color	2

Line No.		Transcript
1	I:	00:50 Describe how you visualize the atom
2	S:	I see it as an orbital now so one positive proton as a nucleus and then an electron going around
3	S:	01:07 yeah they all have like different shells and subshells and the order of the electron that go around so basically how they described it is like an electron cloud so it's not exactly going in a circle but a 3D shape there's like a relative cloud there are electron density
4	I:	What are orbitals?
5	S:	orbitals are like the energy levels in which the electron are moving in
6	I:	Are they at random energies?
7	S:	they are at discrete energies that's what they told us and basically like if a photon or a higher energy or light hits an electron it will be excited and jump to a different subshells
8	I:	why discrete energies?
9	S:	just based on observation i guess
10	I:	do they stay in their orbital?
11	S:	usually they do, yes.
12	I:	02:26 Describe how you visualize light

13 **S:** light is a wave and a particle, so there was that dual theory so light can come hit you as a wave or particle or both
14 **I:** is one more exac than anothert?
15 **S:** no not really I think it's just two different ways to describe it because of it's behaviors
16 **I:** what do these models get you?
17 **S:** well sort of like they wanted us to understand how it behaves and interacts with other atoms and stuff and so I guess like to describe it in two different ways it's easier to understand how it interacts with other materials
18 **I:** 03:37 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?
19 **S:** the rest of the energy goes into the KE of the electron so it gets ejected. I think it's sort of photon particles so there is a little energy packet of light and it hits like an atom and then the electron gets excited moves up the shells and then eventually it gets to the last shell it will break off and then yeah it wil be removed
20 **I:** 04:15 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
21 **S:** I believe it will either absorb the light and stay in that same shell if it's not in a discrete energy level to jump it to a different shell
22 **I:** 04:40 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?
23 **S:** this color is caused by I believe when an electron gets excited it jumps to different shell and then afterwards that energy calms down and it woud go back to it's original shell and so that drop in energy level will emit a color
24 **I:** 05:03 Why are Ne and He tubes different colors?
25 **S:** um, probably because they have different number of shells so it's going to emit a different color because of that
26 **I:** For the 1s to 2s change for both - is it the same color?
27 **S:** I don't know...
28 **I:** 05:30 Over time, would the tubes change color?
29 **S:** no, if the He stayed He then no
30 **I:** 05:41 Is there any amount of energy that wouldn't light the bulb?
31 **S:** probably one that doesn't make the electron excited.
32 **I:** 06:00 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
33 **S:** which kind? Energy level diagram so right now I'm thinking of the spectra - that's not what you want right?
34 **I:** what do you think it would be?
35 **S:** I'm not too sure.
36 **I:** what are the different energy levels in this atom?
37 **S:** 1,2,3,4, 4 different energy levels.
38 **I:** what do these numbers mean?
39 **S:** that's how much energy is needed to make the electron jump to the next energy level
40 **I:** 07:03 Can you draw the absorption spectrum of Hydrogen?
41 **S:** that would have a curve depending on which wavelength it would absorb at
42 **I:** 07:11 How much energy is needed to ionize Hydrogen?
43 **S:** negative 1312 kJ/mol - that was repeated in lecture multiple times. Well since I guess it's H it's the first IE is -1312, that's why the electron
44 **I:** what are the possible jumps for the electron in H?

45 **S:** H has one electron so I thought there was only one energy level, but according to this table there is four.

46 **I:** how much energy to get from 1 to 2?

47 **S:** the difference between 1 and 2

48 **I:** if that was 984…

49 **S:** that's the energy required to make it jump between energy levels 1 and 2

50 **I:** 08:42 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

51 **S:** it would ionize it from n=1, but it doesn't have enough energy to jump it to the next level , so I think it just the electron breaks away from the first IE and the rest to KE

52 **I:** why is it not enough?

53 **S:** so all the energy would go into 1312, and then the rest there is like 200 left

54 **I:** so what is the initial 1312 going into?

55 **S:** moving the electron out of the shell

56 **I:** where does it go?

57 **S:** I believe it just gets separated from the atom so then there just isn't any electron anymore

58 **I:** 09:53 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

59 **S:** I think that just gets absorbed and and the electron don't really.. They might absorb the energy but they won't move

60 **I:** 10:05 984?

61 **S:** If it was originally in n=1, I think because that different is exact for this it would move from n=1 to n=2.

62 **I:** does it need an initial 1312, or only need that diff?

63 **S:** I think it only needs that difference.

64 **I:** how is that case different from 1512?

65 **S:** I think because this energy is so great it goes into the ionization and the KE but then because this isn't any of the exact amts except for the different it would just move up a shell

66 **I:** 11:22 possible emissions?

67 **S:** it couldn do n=4 to 3, 4 to 2, 4 to 1, or any other level 3 to 1, 3 to 2 , 2 to 1

68 **I:** do they all have to go to 1?

69 **S:** eventually. They go back to ground state. It can jump up it can absorb energy and jump up 1 to 2 or 1 to 4 and then it would jump down

70 **I:** going up, does it always have to start at 1?

71 **S:** If there was an initial amount of energy that already made it to different energy level it could start from there but otherwise it would start from 1

Student No: 43

	Evidence	Code
Probabalist/ Determinist	An orbital is a place where an electron is likely to be . so spdf and they all have different shapes nd based on their valence electron s2's and p becomes a 6 they just kinda inhabit different areas like 3 dimensional shapes in the atom	3
Discrete/ Continuous	I guess you could excite it to somewhere in between but it's always gonna fall back to the last energy level that it crossed. because the electron can't exist in between levels so it either has to be in one or another 17:13 (500?) you wouldn't be able to move it up to n2 so the electron would still be in n1 (984?) is that the difference between n1 and n2? It would reside in the n2 energy level. (985?) it also would go to the n2 energy level it would just come back to the n2 because it doesn't have enough energy to get to the n3 (extra energy?) (inaudible, but shakes head like doesn't know)	1
Interpreting Spectra Code	yes, well the first.. the electron is in the n1 start so like the first jump would be up to the n2 level (what is that?) it's the difference between these two so it would be whatever that minus 328 (would you have a line for the differenc between 2 to 3) well no because you only have one electron for H so it can only go one to the other (does it always have to start at one?) I think so.	3
Energy/Force Code	well if it doesn't have enough energy to excite it to a certain level, energy is conserved so it would be false to say it absorbs the energy so I'm not sure. 10:37 (how does that play in - energy is conserved?) um, well you can't like energy is always going to be doing something, so it's either going to be into work, into KE into bumping the electron heat whatever so it's just like energy just doesn't come and disappear it's always going to go to something the current goes through the gas they excite the electron in the gas the atoms and they go up to some energy levels and when they come back down they emit energy which we see as the light you would start with the nucleus and based on what it is you kinda have to picture it how big it is cause that's gonna be related to the pull on the electron because the electron here is at a lower energy state than the electron in the p-orbitals (why different energy levels?) because it's a different I believe pull like the closer they are to... yeah it's coulomb's law the closer they are to the nucleus the more pull it's gonna have on it	4

Line No.		Transcript
1	I:	01:25 Describe how you visualize the atom
2	S:	um, well first you would start with the nucleus and based on what it is you kinda have to picture it how big it is cause that's gonna be related to the pull on the electron. I just kinda, I picture the nucleus and first you picture the rings but now it's kinda like orbitals you picture where the electron might or might not be , so you got those orbital clouds
3	I:	02:11 what do you mean by orbital?
4	S:	An orbital is a place where an electron is likely to be . so spdf and they all have different shapes nd based on their valence electron s2's and p becomes a 6 they just kinda inhabit different areas like 3 dimensional shapes in the atom
5	I:	why do they inhabit these different areas?
6	S:	don't know. don't know why they do that
7	I:	03:00 how is 2p in relation to 2s or 1s?

8 **S:** Well, It's gonna take a different shape, the s is usually a circle around , the p's is gonna be in kind of a dumbell shape , and mostly it's going to be either over her or over here and the node in the middle the e= is not going to be it will be either here or there , one is one side of the atom and the other is on the other side of the atom

9 **I:** how about s's and p's?

10 **S:** I believe like when there is s's and p's together it's going to be circular nodes around so you have the area where the s electron can be and there is a space and then you have where the p electron can be

11 **I:** can you draw it out?

12 **S:** yeah, s's and p's together there is this area around here kinda, this is the area where the s electron can be and then here on either side is where the p electron can be can the electron go in between? from p to s to p I don't think so. they can go from p to p. well it can, it just takes energy the electron cannot freely do it

13 **I:** 04:44 why does it take energy to do so?

14 **S:** because the electron here is at a lower energy state than the electron in the p-orbitals

15 **I:** why are there different energy levels?

16 **S:** because it's a different I believe pull like the closer they are to... yeah it's coulomb's law the closer they are to the nucleus the more pull it's gonna have on it

17 **I:** is it the same for all atoms?

18 **S:** yeah, I believe it's the same for all atoms, yeah.

19 **I:** would a 2p in N and a 2p in O be the same?

20 **S:** no. because there is more positive charge in oxygen than there is in N so the pull is gonna be greater on the p electron in oxygen, I mean in Nitrogen rather than oxygen

21 **I:** 05:52 Describe how you visualize light

22 **S:** I can see it. It kinda depends on what kind of problem or question you are trying to answerlike you can either look at it as like a photon a bunch of photons or a wave. And so If I try to visualize certain types of energy problems I try to think which light has more energy, shorter wavelength so I picture it that way but if you are talking about light excites electron you look at it like a photon hits it and then excites it as opposed to getting caught in a wave.

23 **I:** is one better than another?

24 **S:** I think for certain problems, well it all depends on which one is easier for you to grasp and go with I think they both work to some extent

25 **I:** so which one is really light?

26 **S:** I don't know that. um, I think like light does have photons but there's also properties that light has which also like correspons with wave theory

27 **I:** 07:06 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

28 **S:** the electron is released from the atom and the extra goes to KE of the electron

29 **I:** how is it released?

30 **S:** it excites it above which is all other energy levels it goes up to n infinity it goes beyond like there is a certain point that is the IE that is too [inaudible] for any level to I guess capture it and then once it surpasses all of that it no longer has sufficient pull to the nucleus for it to bring it back

31 **I:** 08:52 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

32 **S:** depending on how much energy it has it will bump it up to a certain energy level and then um it needs to be like exactly the right level it can't be in between so like it goes up to n2 or n3 or something like that
33 **I:** why exactly that amount?
34 **S:** I guess you could excite it to somewhere in between but it's always gonna fall back to the last energy level that it crossed. because the electron can't exist in between levels so it either has to be in one or another
35 **I:** what if it is not one of these levels?
36 **S:** then it would reside in the energy level that it just surpassed
37 **I:** so if I gave it a little more than n=2, would it bump up there and fall to 2?
38 **S:** yeah fall to 2.
39 **I:** so it wouldn't stay at one?
40 **S:** no, I don't think so, it would go to 2
41 **I:** what if it''s not enough to get it anywhere?
42 **S:** well if it doesn't have enough energy to excite it to a certain level, energy is conserved so it would be false to say it absorbs the energy so I'm not sure
43 **I:** 10:37 how does that play in - energy is conserved?
44 **S:** um, well you can't like energy is always going to be doing something, so it's either going to be into work, into KE into bumping the electron heat whatever so it's just like energy just doesn't come and disappear it's always going to go to something
45 **I:** 11:18 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?
46 **S:** as the electron go through, the current goes through the gas they excite the electron in the gas the atoms and they go up to some energy levels and when they come back down they emit energy which we see as the light
47 **I:** 11:41 Why are Ne and He tubes different colors?
48 **S:** because the electron in the orbitals go to different energy states when they up to these certain levels so when they come back down they all release different energies so we see different colors
49 **I:** 11:58 Over time, would the tubes change color?
50 **S:** well if they were perfectly insulated tubes, i don't think... well I guess depnding on what you bump them up to you put a lot of current in you might release a bunch up to the IE but
51 **I:** 12:24 Is there any amount of energy that wouldn't light the bulb?
52 **S:** if you don't have enough energy to bump up any electron to excite any electron to see light
53 **I:** 12:57 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
54 **S:** [draws] that represents as you go this way you are increasing energy and zero would be up here, so the difference between each energy level is going to get smaller and smaller but it's still negative once you reach zero it's ionized
55 **I:** 13:50 How much energy is needed to ionize Hydrogen?
56 **S:** 1312 kJ
57 **I:** 14:06 Can you draw the absorption spectrum of Hydrogen?
58 **S:** Hydrogen has only got 1 electron wait the absorption would be… are you talking about the absorption spectra when you are talking about the different wavelengths here? And which wavelength gets absorbed? Like energy?
59 **I:** yes

60 **S:** I guess I don't really remember what the cross [axis] is but i guess it doesn't matter you will have energy going this way. You would have a line here and then closer. these cross lines, these lines up here where it's like increasing energy needed to excite the electron

61 **I:** 15:07 for H, what are the possibiliites that the electron can do if I put energy in?

62 **S:** it can go up to n2, depending on how much energy you put it can go to n2 n3 n4 so it jumps an energy level each time

63 **I:** so are the lines in the spectra the numbers in the table?

64 **S:** yes, well the first.. the electron is in the n1 start so like the first jump would be up to the n2 level

65 **I:** what is that?

66 **S:** it's the difference between these two so it would be whatever that minus 328

67 **I:** would you have a line for the difference between 2 to 3

68 **S:** well no because you only have one electron for H so it can only go one to the other

69 **I:** does it always have to start at one?

70 **S:** I think so.

71 **I:** 16:28 How is this different from an emission spectra?

72 **S:** an emission would be slightly different becaue you would have these energy levels 2 3 or 4 and you can drop down to 4 to 3 or 4 to 2 or 4 to 1 ; 3 to 2, 3 to 1 so you would have a bunch of different lines to show kind of the different releases of energy

73 **I:** 16:58 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

74 **S:** it would be sent off and it would have KE of 200 kJ

75 **I:** 17:13 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

76 **S:** you wouldn't be able to move it up to n2 so the electron would still be in n1

77 **I:** 984?

78 **S:** is that the difference between n1 and n2? It would reside in the n2 energy level.

79 **I:** 985?

80 **S:** it also would go to the n2 energy level it would just come back to the n2 because it doesn't have enough energy to get to the n3

81 **I:** how about the extra energy?

82 **S:** [inaudible, but shakes head like doesn't know]

Student No: 44

	Evidence	Code
Probabalist/ Determinist	01:34 to me that means like they are there they are moving around and they are not necessarily bound to that one specific area like they can be found cause i remember something from lecture like it showed where they are likely to be found, they are still outside of the heavily populated region where they could be found, but they are most likely to be found there and maybe they are moving around orbiting around	3
Discrete/ Continuous	16:40 (984?) in that case that would raise the level of the electron up to the n=2 shell and then after that the electron would drop back and that would emit the light of that wavelength (985?) that wouldn't do anything, that would pass through because it's not the exact amount required to change shells (so it can't go a little bit above?) no that's like the discrete	3
Interpreting Spectra Code	06:14 if it was lower than the IE? Um, it would not eject it, if it has a specific different between energy levels it would excite it to that energy level, if not it wouldn't be absorbed at all 12:16 these are the energies of the different of like the first shell, the 1s 2s 3s 4s like this energy gap right here is the amount of energy required to raise the electron in H like a single electron from the 1s to the 2s , this much is from the 2s to the 3s or you could do like 1s to , like any of these combinations or the energy different between the levels in H	3
Energy/Force Code	06:43 that is when the electron like electric current is just free floating electron those can be absorbed by the energy can be absorbed by the atoms in the two and then what that energy does is that it excites the electron to a certain energy level and then when those electron in the atom drop back to their original or drop back to a ower they emit that energy in the form of light and sometimes it can be like UV light or IR one of those but like when it emits a certain wavelength of light it's like in the visible spectrum it emits that color when the energy equals zero that's like no attraction between the proton and the electron so when the energy is zero it requires 1312 to get it up to that and that's when it's ionized the effective nuclear charge strengthens pulls electron it might take more energy to raise it up a level than the atom before it so the same thing with atoms going down a group, so maybe there is more tightly .. well as they go down they probably won't be as tightly knit so it would be easier so it would be easier to eject an electron, less energy so diff	4

Line No.		Transcript
1	I:	00:45 Describe how you visualize the atom
2	S:	uh a lot different than I did in the beginning, I picture it as like a nucleus with a lot of empty space between the nucleus and the electron and their orbitals are like areas where they will most likely be found - uh, I forget the name of the eqn but it can predict like where they are where they are most likely, and depending on the number of shells like spd like what subshell they have different patterns of electron orbitals

3 **S:** 01:34 to me that means like they are there they are moving around and they are not necessarily bound to that one specific area like they can be found cause i remember something from lecture like it showed where they are likely to be found, they are still outside of the heavily populated region where they could be found, but they are most likely to be found there and maybe they are moving around orbiting around

4 **I:** 02:05 can they move between orbitals?

5 **S:** uh, yes, you mean like s and p or like different subshells?

6 **I:** like both…

7 **S:** well yeah they can move between different shells because that's what causes like when they drop back down the emitting of light and that's what like when energy is added they go up different subshells or different shells and I imagine they could do the same thing for subshells, like s to p

8 **I:** do you have to have energy to move between them?

9 **S:** yes to move electron from one shell up to another one it requires that specific amount of energy cause if you have like more or less it's not gonna move it up to that shell so you have to have a specific amount of energy but yes that has to be added

10 **I:** 02:57 why is energy important? why are orbitals at different energy levels?

11 **S:** why at different energy levels? it's a good question.. I guess I never thought about why these levels, I just assumed thet were - well if I had to say like why there are different energy levels like maybe I'm thinkining something like maybe the nucleus has more protons or something - I don't know.

12 **I:** 03:32 would 2p of O and N be at the same energy level?

13 **S:** well they'd be the same , the electron that would have the same energy would be on that level , but Oxygen has has another electron on that level , that's my periodic table [gesturing] but it has an extra one but maybe that electron shell has more energy but

14 **I:** 04:18 Describe how you visualize light

15 **S:** I see it kinda of as a wave a waveform and its I picture of it just like a particle that travels along a wave path and it's kinda like in lecture they said it's kinda like if it acted just like a particle so I picture it as like particles like a photon just moving along a wave path so it can be absorbed by atoms

16 **I:** 04:49 why is it sometimes as a particle and sometimes as a wave?

17 **S:** well I think it's uh I remember there was a demo in lecture where they had the wave model and it was going through like the two holes the two slits or whatever and then they caused the different types of wave formation. I think for like the purposes of atoms it can be used as like a particle that's like energy to raise electron but like if you see it in like a room it's kinda like a wave because well I can't see light particles but I guess for the purpose of the bending of light it can be used as a wave

18 **I:** 05:40 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

19 **S:** uh so can we say it's just like H with like 1, so if it's H with one electron and like the light hits that with the IE it will eject it, so if it's something higher than the IE it would be ejected and all the leftover energy applied by the photon or whatever the energy source is that would be turns into KE of the electron

20 **I:** 06:14 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

21 **S:** if it was lower than the IE? Um, it would not eject it, if it has a specific different between energy levels it would excite it to that energy level, if not it wouldn't be absorbed at all

22 **I:** 06:43 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

23 **S:** that is when the electron like electric current is just free floating electron those can be absorbed by the energy can be absorbed by the atoms in the two and then what that energy does is that it excites the electron to a certain energy level and then when those electron in the atom drop back to their original or drop back to a ower they emit that energy in the form of light and sometimes it can be like UV light or IR one of those but like when it emits a certain wavelength of light it's like in the visible spectrum it emits that color

24 **I:** 07:28 Why are Ne and He tubes different colors?

25 **S:** mm, well one.. well I want to say because of the different Ne has more shells maybe it can't drop back to the one unless it's like the 1s electron has moved up but um I would say yeah probably because it can go to - oh! ok, I get it now, Ne has different energy levels to get up to like different shells than He so like I don't know exactly but say He had 1000 to get up to this one Ne might have like 1500 to get to this one like that energy different emits a different wavelength of light

26 **I:** so would a 1s to 2s transition look the same for both? or is each different?

27 **S:** I think it's each one is different ones because if the electron had the same color there wouldn't be like the wide variety uh I would say it has to do with the makeup of the atom itself like the protons that has like a different significant effect on the amount of energy required. oh! maybe like as you say you go across a period, the effective nuclear charge strengthens pulls electron it might take more energy to raise it up a level than the atom before it so the same thing with atoms going down a group, so maybe there is more tightly .. well as they go down they probably won't be as tightly knit so it would be easier so it would be easier to eject an electron, less energy so diff

28 **I:** Over time, would the tubes change color?

29 **S:** depends.. I don't know if it would because like these are all happening like really fast and so like the color you see is a result of like a bunch of different energy drops and stuff like that so if you look at then through the spectroscope glasses or whatever you see like the distinct lines and those are the lines, so maybe when you combine those up that's the light you get.

30 **I:** 10:34 Is there any amount of energy that wouldn't light the bulb?

31 **S:** well I guess like if you didn't have the exact energy between levels that wouldn't light it but see I don't know the electric current through I think those might supply various amts of energy so I'm not too sure whether or not it would like not light it

32 **I:** 11:28 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

33 **S:** just these four?

34 **I:** yeah

35 **S:** 12:16 these are the energies of the different of like the first shell, the 1s 2s 3s 4s like this energy gap right here is the amount of energy required to raise the electron in H like a single electron from the 1s to the 2s , this much is from the 2s to the 3s or you could do like 1s to , like any of these combinations or the energy different between the levels in H

36 **I:** 12:52 How much energy is needed to ionize Hydrogen?

37 **S:** ionize is 1312 because that's to remove it completely like I want to say this is like negative potential energy but I'm not too sure but that is like the first shell and see like these different represent like the different subshells, when the energy equals zero that's like no attraction between the proton and the electron so when the energy is zero it requires 1312 to get it up to that and that's when it's ionized

38 **I:** 13:36 Can you draw the absorption spectrum of Hydrogen?

39 **S:** [draws] oh pretty much the absorption spectra is just it's like the lines indicate how much energy is absorbed to transfer the electron so like this different right here would that number would mark that line so it would be like 1000 kJ/mol. Um, and then like I don't know if you can put 1 to 3 or not, so I think it would be 328 to 146 that would be somewhere there and 146-82 would be there.

40 **I:** 15:02How is this different from an emission spectra?

41 **S:** emission is like I think of it just like the negative, like all that isn't absorbed. Oh, that's transmitted… ok, emission , isn't, I think emission I don't know if there is any big difference or not but I think this one [absorbance] might be in kJ/mol and emission might be in like wavelength nm, but I don't know if that makes a big difference or not...

42 **I:** 15:40 what would an emission spectra be telling you?

43 **S:** like what colors of light are being emitted, what wavelngths

44 **I:** 15:50 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

45 **S:** um, I don't think it would do anything because it doesn't have enough to raise it from n=1 to n=2 so it would just pass through

46 **I:** why not halfway?

47 **S:** because the shells are discrete like 1 2 3 4 there's no like 1.2 shell or 1.7 shell

48 **I:** what does discrete mean?

49 **S:** discrete means just like I can explain it in terms of math, like a continuous function is one that is like connected, but discrete is just a set of like points of values like individual values as opposed to in between

50 **I:** 16:40 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

51 **S:** in that case that would raise the level of the electron up to the n=2 shell and then after that the electron would drop back and that would emit the light of that wvlngth

52 **I:** how about 985?

53 **S:** that wouldn't do anything, that would pass through because it's not the exact amount required to change shells

54 **I:** so it can't go a little bit above?

55 **S:** no that's like the discrete

Student No: 45

	Evidence	Code
Probabalist/ Determinist	01:33 well hydrogen's got one proton it's got one electron it's a little sphere of probability where it's in the 1s shell	3
Discrete/ Continuous	05:03 (why discrete energies? what does that mean?) it's because they can only move between the different orbitals, so they can absorb a certain discrete energy so they can move into the next orbital (why?) I suppose the solutions to Schrodinger'q eqns are places the atom can be, there is no 'in-between' places where it could be, there is only certain solutions 14:47 (500 kJ/mol?) nothing would happen. It's not enough to jump from here to here. I think it would just be reflected (984 kJ?) It would move from here to here (985?) I don't think in moves in that case… cause it can't go into making… I need to read up and verify this but I think it had to exactly that energy or nothing would happen... cause for IE the rest can go into KE but the electron are always moving the same so you can't make them move faster in their little.. they are just somewhere	3
Interpreting Spectra Code	but if you put in this difference then that's the energy to excite it to this level same with this difference and this difference of course it would have to be here to excite it to here or you would have to put in al the different between these two	3
Energy/Force Code	it relates to how closely the electron is attached to the atom, so if the atom is a really high energy it's really easy to remove and if it's a really low energy it's really hard to remove so you can like look at the electronegativity and how big the atom will be you predict that as you go across the periodic table, the energy gets smaller because it's harder to remove electron and if it's greater than the IE so there is enough energy to overcome the attraction between the electron and the nucleus (why is that?) depends on the nuclear charge what shells there are and how they are shielding each other	4

Line No. **Transcript**

1 **I:** 01:33 Describe how you visualize the atom

2 **S:** well hydrogen's got one proton it's got one electron it's a little sphere of probability where it's in the 1s shell except when you shine light on it it can go to other orbitals I think it only went up to, I don't know how far it can go until it's ejected, but i think it's like the 3rd orbital. And all of the things n=1, n=2, n=3 all of the sublevels those are all the same for hydrogen but for any other atom, or for any other atom that has more than one electron , they are at different energies, I think

3 **I:** 02:14 How would you describe oxygen?

4 **S:** so oxygen, which has it's number 8 on the periodic table I believe, so that would be the 1s shell, there's a little sphere of probability, then 2s is another sphere and there is a node in there, a radial node where there is zero percent probability

5 **I:** 02:43 what do you mean by orbital?

6 **S:** orbital they are 'solutions to schrodinger's equation' solving for standing waves where the electron could be

7 **I:** so what does that mean to you?

8 **S:** well schrodinger's eqn, some weird guy came up with this way of figuring out how to explain atomic behavior and where electron would be so he explained it using his eqn and you have solutions to it at each different n level so that's how you get the s orbs or the p orbs d and f

9 **I:** What's the relation between orbitals?

10 **S:** well as n gets bigger, each one gets bigger but there are still like their ranges of probability overlap, and as each orbital as n gets bigger there's more nodes, where there is zero percent probability so like the node is like when you have a sine wave and it's like, which they demonstrated with a rope, like it moves but the node always stays in the same place, that's the point where it's zero

11 **I:** 04:22 why is the energy important?

12 **S:** it relates to how closely the electron is attached to the atom, so if the atom is a really high energy it's really easy to remove and if it's a really low energy it's really hard to remove so you can like look at the electronegativity and how big the atom will be you predict that as you go across the periodic table, the energy gets smaller because it's harder to remove electron

13 **I:** 05:03 why discrete energies? what does that mean?

14 **S:** it's because they can only move between the different orbitals, so they can absorb a certain discrete energy so they can move into the next orbital

15 **I:** why?

16 **S:** I suppose the solutions to Schrodinger's eqns are places the atom can be, there is no 'in-between' places where it could be, there is only certain solutions

17 **I:** 06:52 Describe how you visualize light

18 **S:** um, now I visualize it with photons it's a wave and a particle

19 **I:** what are photons?

20 **S:** the photons are the discrete energy packets that interact with electron and like like when a light shines on an object it's absorbed or reflected depending on the wavelength and it can make an electron shift but that's like UV light you can make an electron move up an orbital

21 **I:** why do you think of that way?

22 **S:** that's what I learned in class!

23 **I:** how do you resolve the fact that sometimes it's wave, sometimes it's particle?

24 **S:** that's what works, when we try to explain what we observe I think it was originally just thought of... I can't remember which one It was either just thought of as a wave, I think it was just thought of as a wave and there were certain behaviors where just being a wave didn't work, it also had to be a particle, or a wavelectronicle - I love that term, it's sounds like an ice cream bar!

25 **I:** 08:26 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

26 **S:** that energy which is above the IE becomes KE of the electron. The electron goes flying off. The atom absorbs the energy and if it's the discrete energy to make it move up between orbitals, and if it's greater than the IE so there is enough energy to overcome the attraction between the electron and the nucleus

27 **I:** 09:00 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

28 **S:** then it would stay on the atom, it may depending it could move up some orbitals. But if it's not one of the discrete energies for the orbitals , nothing would really happen it would just be reflected

29 **I:** 09:24 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

30 **S:** when the electric current is put through it excites some of the atoms and then as the electron start moving back down orbitals the discrete energies are emitted and that's the light you see
31 **I:** 09:40 Why are Ne and He tubes different colors?
32 **S:** because it's a different energy when the electron moves back down so it's a different color. well it's different shells it's moving between Ne and also for all atoms there's slightly different spacing between each shell
33 **I:** why is that?
34 **S:** depends on the nuclear charge what shells there are and how they are shielding each other
35 **I:** 10:15 Over time, would the tubes change color?
36 **S:** I don't think so. cause they are always getting excited to a level and moving back down, and getting excited again and moving back down
37 **I:** 10:27 Is there any amount of energy that wouldn't light the bulb?
38 **S:** well if it was a really low energy and not enough to excite the electron then nothing would happen
39 **I:** would it ever burn out?
40 **S:** I could only imagine if you didn't have enough energy or you had so much you ionized all of them
41 **I:** 11:11Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
42 **S:** is that the this one where you draw the line across [gestures horiz] and have the little lines, or is it just the [draws vertical]?
43 **I:** yeah the second
44 **S:** it's just that one? Yes I can! Somewhere up here that would be zero. So here is.. I'm not very good at spacing...that is it.
45 **I:** what do these tell you?
46 **S:** well these correspond to the different orbs levels and if it was a multi electron atom you would have like 2s and 2p but since it's Hydrogen they are the same, well if you put in more than this amount then that's the IE but if you put in this difference then that's the energy to excite it to this level same with this difference and this difference of course it would have to be here to excite it to here or you would have to put in al the different between these two
47 **I:** 13:18 How much energy is needed to ionize Hydrogen?
48 **S:** 1312 kJ/mol
49 **I:** 13:34 Can you draw the absorption spectrum of Hydrogen?
50 **S:** so it's absorbance and then wvlngth? I don't think I… I don't know how to draw that one…
51 **I:** what are the possibiliites of these discrete energies that this could absorb?
52 **S:** it could absorb this one or this one or this yeah
53 **I:** 1 to 2;1 to 3; 1 to 4?
54 **S:** yeah.
55 **I:** could it go from 3 to 4?
56 **S:** if it was already at 3 but we would have had to already put in energy to get it to 3
57 **I:** 14:20How is this different from an emission spectra?
58 **S:** there are more possibilities there
59 **I:** why?
60 **S:** because as it moves down it can move down one level or multiple levels [points to all possible transitions down]
61 **I:** 14:37 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
62 **S:** then the electron will be ionized and the rest will become KE

63 **I:** 14:47 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

64 **S:** nothing would happen. It's not enough to jump from here to here. I think it would just be reflected

65 **I:** how about 984 kJ?

66 **S:** It would move from here to here

67 **I:** how about 985?

68 **S:** I don't think in moves in that case… cause it can't go into making… I need to read up and verify this but I think it had to exactly that energy or nothing would happen... cause for IE the rest can go into KE but the electron are always moving the same so you can't make them move faster in their little.. they are just somewhere

Student No: 46

	Evidence	Code
Probabalist/ Determinist	electron shells going around it so I guess that's primarily the way I'm thinking about it then there's also cause it's diatomic - the ball space that one, I think about that too 01:48 so basically you have the nucleus which has the neutrons and protons and then you have the electron circle it and there's certain shells	2
Discrete/ Continuous	discrete means there is a certain... it's kinda like... I know neurons have a threshold kinda thing like you need that certain amount of energy before you can actually trigger a response, so it's kinda like you need a certain amount of energy it's kinda like stairs, like you need a certain amount of energy to go to the next level you can't go halfway to the stair otherwise it just goes back down again	2
Interpreting Spectra Code	the difference between these 2 can also determine the energy that's needed to move from n=1 to n=2	3
Energy/Force Code	when it comes down it releases a certain wavelength , that's what we see the color 17:22 (500?) ground state? N=1 ok yeah, so 500 you said? I don't think anything will happen - well I'm not sure if nothing happens or if light is emitted, or it just goes through (so what do you think goes through? Or emitted?) On my MT, I said it goes through probably because since it doesn't do anything to the.. that energy doesn't do anything here, I just thought it would go through it , but I'm not too sure about that part of it might be because of like the effective nuclear charge, so sometimes for a smaller molecule the nucleus plays a greater role in holding the atom together so it requires more energy for it to go out a level	4

Line No.		Transcript
1	**I:**	01:14 Describe how you visualize the atom
2	**S:**	um ok so basically I guess as soon as you tell me to visualize the atom I kinda imagine like a nucleus with electron shells going around it so I guess that's primarily the way I'm thinking about it then there's also cause it's diatomic - the ball space that one, I think about that too
3	**S:**	01:48 so basically you have the nucleus which has the neutrons and protons and then you have the electron circle it and there's certain shells like certain quantum numbers which also dictate where the electron can be and so a H has one shell around it with one electron that circles it and it can be anywhere in the molecule but there's like a wave model that suggest that there is a certain node where it can't be or can't exist and so that's kinda where the shell kinda resembles, where it can go
4	**I:**	is it like a circular pattern?
5	**S:**	not necessarily, it can go wherever but I guess to simplify things it's one way like a model
6	**I:**	02:47 How would you describe oxygen?
7	**S:**	oxygen has 8 valence, 8 total so 6 valence, there is like an inner shell, it has 2 core electron, and it has 8 valence shells, so there is the neutron , then one shell then another shell and the 8 electron are on that shell but they are kinda they are all going around it in different directions but to simplify things in that model they are all dotted on that line right there
8	**I:**	are they near each other?

9 **S:** they can be, but it depends because electron constantly move so there is always london dispersion forces which electron can gather on one side or gather like that would cause polarity so it can be sometimes, it can be all over the place

10 **I:** 03:42 can they go in between? from 1 to 2?

11 **S:** they can but there is energies, it's discrete levels so like you need to input a certain amount of energy for it to go up

12 **I:** what does discrete mean to you?

13 **S:** discrete means there is a certain... it's kinda like... I know neurons have a threshold kinda thing like you need that certain amount of energy before you can actually trigger a response, so it's kinda like you need a certain amount of energy it's kinda like stairs, like you need a certain amount of energy to go to the next level you can't go halfway to the stair otherwise it just goes back down again

14 **I:** 04:17 why?

15 **S:** lemme think, I guess because it's a wave model, there are certain nodes created when you make a wave, so the electron can't exist there, so that's why there are certain levels where it existed so that's why there's discrete levels where the electron can be

16 **I:** 05:50 would oxygen and another element have the 2nd energy level of same value?

17 **S:** well, according to like the energy level model like those in lecture it kinda shows what comes first and what comes last, so I guess they are kinda universal to some extent but I guess like the amount of energy for it go up and down it differs

18 **I:** why?

19 **S:** part of it might be because of like the effective nuclear charge, so sometimes for a smaller molecule the nucleus plays a greater role in holding the atom together so it requires more energy for it to go out a level

20 **I:** 06:33 Describe how you visualize light

21 **S:** oh yeah, I have a better understanding of it now compared to before. So basically light is characterized by a wavelength and also the frequency, so wavelength is basically a photon of light that goes [gestures wave] like forms a wave and stronger lights have.. it's an inverse relationship between wavelength and frequency and so if you have a greater wavelength you have a smaller frequency and stronger lights like gamma radiation that have smaller frequency so there is more energy associated with it, according to the formula as well, so basically what happens is that there is light from a source and it reflects off of whatever surface you are looking at your eye, it's the wavelengths of light that are reflected that eventually goes up to your eye. like for this case this desk here is absorbing everything but brown I meant there is kinda a distribution or whatever, so I'm perceiving brown and it's kinda taking it everything else

22 **I:** 08:10 why a wave?

23 **S:** there was this picture in lecture, a light source and a pinhole, y'know what I am talking about? also it kinda has a rippling effect, so it's kinda how it works

24 **I:** 08:29 why are there different models?

25 **S:** cause the nature of models is to simplify our surrounding and nature and things like that, so each of the models answers a different aspect of it , like there's the ray model which explains shadows... and there is the wave model which explains so many other things, so it's kinda like each model answers a different facet of nature

26 **I:** 09:08 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

27 **S:** um so that would mean the atom can, it will ionize but there is also like KE involved, it goes from PE to KE, the excess energy is converted into KE

28 **I:** 09:39 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

29 **S:** well it depends because, this was actually on the MT, I don't know if I got it right or not but, um, ok like if it's exactly enough energy to allow a certain electron to go to a different level , then that would be the case, but if it doesn't completely… like let's say it needs 1000 kJ for it to go from n=1 to n=3 , and ionization is 1200, so if it's 1000 it would go to that energy level, but if the energy is 1100, like it wouldn't hit the ionization or that, it would just go back down

30 **I:** can it raise it a little and go back down?

31 **S:** I'm not sure about that.

32 **I:** 10:35 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

33 **S:** the different between electro-spectrums is the ionization of electron, but with gas discharge tubes, it's the electron going to an outer shell and falling back down again, which causes light to.. That's the light that's associated with it

34 **I:** 10:53 Why are Ne and He tubes different colors?

35 **S:** there is a certain wavelength that gets emitted when it comes down, so I guess its'.. it's intrinsic to the atom kinda, when it comes down it releases a certain wavelength , that's what we see the color

36 **I:** is it just that it's going frm 3 to 1 vs 2 to 1? or are their energy levels different?

37 **S:** well, I'm pretty sure that if it can go from 3 to 1 it can also go 3 to 2 and 2 to 1 and it kinda just goes down in those discrete steps

38 **I:** 11:41 Over time, would the tubes change color?

39 **S:** I don't think so partly because I think that there is electron constantly there, it's not like you are ionizing them so they have to be replaced , but the electron are constantly going up and down that's what emitting the light so I guess it wouldn't change color because there's always electron in the ground state which can be shot up again

40 **I:** can it ever run out?

41 **S:** not that I can think of, I'm not sure though

42 **I:** 12:15 Is there any amount of energy that wouldn't light the bulb?

43 **S:** If not enough energy is inputted so the electron can go up to a certain level then that wouldn't work

44 **I:** 13:50 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

45 **S:** ok, so basically this just represents the number of.. The energy level that is associated with each quantum number, so basically an electron here at n=1 would require 1312 kJ/mol for it be ionized completely, like that's its location but also, the differencet between these 2 can also determine the energy that's needed to move from n=1 to n=2

46 **I:** 14:14 How much energy is needed to ionize Hydrogen?

47 **S:** anything greater than 1312

48 **I:** 14:44 Can you draw the absorption spectrum of Hydrogen?

49 **S:** so basically, this is my thinking, since there is a certain amount of energy needed for it to go from here to here, there is an eqn that goes $E = hv$, so basically frequency is related to wvlgnths too, so since plancks constant is constant.. So for an absorption spectrum that would mean there are different wavelengths that are absorbed

50 **I:** what are the possible jumps?

51 **S:** like it can go from n=1 to n=2, we're assuming from ground state right?

52 **I:** yeah

53 **S:** n=1 to n=2; n=1 to n=3; n=1 to n=4 or ionized

54 **I:** can it go from 2 to 3?

55 **S:** oh yeah.

56 **I:** 16:45 How is this different from an emission spectra?

57 **S:** ok so if this is the absorption spectra, there should be more probably, like these are colored in, like these are colored they might be blue or something, but an emission spectra it's everything but those two lines, everything else is colored in because that's the ones that's being absorbed and everything else is being emitted

58 **I:** 17:22 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

59 **S:** ground state? N=1 ok yeah, so 500 you said? I don't think anything will happen - well I'm not sure if nothing happens or if light is emitted, or it just goes through

60 **I:** so what do you think does it go through? Or emitted?

61 **S:** On my MT, I said it goes through probably because since it doesn't do anything to the.. that energy doesn't do anything here, I just thought it would go through it , but I'm not too sure about that

62 **I:** 17:14 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

63 **S:** it would ionize

64 **I:** 18:13 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

65 **S:** [adds them on paper..] ok it would go to the n=2

66 **I:** 18:36 how about 985?

67 **S:** nothing would happen, because it doesn't exacty hit that level, it overshoots it by 1 kJ.

68 **I:** how is it different from 500?

69 **S:** ok, ok, nothing would happen for both

Student No: 47

	Evidence	Code
Probabalist/ Determinist	but I picture it just as kinda like randomly going spot to spot with the most density in the darkest part of the cloud (what do the clouds represent in the model) i think it's areas of probabilities, the densest part would be the darkest (probability of what?) of the electron being there	3
Discrete/ Continuous	I mean that certain orbitals, in order to excite the electron to that orbital, a very specific energy is required so anything beyond that or below that has the possibility of not even doing anything.. that's a bad way to put it... anything not the energy basically can't excite it to that level 16:41 (500?) it would end up in some middle region here I guess so I think it would just pass through, nothing would happen (984?) then it would go to n2 I think (985?) I think it would just pass through	3
Interpreting Spectra Code	16:41 (500?) it would end up in some middle region here I guess so I think it would just pass through, nothing would happen (984?) then it would go to n2 I think (985?) I think it would just pass through there's an energy difference, and that difference is ejected as a photon, so we see that light, and depending on the wvlngth, that would correspond to different colors or possible other types of radiation	3
Energy/Force Code	excites it, normally it would excite it to a higher orbital if the energy were right but since it's beyond the IE it would move it to a distance infinitely far which is in actuality not really that far, but to the atom it's far. um, so beyond that point there would be no attraction to the nucleus so it would just fly off	4

Line No. **Transcript**

1 **I:** 00:58 Describe how you visualize the atom

2 **S:** ok now that we've learned unit 4, it's a little bit different obviously.. I think now I see it as... well protons are basically the same, the nucleus - protons and neutrons... and then out of the models we learned I think in my mind it's a mixture of the energy levels, the Bohr model and also maybe the cloud, the electron cloud model... , so it depends on what context I think of it in and which one is more convenient ... both those two are both are equally valid to think about

3 **I:** 01:44 tell me about the electron, what's going on?

4 **S:** I don't know I tried to picture them before and looked on google like how should I think about this, but I couldn't find a simulation or anything I was looking for... but I picture it just as kinda like randomly going spot to spot with the most density in the darkest part of the cloud

5 **I:** what do the clouds represent in the model?

6 **S:** i think it's areas of probabilities, the densest part would be the darkest

7 **I:** probability of what?

8 **S:** of the electron being there

9 **I:** 02:52 do the electrons stay in one cloud?

10 **S:** I think it would be going like layer to layer sort of, that's just the way I thought of it

11 **I:** 03:09 Can you draw the 2p orbital in Oxygen?

12 **S:** ok so you have a nucleus and then like 2 lobes of kinda cloud density areas, but it would like vary in concentration.

13 **I:** is there empty space in here?

14 **S:** I guess it's a place of zero probability? I'm not really sure how to draw that well

15 **I:** how does the 2s fit in?

16 **S:** um, I guess I think maybe it would be like sort of overlapped not completely because...actually I don't have a good reason, I just know that...

17 **I:** 04:23 describe these layers

18 **S:** uh ok so there's nodes I guess so like here, that's zero probability for the nodes for the 2p I guess and then 2s would have would have like maybe like a shell and then another one

19 **I:** what is the difference between layers?

20 **S:** energy I guess, size...

21 **I:** 04:52 why is energy important? Can you change energies?

22 **S:** um, I think it's just one given energy, I don't know if it would change, maybe when the bond we learned MO , the orbitals themselves change and I guess the energies probably change

23 **I:** 05:31 Describe how you visualize light

24 **S:** I like thinking about it in terms of photons I just think it's easier that way, more tangible to think of it as a particle.

25 **I:** how about any other ways?

26 **S:** the wave model I guess, I'm not really too sure how to think about that one because I'm not sure how to picture it as a wave, like just a simple sine wave or maybe something like kinda radiating out in all directions, I'm not really sure so I kinda stay away from that one

27 **I:** 06:07 is one model more complete?

28 **S:** I think they both have their advantages like in terms of perceiving things, I think, well since there is that issue of the duality between them, I think they are both complete in some aspects but I think by combining them and realizing that light has both wave and particle properties, you have more of a full picture

29 **I:** 06:50 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

30 **S:** it would eject the electron with some KE in excess

31 **I:** how does it eject it?

32 **S:** so the way I think about it is a photon comes in, hits an electron and then transfers its energy to that, so it excites it, normally it would excite it to a higher orbital if the energy were right but since it's beyond the IE it would move it to a distance infinitely far which is in actuality not really that far, but to the atom it's far. um, so beyond that point there would be no attraction to the nucleus so it would just fly off

33 **I:** 07:48 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

34 **S:** I think it would depend on how much then because the orbitals are discrete energies so if it's not just exactly that energy, I think there is a possibility of nothing happening, the light would just go through

35 **I:** what do you mean by discrete?

36 **S:** I mean that certain orbitals, in order to excite the electron to that orbital, a very specific energy is required so anything beyond that or below that has the possibility of not even doing anything.. that's a bad way to put it... anything not the energy basically can't excite it to that level

37 **I:** 09:18 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

38 **S:** ok I think this was done in lecture , the simulation, so it would be like a stream of electron flowing through this tube of gas and the free electron would strike the electron on the atom, and then excite them to higher orbitals but not ionize them, so when they fall back down to the ground state some energy is.. there's an energy difference, and that difference is ejected as a photon, so we see that light, and depending on the wvlngth, that would correspond to different colors or possible other types of radiation

39 **I:** 10:06 Why are Ne and He tubes different colors?

40 **S:** I think it's because their energies are different for the orbitals, so when an electron falls from a certain orbital in Ne that corresponding drop would be different for whatever gas

41 **I:** why are they different?

42 **S:** I guess one reason would be because of the different numbers of protons in the nucleus, so they would exert a different pull on the electron in different atoms, I'm sure there are other things, that's the main thing

43 **I:** 10:50 Over time, would the tubes change color?

44 **S:** I don't think so because I see it as electron just keep going from here to here and back and back so they are not being ionized so I think it would just stay within their atoms

45 **I:** 11:26 Is there any amount of energy that wouldn't light the bulb?

46 **S:** yeah I guess, where if the energy is not enough to excite it to the next number of n I guess, but if it's like in between somewhere I think it would just pass through or not really affect it

47 **I:** 12:30 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

48 **S:** ok so I think n=1 would be somewhere down here in reference to zero which is like "infinite" separation. So I guess from 1 to 2 would the largest gap and then each successive one is smaller, the difference is smaller, and I didn't do a good job portraying that

49 **I:** 12:59 How much energy is needed to ionize Hydrogen?

50 **S:** from this level here I guess, 1312 to get to zero which would be the set point for the ionization

51 **I:** 13:19 Can you draw the absorption spectrum of Hydrogen?

52 **S:** [draws horiz line…]

53 **S:** 13:53 um these would be peaks in the wvngth of light absorbed so I think at certain wavelengths the light passing through would bet absorbed, the light would absorbed at certain wavelengths and these would be the correct energies to excite from one level to another, so a low wavelength would correspond to this energy 1312 which is a large possible energy absorbed, um sorry that's not it, maybe it would be like this, I don't know, like a big chunk here, so anything beyond this would ionize it and then from 2 to 3, 3 to 4, it would be smaller

54 **I:** what are the possible jumps for the H electron?

55 **S:** I think I brought this up in OH and the answer I got from prof Stacy was that it's possible to jump from the ground state to any other orbital, but once it's at another orbital I think she said it falls back down so quickly that it's not really possible for it to go from like 2 to 4 or something

56 **I:** 15:32 How is this different from an emission spectra?

57 **S:** absorption to me it's like its absorbing a certain energy and it's going from a lower orbital to a higher one or completely ionized or something like that. Emission would be falling from a higher one to a lower one and the resultant photon would I guess be analyzed, and we would find out all this information about it

58 **I:** so would it be the same peaks? 4to1, 3to1, 2to1?

59 **S:** i think it can fall from like let's say 4 to 3, 3 to 2, so they would have more peaks

60 **I:** 16:29 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

61 **S:** I think that would be more than enough to ionize it so it would eject the electron and then have some KE of it's own

62 **I:** 16:41 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

63 **S:** it would end up in some middle region here I guess so I think it would just pass through, nothing would happen

64 **I:** how about 984?

65 **S:** then it would go to n2 I think

66 **I:** how about 985?

67 **S:** I think it would just pass through unless it's like an acceptable [inaudible] or something

Student No: 48

	Evidence	Code
Probabalist/ Determinist	but I think like after learning about bonding and antibonding and stuff, it seems more complex but I don't think I fully understand quite yet what it exactly looks like. And I kinda get the sense that the professors don't really know what it 'exactly' looks like either so the clouds are like the path of the electron they are just like places i the plane where you can find the electron, fairly certain	2
Discrete/ Continuous	cause my mom always, my mom's a teacher too, she always says that the reason that we have these models, these theories is to describe what we see and so then I think when they were showing like the emission spectrum of H, there are only certain values, they are trying to explain those using discrete energy values 14:40 (984?) it would jump up to here, and then when it decayed it would give off light with 984.. Whatever wavelength that corresponds to 14:53 (985?) still transmitted. (why not n=2?) I don't think it works that way. I know that it has to be discrete energy levels so that would just be possible, and plus I don't even know where the KE would go	3
Interpreting Spectra Code	so I guess from here to here would be the different between n=1 and n=2 , so i guess in this case it's 328.. and then from 1 to infinity (so to go from n=1 to n=2 it takes 328?) no it takes the difference between these two. and then from here to here it would be the different between this and zero which is 1312 , and I know that's the IE	3
Energy/Force Code	well, I think light is a form of energy and it gives energy to the electron and when it has more than enough energy to break away, then it just gives that too and I think that specific energy of the electric current gets electron in the Ne or He to jump to higher energy level and then.. I know that they jump up and decay right back down, right after, and I guess when it decays it emits energy, and that energy is of a certain wavelength	2

Line No. **Transcript**

1 **I:** 00:57 Describe how you visualize the atom

2 **S:** well I think before I always thought like an atom was kinda like a ball with orbits around it, but I think like after learning about bonding and antibonding and stuff, it seems more complex but I don't think I fully understand quite yet what it exactly looks like. And I kinda get the sense that the professors don't really know what it 'exactly' looks like either

3 **I:** 01:44 How would you describe oxygen?

4 **S:** well I think immediately I would think of like a 1s, 2s that kinda stuff first, and in my head it seems like we have all the different energy levels I guess, like n=1,2,3,4 , and all the clouds or balloons kinda overlap each other, so it becomes almost like a flower, cause it's like the central s and then the p's come out like this

5 **I:** 02:18 what are orbitals?

6 **S:** where you can find the electron I guess. because I know that every shell holds 2 electron so the clouds are like the path of the electron they are just like places i the plane where you can find the electron, fairly certain

7 **I:** can the electron go from 1s to 2s, or are they staying in their own shells?

8 **S:** you mean like a ground state element? yeah I think they mainly just stay in their orbital, until they get excited I guess

9 **I:** 03:11 Draw the 2p orbital for oxygen.

10 **S:** a 2p orbital? so this is like the nucleus, imagine there is one.. this and like that...

11 **I:** how about the 2s?

12 **S:** I'm guessing just right here

13 **I:** so they overlap?

14 **S:** yeah.

15 **I:** 03:51 why levels? levels of what?

16 **S:** I guess the level is just a way to categorize the energy of the electron within the atom and I think.. cause the profs keep stressing that the energy levels are discrete so for an atom of a particular element there can only be certain levels, and I guess these orbitals describe the levels they can be in

17 **I:** 04:23 what do you mean by discrete?

18 **S:** just like one value, it's not like a range, just one value

19 **I:** why only one value? any ideas?

20 **S:** I think it's not so much the values that they care about but I think it's the fact that.. cause my mom always, my mom's a teacher too, she always says that the reason that we have these models, these theories is to describe what we see and so then I think when they were showing like the emission spectrum of H, there are only certain values, they are trying to explain those using discrete energy values

21 **I:** 05:18 Describe how you visualize light

22 **S:** um, I think in the begginning of class they mentioned that light can be seen in three ways , particles, waves or rays - I kinda see the ray one more, cause that's like how people draw it I guess, but I think light is a form of energy, and it can be represented in different ways depending on like what level you are looking at, like macroscopically it would be rays, but I think when it comes down to talking about atoms I am guessing photons.

23 **I:** so do these different models work in different places?

24 **S:** yeah.

25 **I:** 06:06 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

26 **S:** one of the electron in the atom will I guess be removed, and then the extra energy, I mean.. The energy from the photon that is greater than the IE will go to the KE to make it fly away

27 **I:** how does that happen? How does light interact with the atom?

28 **S:** well, I think light is a form of energy and it gives energy to the electron and when it has more than enough energy to break away, then it just gives that too

29 **I:** 06:45 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

30 **S:** if it was less, the electron would not be removed from the atom, but it could jump to another energy level depending on the exact energy of that photon

31 **I:** exact, exact or a little extra?

32 **S:** I think it has to be exact exact

33 **I:** 07:40 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

34 **S:** um, when, so when you put an electric current through a tube you are basically supplying energy to whatever is in the tube, I guess in this case it's Ne or He, and I think that specific energy of the electric current gets electron in the Ne or He to jump to higher energy level and then.. I know that they jump up and decay right back down, right after, and I guess when it decays it emits energy, and that energy is of a certain wavelength

35 **I:** 08:23 Why are Ne and He tubes different colors?

36 **S:** because the energy required to bump it up to a different energy level is different for Ne and He, and so the amount of energy they emit when they come down is different

37 **I:** so is He 1s different from Ne 1s?

38 **S:** I think so, yeah.

39 **I:** any ideas why?

40 **S:** not really, I think just cause they are different elements

41 **I:** 09:01 Over time, would the tubes change color?

42 **S:** I don't think so.

43 **I:** why not?

44 **S:** because I guess in my head I kinda think that it would be really hard for an element to just change it's own properties, and when things decay like rust they are outside to oxygen, well not decay, but, and if they are in a tube I don't think there is a lot of outside interference, and so there's probably little chance of it just changing I guess

45 **I:** 09:40 Is there any amount of energy that wouldn't light the bulb?

46 **S:** um, well I guess if you run a current that's less than the energy required for it to jump up to the next energy level, then it won't emit light

47 **I:** 10:20 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

48 **S:** ok, so this is increasing energy. And then this would be 1312, n=1, and then n=2, and then I know you can keep going up and it becomes like n=infinity, which is like infinite separation.

49 **I:** what do these represent?

50 **S:** um, the amount of energy required to like move from one to another, cause I know when you go from n=1, cause Hydrogen only has one electron, so .. this is H, and you have just one electron, it would be like this , so I guess from here to here would be the different between n=1 and n=2 , so i guess in this case it's 328.. and then from 1 to infinity

51 **I:** so to go from n=1 to n=2 it takes 328?

52 **S:** no it takes the difference between these two. and then from here to here it would be the different between this and zero which is 1312 , and I know that's the IE

53 **I:** 11:51 How much energy is needed to ionize Hydrogen?

54 **S:** 1312 kJ/mol

55 **I:** 12:00 Can you draw the absorption spectrum of Hydrogen?

56 **S:** uh, there's a bunch of spectra we have to know… I know there is one like this… and somewhere around 1312 it's like that… I can't remember if it's absorption or photo electric something or I can't remember

57 **I:** what are possible absorptions?

58 **S:** oh! I remember now... from here to here, it's like 984, so I know there is a line here. I remember it's like kinda turned on it's side ... and then from.. I know when it gets absorbed, it can go from n=1.. 1 to 2, 1 to 3, 1 to 4. but it doesn't go 2 to 3, 2 to 4.

59 **I:** how would you define those numbers?

60 **S:** it's the difference between these

61 **I:** 13:31 How is this different from an emission spectra?

62 **S:** Absorption only goes from 1, 1to2, 1to3, 1to4, but emission can go from 4to3, 4to2, 4 to 1 , 3to2, 3to1, 2to 1 I think if the electron starts out here then it can absorb this much or this much or this much. But once it jumps up to n=2 it decays so fast so there's no time for it to jump up again

63 **I:** 14:10 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

64 **S:** 1512? Well that's more than the IE so not only would it be ripped off it would also have enough KE to just go away

65 **I:** 14:22 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

66 **S:** 500? Well that doesn't correspond to any of the absorptions so it would just be transmitted, it just goes through, it doesn't give any energy to the electron

67 **I:** 14:40 how about 984?

68 **S:** it would jump up to here, and then when it decayed it would give off light with 984.. Whatever wavelength that corresponds to

69 **I:** 14:53 985?

70 **S:** still transmitted.

71 **I:** why not n=2?

72 **S:** I don't think it works that way. I know that it has to be discrete energy levels so that would just be possible, and plus I don't even know where the KE would go

Student No: 49

	Evidence	Code
Probabalist/ Determinist	S is a spherical thing, spherical area where the electron is most likely to be	3
Discrete/ Continuous	06:34 it transmits right through not really affected, meaning like because it's not the discrete particle or amount that it's looking for it has no effect on the electron and it will just go right through the atom (why?) I guess like we said energy needs to be discrete, so if you have something that's less then it's not enough to get over the PE and so you won't even move I think or it might but it's not strong enough and it falls back down 12:37 well then it would do nothing, because it's not the energy needed to get to 2 (984?) it would go to 2 (990?) I think atomically what happens is it has to be the same amount	3
Interpreting Spectra Code	to get it all the way out would take 1312, to get it there it would take the difference (what do these numbers represent) they tell you how much discrete energy it would take to get it to the next shell	3
Energy/Force Code	04:19 as it absorbs energy, it can only absorb a discrete amount for it to get from 1 to 2, as it gets to 2 it will release energy as it goes back to its stable state, and that comes off usually in the form of light so basically the spark provides the energy needed to excite the electron to a higher energy state as it goes back down it emits light	2

Line No.		Transcript
1	**I:**	01:18 Describe how you visualize the atom
2	**S:**	just kinda like nucleus with a proton, if it's H the element it would have an electron
3	**I:**	what makes H different from O?
4	**S:**	the amount of electron it has and the effective nuclear charge and where it is in the periodic table .
5	**I:**	tell me about the electron
6	**S:**	they are in the shell, the 1s , it has only one
7	**I:**	how about the 1s?
8	**S:**	it is a subshell. S is a spherical thing, spherical area where the electron is most likely to be. P is dumbell. d is kinda like a clover f is too complicated to draw
9	**I:**	03:09 How would you describe oxygen?
10	**S:**	Oxygen will have like the 1s 2s it will have also the p
11	**I:**	are they in the same space?
12	**S:**	I don't think so because they are different shells. The 1s only has the s, but when you go to the sub level of 2 it has both s and p. The dumbell is like that [gestures figure 8] and the spheres are a little bit bigger [gestures spheres]
13	**I:**	03:55 what is the difference in distance?
14	**S:**	between 1 and 2? the difference is how much energy it takes to excite the electron from one to 2 , but as you go to 3 4 5, the spaces get closer and closer
15	**I:**	04:19 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
16	**S:**	as it absorbs energy, it can only absorb a discrete amount for it to get from 1 to 2, as it gets to 2 it will release energy as it goes back to its stable state, and that comes off usually in the form of light
17	**I:**	04:41 why do electrons have discrete energies?

18 **S:** you have to look at it as the photon or the particle way of light instead of the wave way of light because if you think of it as a wave then you will say ok all kinds of energies would be able to work and it depends on the intensity and stuff, if you have a discrete amount of high energy you will be able to excite it to the next state and if you don't have anough it will just transmit

19 **I:** 05:17 Describe how you visualize light

20 **S:** complicated cause it can be both a wave and a particle. If you think about light in the environment, you will think of a ray because that's what you see. But then it depends on the situation, because if you see like a flashlight or something and you shine it through a hole you will see kinda like a wavelike pattern but then at the same time when you look at something I can't like see behind the desk because there like particles

21 **I:** 06:03 what do these models get you?

22 **S:** at the end they are all kinda related through energy with the hc/wvlgnth. but they are different ways to look at what light does to the environment

23 **I:** 06:25 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

24 **S:** it will be transferred as KE cause it has enough to be used like that

25 **S:** 06:34 it transmits right through not really affected, meaning like because it's not the discrete particle or amount that it's looking for it has no effect on the electron and it will just go right through the atom

26 **I:** why?

27 **S:** I guess like we said energy needs to be discrete, so if you have something that's less then it's not enough to get over the PE and so you won't even move I think or it might but it's not strong enough and it falls back down

28 **I:** 07:27 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

29 **S:** so basically the spark provides the energy needed to excite the electron to a higher energy state as it goes back down it emits light

30 **I:** Why are Ne and He tubes different colors?

31 **S:** they have different enerigies to get from 1 to 2 to 3

32 **I:** why?

33 **S:** because they have.. The atomic size is different I know He is much smaller than Ne, has much less electron and only has one subshell

34 **I:** Over time, would the tubes change color?

35 **S:** cause energy is discrete I think it will go until there is no spark or excited back and get it back down

36 **I:** if it was always plugged in?

37 **S:** then I assume the same light will be emitted

38 **I:** Is there any amount of energy that wouldn't light the bulb?

39 **S:** maybe like x-ray, or not xray too small, something like infrared or something

40 **I:** 09:52 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

41 **S:** like how much it takes to ionize everything? [draws horizontal…] to get it all the way out would take 1312, to get it there it would take the difference

42 **I:** what do these numbers represent?

43 **S:** they tell you how much discrete energy it would take to get it to the next shell

44 **I:** 11:00 How much energy is needed to ionize Hydrogen?

45 **S:** 1312

46 **I:** 11:20 Can you draw the absorption spectrum of Hydrogen?

47 **S:** what it emits, I'm not sure what color 1312… I have no idea, I don't remember what color. Absorption tells you what light kinda reacts with the thing because it goes in, transmittance is what does not affect . Emission is something that happens.… I had problems with this in class I think because there was confusion of what is transmittance and what is emission was, but my understanding was that as you go down like you go from 3 to 2 you emit light

48 **I:** can you absorb from 2 to 3?

49 **S:** no, it starts off in 1

50 **I:** 12:24 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

51 **S:** 1512 well the rest will just go into KE and it will just move faster

52 **I:** 12:37 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

53 **S:** well then it would do nothing, because it's not the energy needed to get to 2

54 **I:** how about 984?

55 **S:** it would go to 2

56 **I:** how about 990?

57 **S:** I think atomically what happens is it has to be the same amount

Student No: 50

	Evidence	Code
Probabalist/ Determinist	Well the electron are attracted to the nucleus so they don't go very far away and they just go around in some random motion (near each other? far away?) I don't think it's definite where they are but I don't think they are all clumped together they are kinda like equally spread out	3
Discrete/ Continuous	03:43 um, it would move a little bit but it wouldn't actually move energies it would just like vibrate 09:55 (984?) I think it would just vibrate the electron but it won't actually change the level (if you put in enough energy of the different then what would happen?) I think it would go to the next level. (a tiny bit more) I feel like it would go but I'm not sure	1
Interpreting Spectra Code	06:27 um, possible, lines , right? Um.. Kinda like this, but I'm not sure. I guess they represent each change in energy and I assume well hydrogen only has one electron so I assume each one is only one electron, so I'm not sure, so they are all the same height, and then these are closer together here and that's further away. (at 1312, 328, 146?) yes.	1
Energy/Force Code	that's what I'm not sure about. I feel like.. I'm not sure if you need the specific 1312 amount of energy or not, so.. Because there is like specific energy levels you can't go to like the middle of one. But I guess you can always have 1312 and have excess energy	2

Line No.		Transcript
1	**I:**	00:55 Describe how you visualize the atom
2	**S:**	the atom? Um I kinda just like there is the nucleus in the center and obviously it's really small and then there is sorta a cloud around it where it has electron how many ever there are. Well the electron are attracted to the nucleus so they don't go very far away and they just go around in some random motion
3	**I:**	Are they near each other? Or far away?
4	**S:**	I don't think it's definite where they are but I don't think they are all clumped together they are kinda like equally spread out
5	**I:**	01:57 Can you describe the 2p orbital in Oxygen?
6	**S:**	I'm just going to go with… there would be the nucleus and then there would be like a lobe or whatever they are called on the other side too
7	**I:**	02:23 Describe how you visualize light
8	**S:**	light? Um, it's like.. It's um waves and particles. Waves in that like um like it can be like blurry like if you shine it from far away you wouldn't see distinct lines whereas if it was particles you'd just see the distinct lines, so it kinda moves a little bit so
9	**I:**	03:08 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?
10	**S:**	um the atom loses an electron. It bumps it out of its place, and takes it to a situation of an atom with a higher energy
11	**I:**	03:43 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
12	**S:**	um, it would move a little bit but it wouldn't actually move energies it would just like vibrate
13	**I:**	04:04 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

14 **S:** um, well the atoms are reflecting they are also absorbing certain wavelengths of light so that the color they look like is the color they reflect obviously the other colors they absorb

15 **I:** Why are Ne and He tubes different colors?

16 **S:** because well they're different atoms and I guess it takes different energies of light to excite the electron or change their energies.

17 **I:** What do you mean by excite?

18 **S:** it means raising the energy level I think, I'm not really sure. Isn't it when it goes from like either a higher state to a lower state or like yeah

19 **I:** 05:19 Over time, would the tubes change color?

20 **S:** no cause I think the electron are constantly moving, they're moving back

21 **I:** is there any way they would change color?

22 **S:** you could put something else in there or I don't know

23 **I:** 05:35 Is there any amount of energy that wouldn’t light the bulb?

24 **S:** yeah, well energy that's lower than the visibe spectrum probably would not light it, I think it just depends on the atom though

25 **I:** 06:27 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

26 **S:** um, possible, lines , right? Um.. Kinda like this, but I'm not sure. I guess they represent each change in energy and I assume well hydrogen only has one electron so I assume each one is only one electron, so I'm not sure, so they are all the same height, and then these are closer together here and that's further away.

27 **I:** at 1312, 328, 146?

28 **S:** yes.

29 **I:** 07:42 How much energy is needed to ionize Hydrogen?

30 **S:** well I guess for the first level its 1312 kJ

31 **I:** 07:56 Can you draw the absorption spectrum of Hydrogen?

32 **S:** um, I don't know. An absorption spectrum? I guess um what the energies are of the different light so you know which one corresponds to those

33 **I:** 08:39 How is this different from an emission spectra?

34 **S:** um, emission spectra? I guess it would be similar to, it would be the opposite of the absorption spectra. Well absorption spectra describes all the colors you don't see, and the emission spectra shows all the colors you do see

35 **I:** 09:11 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

36 **S:** that's what I'm not sure about. I feel like.. I'm not sure if you need the specific 1312 amount of energy or not, so.. Because there is like specific energy levels you can't go to like the middle of one. But I guess you can always have 1312 and have excess energy

37 **I:** 09:55 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

38 **S:** I think it would just vibrate the electron but it won't actually change the level

39 **I:** if you put in enough energy of the difference then what would happen?

40 **S:** I think it would go to the next level.

41 **I:** a tiny bit more

42 **S:** I feel like it would go but I'm not sure

Student No: 51

	Evidence	Code
Probabalist/ Determinist	And basically like we describe it sort of like a cloud, and it can be found anywhere within that region.	**2**
Discrete/ Continuous	And then with the whole quantized thing, like it has to be like a specific amount because you can't like stand on a point of a stair, you have to be like on one step or another. does that make sense? (can you be in between those 2 levels?) not really. (what are ways it can get excited) you mean like where it can go? it can go to all of them (draws) 12:29 (more than 984?) if it were at n=2 again. It would be ionized and the rest of the energy would be Kinetic energy. Like my GSI used this analogy with like a marble or something down underground and then it takes a certain amount of energy to get it up to the ground and then and if there is more energy than that then it goes into KE	**1**
Interpreting Spectra Code	18:13 (look at diagram, what energies are emitted?) if it were like here or something and it would go back down, would it emit like 984? (3 to 1?) it would be 984 or whatever plus the difference between these two.. (can H in its ground state have an emission?) maybe, well why no is because it's in it's ground state, why yes, I'm not sure...	**2**
Energy/Force Code	(why?) because the light is energy, then it gets rid of that energy so it can go down to lower energy	**2**

Line No.		Transcript
1	**I:**	00:26 Describe how you visualize the atom
2	**S:**	um, well I guess a circle with a valence electron
3	**I:**	what does that mean?
4	**S:**	like the outer electron involved in bonding and stuff.
5	**I:**	how is it located?
6	**S:**	you mean the probability of where it's located. It's the wave function squared or something, the probability. And basically like we describe it sort of like a cloud, and it can be found anywhere within that region. For H, it's just an e-, so i guess it's like... I don't know...
7	**I:**	01:21 How would you describe oxygen?
8	**S:**	Oxygen has 6 and so it has more like subshells I guess even though that model doesn't really work after Boron or something.
9	**I:**	what is a subshell?
10	**S:**	it's like, when we were learning about the octet rule and stuff, the shells are where the electron are and stuff. like 2 and the rest are like 8 I guess. But, they said it doens't really work after Boron, then you use like orbitals, orbitals and stuff like that
11	**I:**	what's an orbital?
12	**S:**	An orbital is like somewhere where there is a probability of finding the electron
13	**S:**	02:11 Oxygen is 8, right? Ok, so there would be like 1s2 and 2s2 and then p6, but it would only go up to p4
14	**I:**	02:38 Can you draw the 1s & 2s orbitals?
15	**S:**	oh, um, 1s is like sorta like that, the 2s is like that
16	**I:**	where is the nucleus?
17	**S:**	it would be there

18 **S:** 03:36 In the 1s, there is like 2, there are 2 separate orbitals I guess, so there can be separate electron in both of them, so I guess that represents like.. the inner one is like the one where the electron from the 1s are, and the outer is the electron from the 2s

19 **I:** are 1s and 2s distinct?

20 **S:** I'm not sure, but I think they are distinct

21 **I:** 04:13 Describe how you visualize light

22 **S:** we kinda did it where we talked about it as a wave and also as a particle. For particles we talk about that with like photons. Photons are like, it's like quantized, so they are like discrete little packets of light I guess, energy

23 **I:** what is quantized?

24 **S:** um, like discrete amount, it's not just like all over the place I guess, it can't be just ike any amount I guess

25 **I:** 05:19 describe the wave model.

26 **S:** well the wave, like when we talked about nodes and stuff that has to do with waves, cause it's like standing wave and then , standing waves are when you like pull on each end, right? and the node is where there is no vibration going on, node is where no electron will be found, I guess

27 **I:** 06:04 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

28 **S:** if the light is of a specific energy, the ionization energy, then the electron will be ejected, and if it's higher than that energy, then the electron will be ejected with some excess energy that would be KE

29 **I:** what is ejected?

30 **S:** I kinda forgot that but when I think of like ejected I think of what the word means like ejected like I'm not 100% sure, but when the electron is ejected I don't really know where it goes, but out

31 **I:** 06:45 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

32 **S:** then it's just excited I guess. Moves to a higher energy state. Like pretend this is like an energy state [points to 1s drawing] and then they were like excited they can move up to the next one. I think of like stairs I guess. And then with the whole quantized thing, like it has to be like a specific amount because you can't like stand on a point of a stair, you have to be like on one step or another. does that make sense?

33 **I:** can you be in between those 2 levels?

34 **S:** not really.

35 **I:** what are the ways it can get excited?

36 **S:** you mean like where it can go? it can go to all of them [draws]

37 **I:** 08:14 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

38 **S:** like that and zero is like up here. This is not to scale [laughs] what I never really got was why it was negative.

39 **I:** what does the zero mean?

40 **S:** I'm not too sure…

41 **I:** 09:09 How much energy is needed to ionize Hydrogen?

42 **S:** [points to -1312]

43 **I:** why?

44 **S:** why? Cause it is… it's the number that we were told

45 **I:** how come there are 4 levels?

46 **S:** that's something I never quite understood myself. I guess it's just somewhere.. Even if it's just one valence electron one orbital state I guess, there just can be in between which is kinda contradicting what I said before about there not being any in-betweens but I'm not sure..
47 **I:** 10:11 tell me what happens if the H electron was excited.
48 **S:** [silence]
49 **I:** if it's the ground state, what energy does the electron have?
50 **S:** Is that zero?
51 **I:** what do you think?
52 **S:** I don't know cause if like if this is the energy, I'm confused. if this is like the ionization energy to get it out then if it's excited the energy is obviously going to be lower than that cause the electron is not really being ejected so the ground state would be not that. so then maybe it's zero, but that also doesn't feel right. I'm not sure, but it's somewhere between here and there.
53 **I:** 10:59 how much energy would it take to go from 1 to 2?
54 **S:** would it just be like that minus that? [calculates] would it be that? do the negatives... just do the magnitudes?
55 **I:** 11:30 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?
56 **S:** well if it were here, [n=1] then it would end up there, I guess… well it depends on where it is… well I'm not 100% sure where the ground state is right now
57 **I:** what does ground state mean?
58 **S:** it's the most stable lowest energy, PE. It would get excited, and if it's there [n=2] it would get ionized
59 **I:** 12:29 What happens if you shine light on hydrogen with an energy more than 984?
60 **S:** if it were at n=2 again. It would be ionized and the rest of the energy would be Kinetic energy. Like my GSI used this analogy with like a marble or something down underground and then it takes a certain amount of energy to get it up to the ground and then and if there is more energy than that then it goes into KE
61 **I:** 13:25 500kJ?
62 **S:** it just gets excited I guess?
63 **I:** let's say ground state is n=1
64 **S:** wait, but that's the IE... that's the ground state too? how would it not be ejected all the time. if the ground state is the amount of energy it takes to eject an electron, wouldn't it be ejected once at least?
65 **I:** if the ground state is 4..
66 **S:** that makes more sense, it's lower energy, farther away from 1312..
67 **S:** 16:00 I'm confused, so the ground state it takes the most energy to get it out of... wait is this like, is the ground state here before you put in the 1312. from here you would need 1312, but it's not like at 1312 - wow, this would have been helpful like a month ago...
68 **I:** 16:57 how about 980?
69 **S:** it would be like here, I guess like a number line points to in between levels , but I'm not sure exactly what would happen
70 **I:** 990?
71 **S:** I guess it would be a little bit above, but I'm not 100% sure what would happen exactly
72 **I:** 13:05 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
73 **S:** I would assume there would just be KE, 200kJ
74 **I:** 17:32 What is an emission spectra?

75 **S:** yeah, if it's like excited enough or something then it emits light I guess. When it emits, it goes back down to the ground state., or down to a lower energy state.

76 **I:** why?

77 **S:** because the light is energy, then it gets rid of that energy so it can go down to lower energy

78 **I:** 18:13 look at diagram, what energies are emitted?

79 **S:** if it were like here or something and it would go back down, would it emit like 984?

80 **I:** 3 to 1?

81 **S:** it would be 984 or whatever plus the difference between these two..

82 **I:** can H in its ground state have an emission?

83 **S:** maybe, well why no is because it's in it's ground state, why yes, I'm not sure...

84 **I:** 19:53 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

85 **S:** the absorption and emission spectra. Well I guess they are sort of like antagonistic, like one, like if something absorbs red stuff longer wavelengths, then it will emit shorter wavelengths

Student No: 53

	Evidence	Code
Probabalist/ Determinist	electron spins around it quickly like energy shell, it's kinda hard to predict where that electron is I picture them kinda circular, I think they are in the orbital, they are not outside the orbital because if they are outside the orbital, I don't think they would have enough attraction to the proton, the nucleus.	2
Discrete/ Continuous	16:00 (500?) Nothing would happen. It would not, it would not have enough energy to go from n=1 to n=2 (would the electron move at all?) it would probably jump a bit and fall back down, on the visual level, nothing would happen nothing would be observed	2
Interpreting Spectra Code	and the next one should be aournd 900, the different between these two, and that's the energy required for it to go from n=1 to n=2, that's specific so if it's like 1000 kJ/mol, nothing would happen, it would just be transmitted	3
Energy/Force Code	I think the electron current would diminish energy (how would that affect the atom?) the electron won't be as energetic, so they might not jump as far... yes. except O 2p orbital it has 4 electron, so more electron repulsion means this is easier to ionize, taking away this e 10:47 (why different colors?) because their electron are kinda different, they experience different forces because like the nucleus of He is not as big as the nucleus of Ne so the electron would feel different forces in the 2 atoms (so if both have n=1 to 2 and fall back down, would they look the same color?) nope. the electron feel differently (are the 2 energy levels for 2 different atoms diff, or the same with different forces) I think they are different. because each atom has their own unique IE, each atom has it's own specific n=blah blah blah energy	4

Line No.		Transcript
1	**I:**	01:04 Describe how you visualize the atom
2	**S:**	I just visualize it there is a small nucleus in the center, and for Hydrogen that's usually just one proton and the electron spins around it quickly like energy shell, it's kinda hard to predict where that electron is but compared to the size of the atom the nucleus, the neutrons and protons, are very small. Energy shell is where the electron can jump up, the electron can jump up the energy shells, if it jumps up high enough it goes away from the atom then the electron becomes ion. If it goes to say n=1 to n=5 then energy is absorbed. If it jumps down, like from n=4 to n=2, then energy is emitted
3	**I:**	02:18 why these energies?
4	**S:**	that's a good question... why these energies in the first place? Then otherwise we wouldn't see color? because of specific wavelengths of light are emitted, I think our universe would be really different if energy shells did not exist because like I think by definition the electron do have to transition between different energy shells
5	**I:**	03:17 How would you describe oxygen?
6	**S:**	it's… oxygen also has a nucleus. Usually has 8 protons, 8 neutrons, probably an isotope might have nine neutrons. It has 8 electron spinning on the outside. And 2 of them are core electron, so they are harder to be ionized, but then there's a n=2 shell , it contains 6 electron 2 of them are in the 2s orbital and 4 of them are in the 2p orbital
7	**I:**	04:08 Is there a difference between s and p?

8 **S:** s orbitals, they are spherical, so they can only contain 2 electron , cause one with an upward spin, one with a downward spin. P-orbs they are dumbells so they have more axes so x y and z axes, so they have 6 electron can occupy the p orbital shells one up the other down like 3 times across each of the axes. And I think p orbitals are generally higher level than s orbitals

9 **I:** where are the electrons?

10 **S:** I picture them kinda circular, I think they are in the orbital, they are not outside the orbital because if they are outside the orbital, I don't think they would have enough attraction to the proton, the nucleus.

11 **I:** are all orbitals circular?

12 **S:** That's how I would imagine them.

13 **I:** can you draw 2s and 2p? how do they go together?

14 **S:** 2s is more like spherical. 2p is more like... I think they kinda overlap.

15 **I:** 06:17 are 2p orbitals in O same as N?

16 **S:** yes. except O's 2p orbital it has 4 electron, so more electron repulsion means this is easier to ionize, taking away this electron. Well N is only one electron per...

17 **I:** 06:55 Describe how you visualize light

18 **S:** light. I visualize light as a specific wvlngth. There's visible light which is a very small section of the EM Spectrum. I just visualize it as a certain wvlngth, has a certain frequency, certain energy, but not necessarily a certain intensity. I kinda see it like a sine curve - if it's like this it has a long wvlngth, if it's like this it has a short wvlngth.

19 **I:** 07:48 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

20 **S:** oh some of the energy will be used to ionize the electron but the rest of it will go to KE as motion

21 **I:** 08:09 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

22 **S:** then nothing happens, it doesn't necessarily have to be ionized but the electron from n=1 to n=2 if that energy is specific for the different in energy levels.

23 **I:** why?

24 **S:** because if it's not specific, the light is just transmitted. I remember we had an exam question like that on the MT, and I think I missed it. I said that it gets released as KE the answer but instead it just has to be a specific energy or nothing happens, like it jumps from n=1 to ...

25 **I:** 09:21 can you think of atomic structure and why it has to be that specific energy?

26 **S:** if you think this is n=1 n=2, a jump here if it wasn't specific it would just fall back down and light would just be transmitted. It can't fall back here [n=2]

27 **I:** 09:50 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

28 **S:** I think it's the specific energy that is emitted like for example n=5 going to n=1 is a pretty big jump so that might be high energy so that means it might be shorter wavelength so if it's the visible light spectrum it might be something like red. But if it's like n=3 to n=1 , that's smaller energy, that means longer wavelength and less energy, so that would correspond.. no! this one would correspond to something like violet, and this might correspond to something like red. red has a longer wavelength that it reflects

29 **I:** 10:47 Why are Ne and He tubes different colors?

30 **S:** because their electron are kinda different, they experience different forces because like the nucleus of He is not as big as the nucleus of Ne so the electron would feel different forces in the 2 atoms

31 **I:** so if both have n=1 to 2 and fall back down, would they look the same color?

32 **S:** nope. the electron feel differently

33 **I:** are the 2 energy levels for 2 different atoms different, or the same with different forces?

34 **S:** I think they are different. because each atom has their own unique IE, each atom has it's own specific n=blah blah blah energy

35 **I:** 11:53 Over time, would the tubes change color?

36 **S:** um, if the energy diminishes, the wavelength could increase which means color can change.

37 **I:** what energy would have to diminish?

38 **S:** I think the electron current would diminish energy

39 **I:** how would that affect the atom?

40 **S:** the electron won't be as energetic, so they might not jump as far...

41 **I:** 12:45 Is there any amount of energy that wouldn't light the bulb?

42 **S:** uh, yes, there is a really small energy that... I picture that if the energy is really small then it wouldn't really light the bulb. The electron won't have enough energy to jump.

43 **I:** 14:07 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

44 **S:** I can't really think of a photo spectrum diagram which relates to IE. So this is now the energy required to … so this is like 2000, and this is 1312.. This is the amount of energy required to make the electron go up to like n=infinity, like ionize, and the next one should be aournd 900, the different between these two, and that's the energy required for it to go from n=1 to n=2, that's specific so if it's like 1000 kJ/mol, nothing would happen, it would just be transmitted

45 **I:** 15:07 are these all the possible absorptions that can happen?

46 **S:** yes, absorption has to start from n=1 but emission on the other hand, it can start from n=4, n=3 , n=5 and jump anywhere

47 **I:** 15:30 so the emission would have those lines plus more?

48 **S:** yes.

49 **I:** and any combo

50 **S:** yes

51 **I:** 15:37 How much energy is needed to ionize Hydrogen?

52 **S:** 1312 kJ/mol, because that's the amount of energy that required for the electron pair to go off all the n levels

53 **I:** 16:00 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

54 **S:** Nothing would happen. It would not, it would not have enough energy to go from n=1 to n=2

55 **I:** would the electron move at all?

56 **S:** it would probably jump a bit and fall back down, on the visual level, nothing would happen nothing would be observed

57 **I:** 16:30 984?

58 **S:** then it would move from n=1 to n=2

59 **I:** 985?

60 **S:** then light would just be transmitted, it would not go to n=2

61 **I:** would the electron move at all in that case?

62 **S:** not really.

Student No: 54

	Evidence	Code
Probabalist/ Determinist	it's a cloud instead, a space where electron are most likely to be.	3
Discrete/ Continuous	11:49 finding differences between the energy levels, but I'm still not sure if the absorbance will be between 3 and 2… jumps from one energy level to another. The different from ground state to other levels.. Not sure...	3
Interpreting Spectra Code	11:49 finding differences between the energy levels, but I'm still not sure if the absorbance will be between 3 and 2… jumps from one energy level to another. The different from ground state to other levels.. Not sure...	3
Energy/Force Code	the electron needs to get energy somewhere in order to get propelled to the next level. can't be in between levels. don't know why, for IE, excess will go to KE. but when jumping to next level, excess energy ... usually as it moves faster it moves in a bigger area, the KE is what causes it to move out... 06:40 KE is what causes the jump to the next energy level... the electron releasing energy as it's going down from excited states, any position that it's not at its resting ground state. He and Ne have different energy levels, absorb different energies,so emit different lights. When it is zero, no attractive forces are holding it Because of nuclear attractions, if one has stronger nuclear attractions, it will take more to get it to the next energy level	4

Line No. **Transcript**

1 **I:** 00:57 Describe how you visualize the atom

2 **S:** with the new Schrodinger model, it's a cloud instead, a space where electron are most likely to be.

3 **I:** 01:24 How would you describe oxygen?

4 **S:** H atom only has only little cloud - spherical. O has a dumbell shape. The clouds are a function.. The function squared is the probability of where it's gonna be. There is equal chances of the electron being around a certain radius around the nucleus

5 **I:** 02:18 Describe how you visualize light

6 **S:** both a wave and a particle. It's very abstract it means that it has properties of both, different types of energies, can do different things to atoms. Particle is a discrete item, each distinct thing has its own properties. Wave model… wavelength - tells us the particle's properties, like it's energy level how it affects the eye

7 **I:** 04:15 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

8 **S:** the electron jumps up, or gets removed from the atom, or it will fall down

9 **I:** 04:35 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

10 **S:** it could make the electron jump from one state to another, but only if it is the discrete amt. There are certain energy levels of the electron and to jump it takes a specific amount of energy. If the electron does not have that amount of energy, it doesn't do anything, and the light shines through. energy levels are little spaces for the electron to be in. the electron needs to get energy somewhere in order to get propelled to the next level. can't be in between levels. don't know why, for IE, excess will go to KE. but when jumping to next level, excess energy ... usually as it moves faster it moves in a bigger area, the KE is what causes it to move out...

11 **I:** Why is that?

12 **S:** 06:40 KE is what causes the jump to the next energy level...

13 **I:** 07:05 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

14 **S:** the electron releasing energy as it's going down from excited states, any position that it's not at its resting ground state. He and Ne have different energy levels, absorb different energies,so emit different lights. Because of nuclear attractions, if one has stronger nuclear attractions, it will take more to get it to the next energy level

15 **I:** Over time, would the tubes change color?

16 **S:** 08:14 won't change color, as it emits light goes back to ground state, continued flow of charge continuing jumping up and down....

17 **I:** Is there any amount of energy that wouldn't light the bulb?

18 **S:** 09:07 if it's in between the energy states or not enough to make it jump to the next energy level.

19 **I:** 09:37 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

20 **S:** this would be infinity, n=1… [draws] changes to zero.. different levels for the energy states it could be in

21 **I:** 10:48 How much energy is needed to ionize Hydrogen?

22 **S:** 1312kJ, jumping from lowest state up to zero, represents no PE… [hesitates] when it is neg, add this much and will release energy. When it is zero, no attractive forces are holding it

23 **I:** 11:49 Can you draw the absorption spectrum of Hydrogen?

24 **S:** finding differences between the energy levels, but I'm still not sure if the absorbance will be between 3 and 2… jumps from one energy level to another. The different from ground state to other levels.. Not sure...

25 **I:** 14:06 What happens if you shine light on hydrogen with an energy of 980 kJ/mol?

26 **S:** 980 will jump to the n=2 level, 500 kJ nothing will happen, light will be transmitted, at 1500 will be ionized, excess to KE,

27 **I:** 14:51 How is this different from an emission spectra?

28 **S:** jumping back to ground state[(draws arrows]

Student No: 55

	Evidence	Code
Probabalist/ Determinist	01:22 well an atom of H I kind of see it as kinda a fuzzy type of ball because I guess you have this orbital and the electron spins around really fast so there's just a probability of where you would find it and so yeah it's just sorta like a fuzzy type of object	3
Discrete/ Continuous	18:34 (984?) then yes it would go from the first level to the second level (985) hm, I don't know, like logically I want to say that it goes to the n2 level because it's close but I don't know .. But the energy levels are really really distinct so I don't think it will get absorbed	3
Interpreting Spectra Code	14:40 (what do those represent to you?) it just represents the amount of energy needed to go from one level to another and then like you can sort of subtract it it , so like less energy is needed to go from the 2 to 3 level than like from the 1 to 2 or 1 to 3 (so are those numbers there the amount of energy needed to go?) um, I think these numbers are like the amount of energy needed to like ionize the electron the atom when the electron is in that shell, like if you wanted to ionize H when there is an electron in the first shell you would need 1312 kJ but like just to move it in between the shells it's the difference	3
Energy/Force Code	I don't know it's just a small source of energy basically hits the electron and it gets excited so it like jumps away from it from the nucleus 12:23 (min energy?) yeah, I suppose, like I don't know there is always a certain amount of energy you need to get the electron to go from one shell to another shell, if you have less than that amount like it's different for every atom, but if you have less than that amount then it probably wouldn't be absorbed it would just go through 08:37 well then it wouldn't be ionized because it doesn't have enough energy to jump past the shells and so it is still attracted to the nucleus the energy required to get the electron away from the nucleus of He is like much higher than that of H, cause there is like more attraction because it has a larger positive nucleus but so ok, no I don't think that He releases the same wavelength just because that energy is different , and so energy would be released as light in a different wavelength 11:16 (why energy levels different in different atoms?) um just because ofthe attractive forces of the nucleus, the larger the nucleus, the more attraction the electron have they are closer to it so	4

Line No.		Transcript
1	I:	01:22 Describe how you visualize the atom
2	S:	well an atom of H I kind of see it as kinda a fuzzy type of ball because I guess you have this orbital and the electron spins around really fast so there's just a probability of where you would find it and so yeah it's just sorta like a fuzzy type of object
3	I:	01:49 How about in oxygen, describe this fuzziness
4	S:	it's just uh the electron cloud is produced by the different orbitals so there is several layers of orbitals like I know there is a p orbital that is the most outer valence shell
5	I:	what do you mean by orbital?

6 **S:** well as I understand it it's where the electron are, where a certain number of electron are most likely to reside it's where they are like most stable so it has different patterns like closer to the nucleus there's s orbitals where it's circles and then I don't know I guess the electron they don't need to be paired up with each other so the space each other out they like go in separate orbitals so they are not colliding

7 **I:** 03:17 Can you draw the 2p orbital in oxygen?

8 **S:** well, here's the nucleus I'd say, it kinda has something like this but… I know there's 3 2p orbitals so kinda like I guess the electron kinda like flows in some pattern around

9 **I:** why does it stay in the orbital?

10 **S:** I don't know it's because of some repulsion from the other orbitals, I don't know geometrically stable

11 **I:** Can you add 2s into the picture?

12 **S:** um, I'm not sure exactly , well I know 2s comes before 2p so it has to be somewhere like in here I'm guessing nd so yeah it's somewhere like that and you have the 1s like way down there

13 **I:** so do they overlap?

14 **S:** to some extent, yeah.

15 **I:** 04:51 anything else unique about them?

16 **S:** yeah, the electron can shift up and down between orbitals but they need like a certain amount of energy and when they like come back down they release energy in the form of light

17 **I:** 05:40 Describe how you visualize light

18 **S:** Well, I guess.. It's still a hard question because I guess I'm not sure if light is like a wave model or a particle model but I guess light is like mainly made up of a lot of small particles that just kinda move in a wave sort of

19 **I:** 05:50 what do they get you?

20 **S:** well just cause like i don't know the wave model can be shown by like diffraction and how you can separate light into its different wavelengths and different colors but that's opposed to like a shadow a particle method would describe it better cause there is no really haze on a shadow or something. or like black body radiation I guess you are exciting a black object so it shoots off different colors

21 **I:** 06:59 is it more like one?

22 **S:** um, no, no I kinda think they are both useful there's no dominant one

23 **I:** 07:30 What happens when light hits a Hydrogen Atom with energy Greater than the Ionization energy?

24 **S:** well that energy that is required to ionize it like the extra energy left over just goes into KE like kick the electron off. So if it hit it with exactly the right amount of energy frm what I'm told the electron separates but it doesn't really have any KE to go anywhere. what happens when hits? I don't know, I never thought of it as like a collision with a photon and an electron but.. I don't know it's just a small source of energy basically hits the electron and it gets excited so it like jumps away from it from the nucleus

25 **I:** 08:37 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

26 **S:** well then it wouldn't be ionized because it doesn't have enough energy to jump past the shells and so it is still attracted to the nucleus, so yeah I don't think it would go anywhere. If it had exactly enough energy to go from one shell to another, it might do that

27 **I:** 09:10 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

28 **S:** um, well I guess the amount of electron and shells you have available.. Well every atom sort of has it's own shell.. Well ok you see more electron in the shells that are available so I think Ne since it has more electron it can like jump up to different levels to shells and when they fall back down they release like a different wavelength. So I guess H... I don't know is just a smaller atom so i don't think it has as great of a range so where the electron can go up and fall down to

29 **I:** would Helium's 1 to 2 be the same as Neon's 1 to 2?

30 **S:** um, I suppose so.

31 **I:** so 1s is same energy for every atom?

32 **S:** well the energy to get it to go from 1 to 2? no, I don't think so. when we looked at the photoelectron spectrum, the energy required to get the electron away from the nucleus of He is like much higher than that of H, cause there is like more attraction because it has a larger positive nucleus but so ok, no I don't think that He releases the same wavelength just because that energy is different , and so energy would be released as light in a different wavelength

33 **I:** 11:16 why are energy levels different in different atoms?

34 **S:** um just because ofthe attractive forces of the nucleus, the larger the nucleus, the more attraction the electron have they are closer to it so

35 **I:** you first said they would be the same, why?

36 **S:** I guess I was just thinking of it in terms of numbers like one level like they all have the n=2 n=1 level so I just, I don't know

37 **I:** 11:50 Over time, would the tubes change color?

38 **S:** um, I don't know, as far as I know, no maybe if electron were getting more energy than what's required or being kicked off and so eventually the electron can jump to the same level or...

39 **I:** 12:23 Is there any amount of energy that wouldn't light the bulb?

40 **S:** yeah, I suppose, like I don't know there is always a certain amount of energy you need to get the electron to go from one shell to another shell, if you have less than that amount like it's different for every atom, but if you have less than that amount then it probably wouldn't be absorbed it would just go through

41 **I:** 13:10 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

42 **S:** I think so… I'm just confused about the name cause I know the.. I just can't put the name to it… so I know there's like an arrow with PE's on it or something… so I guess the energy diagram would be like this so n=1 would be the lowest level because it's like most negative and then n2 would be... there's a big difference between n2 and n1 so it would be sort of up here and then 3 and 4 would have sort of a smaller gap

43 **I:** 14:40 what do those represent to you?

44 **S:** it just represents the amount of energy needed to go from one level to another and then like you can sort of subtract it it , so like less energy is needed to go from the 2 to 3 level than like from the 1 to 2 or 1 to 3 so are those numbers there the amount of energy needed to go?

45 **S:** um, I think these numbers are like the amount of energy needed to like ionize the electron the atom when the electron is in that shell, like if you wanted to ionize H when there is an electron in the first shell you would need 1312 kJ but like just to move it in between the shells it's the difference

46 **I:** 15:53Can you draw the absorption spectrum of Hydrogen?

47 **S:** like the absorption spectra I know is like wavelength vs. …

48 **I:** what are the possible absirptions that can happen?
49 **S:** energy can be absorbed from the 1 to 2 level, or the 1 to 3 or the 1 to 4
50 **I:** why always from 1?
51 **S:** well cause the electron in the hydrogen atom like resides in like the 1s level
52 **I:** could you put it to 2 and then 3?
53 **S:** I suppose, like 2 different steps? I would think if you give it enough energy to get it to 2 it would fall back down and energy would be released by the atom
54 **I:** 17:13 How is this different from an emission spectra?
55 **S:** like emission is when it falls back down
56 **I:** is it always going to 1? Is it the opposite?
57 **S:** No, ok, no the electron can go from like the n3 level to the n2, the n2 to the n1
58 **I:** more lines in the emission?
59 **S:** I think so
60 **I:** 17:48 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
61 **S:** um, I guess since it's past that IE it ionize the electron and the leftover 200 kJ would go into the KE to move the electron
62 **I:** 18:11 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?
63 **S:** well then I don't think the electron would do anything becaue it's like not enough it's less than the difference between the first 2 levels of shells like 1 and 2 so like the energy wouldn't be absorbed or anything, it would just be transmitted through the atom
64 **I:** 18:34 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?
65 **S:** then yes it would go from the first level to the second level
66 **I:** how about 985?
67 **S:** hm, I don't know, like logically I want to say that it goes to the n2 level because it's close but I don't know .. But the energy levels are really really distinct so I don't think it will get absorbed

Student No: 56

	Evidence	Code
Probabalist/ Determinist	It's gonna appear like a cloud but there is only one electron there.. The cloud is any place the electron could be, it's got an equal chance of being at any point in that cloud, within the 1s orbital.	3
Discrete/ Continuous	nothing will happen -because of the whole discrete packet theory.. it says that uh it has to be this energy. you can't bump an electron up cause i t's not the same frequency, you can't bumpan electron up and have a little extra energy leftover to go, have a fraction of it go over, it has to be this discrete packet, so nothing is going to happen. If you shine something a little less intense, like 984, then it will get bumped up	3
Interpreting Spectra Code	22:10 1312 the different between the 2 energies is the energy required to bump it up, from n1 to n2 you have 984, 1166 from n1 to n3, and n1 to n4.	3
Energy/Force Code	it has the certain energy needed to get it to the next level. the atom emits light, how far the electron drops will determine the energy of the light, therefore the wavelength of light. mathematically it made sense... i saw this chart where it was going to a higher orbital, and the energies that correspond to that. Also Majda's animation made a lot of sense, depending on how much energy went into the atom, a different colored "ball" was emitted, a certain wavelength of light. red ball vs. green ball, green is higher energy...	2

Line No.		Transcript
1	**I:**	01:03Describe how you visualize the hydrogen atom
2	**S:**	it's kinda like 1 proton, a dot in center, 1s1, a solid.. I wouldn't say cloud.. It's gonna appear like a cloud but there is only one electron there..
3	**I:**	So tell me a little bit more about that
4	**S:**	The cloud is any place the electron could be, it's got an equal chance of being at any point in that cloud, within the s-1 orbital.
5	**I:**	you said solid? or what is this cloud?
6	**S:**	1:47, if you were looking at it, it would look solid, because the electrons move very very fast, like if I wave my hand like this it looks solid.. it's like an area a general area where the electron can be at any point in time
7	**I:**	you said 1-s, so what does 1s mean?
8	**S:**	2:07 it's means the first energy level above the proton.. as you get to higher energy levels you get more electron and stuff...
9	**I:**	so what does that mean, energy level?
10	**S:**	I guess you can call it an "altitude" where the electron would inhabit at any given time,
11	**I:**	by altitude, you mean?
12	**S:**	altitude, i don't know how to describe it beyond that, kinda like a shell, like this shell you got 2 electrons, this next shell you got another 2, and all of a sudden it jumps to six, it has to do with like the area and stuff how close the electron like to be to each other,I really didn't get too much into the woods on that, but I get where the shells are what they look like
13	**I:**	so the higher shells, the altitude, are they further away from the nucleus?
14	**S:**	yeah, they are further away, I guess that's what I was trying to say that they are further away
15	**I:**	If you think about the 1s and the 2s, are they distinct areas in space, or do they overlap?

16 **S:** they are.. if you are talking 2s, what was it, what was the name called? but he came up with these like cloud configurations, I know at 2s you're gonna get 1 node, so it's gonna be like part of a bullseye so i would say they are 2 distinct spaces, cause there's like a separation a node is where no electron exists

17 **I:** so what is the inner area before the node?

18 **S:** 04:08 it's part of the core and everything outsidethat is the valence, and huge energy differencw between the two, especially when you are kicking off electrons and stuff

19 **I:** 04:28 How would you describe oxygen?

20 **S:** uh, oxygen it's kinda sitting, I know it's sitting on a p4 or something on the periodic table, so probably looking at that little dumbell shape, it's got one node cause it's still at the 2 level. it's got 4 electrons no 6 electrons on the very outside level, 2 electrons on the very inside.

21 **I:** so those 6 on the outside, where are they?

22 **S:** they're kinda in sublevels - there's like 2s, p4 they're kinda in the same general area in space, but there's like a bit of separation but not as much as between 2s and 1s, the 2s and 2p kinda share, but there's a separation

23 **I:** the p - you said it was dumbell shaped can it be outside of the dumbell?

24 **S:** 05:59 i didn't get too much into that one either

25 **I:** if you had to take a guess, what would you say?

26 **S:** I would guess the dumbell is how the valence part is shaped, inside that you got a tiny like an extremely tiny kinda core, and these models represent only valence because that's... I'm guessing it gets exponentially smaller as you get closer to the nucleus.

27 **I:** what gets smaller?

28 **S:** like the clouds. like you are looking at the 1s, it's solid, the 2s you got larger, but everything else gets so much larger that when you are looking at all the suborbitals beneath tha tit's like a tiny little dot because you can't quite see it because that's how far you're zoomded out, that's how I guess the structure would work

29 **I:** 07:10 the 2s and the 2p - how are they related in size?

30 **S:** the 2s it's kinda like in the center of the dumbell, kinda occupying that center spot, the p's are on the outside with the exception of the blank area between the 2 parts of the dumbell

31 **I:** 07:50 Describe how you visualize light

32 **S:** I can give you the book definition

33 **I:** ok

34 **S:** it's in packets, you got your magnetic and your electric doing this thing [gestures wave] and travel kinda in packets at certain wavelengths or energy levels and yeah

35 **I:** so how do the packets have the wavelength?

36 **S:** I guess the speed at which they are vibrating, or no.. the distance between at which they are doing this thing [gestures wave up and down] the distance between the crests in the waves that's the wavelength, the tighter it is the higher the energy, the wider it is the lower the energy

37 **I:** 8:47 so if you have light that hits the hydrogen atom, what happens?

38 **S:** it depends on the energy of light, it's kinda like a quantified amount of energy, you need this much like specifically this much energy to either bump an H electron to a higher orbital or to kick it off entirely, anything less won't do anything, anything more would simply give the electron more KE

39 **I:** so let's say it has more than the IE, then what happens?

40 **S:** 09:50 the excess energy just goes, gets translated into KE for the electron

41 **I:** so let's say it has less than the IE. What are the possible things that can happen?

42 **S:** [silence]

43 **I:** so you mentioned quantified? what does that mean?

44 **S:** certain wavelengths of light will bump an electron to a higher orbital

45 **I:** why?

46 **S:** because I guess it's going at the same frequency as the electron or has exactly the amount of energy needed to transition to another orbital. so if white light like is hitting an electon, or white light is hitting at atom, you have certain wavelengths of light that are going to do certain things but uh but not all of it will be transmitted, not all of it is going to go completely through and when the electrons get excited to a higher orbital depending on the orbital they get excited to they might just come back down to 3 or 2 or jump straight back down to 1 in that case the atom kinds emits sort of light and this is corresponding to the amount of energy that was put into it and how far the electron drops will determine the energy of the light and therefore determine the wavelength of the light and

47 **I:** did this seem odd when you were learning this?

48 **S:** honestly, I missed that lecture, i learned it in discussion and the night before on the homework

49 **I:** is this the first time you'd seen it?

50 **S:** yeah, mathematically it made sense, like you bump an electron up to a certain orbital and the difference in the energies is going to come out as a wavelenght of light and that energy is going to correspond to a wavelength, you're gonna do some crazy mathematical stuff to it and turn it into a wavelength and it's going to be different depending on the orbitals, so looking at it, I mean they way I learned it was looking at the math and stuff

51 **S:** I saw this chart where it was going up to a higher orbital and then it showed all the places where it could go down and the energy that it emits as it goes down and it just made sense. What really made sense was the day after that I actually went to lecture I saw Prof. Majda he put up a sorta animation i guess where you got a hydrogen electron just spinning around and you got light coming at it and depending on how much energy he put into that light, or exactly how much different wavelengths he put into it, the electron would jump either really high and do this thing [gesture fall down in steps] or jump really high and jump straight back down, and depending on that , a different color "ball" was emitted

52 **I:** what do those balls represent?

53 **S:** a certain wavelength of light. I know that if it jumped straight up there and then hit an orbital on it's way down it would be a red "ball" but if it jumped straight up and went all the way down it might emit a green "ball" that kinda thing

54 **I:** so which one is higher energy? red or green

55 **S:** uh, green.. that was just me messing up, I was just arbitratily

56 **I:** no, I think you had it right...

57 **I:** 13:26 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

58 **S:** uh, electron coming back to ground state.

59 **I:** can you tell me more about that?

60 **S:** As you put electricity through it you excite the electrons to a higher orbitals, so it's not just light that does this so it's electricity it's also heat, the electron gets excited and then it comes back down. and then how we get different color neon signs is depending on how much electrcity you put into it, a certain I guess voltage you'll get blue, cause that's how the orbitals work out. Another voltage you'll get green

61 **I:** So what causes those different colors? with the more voltage?

62 **S:** um, you jump, different voltages will jump an electron to different orbitals and as they come down they will emit a certain combination of wavelengths uh so say you got one that'll emit I don't know yellow and blue and you'll get green. One that'll emit just red and you get red

63 **I:** Let's say you fixed the voltage and looked at it over time, would the tube change color?

64 **S:** 15:00 not really.

65 **I:** why not?

66 **S:** cause you're not really getting rid of electrons you're just bumping them up and down and stuff , I haven't learned anything contrary to this so i'm guessing you can do this all day, so for different.. I think I know the question you're getting at.. the one with the photocell, will the photocell eventually run out or something, I actually googled that one after the test

67 **I:** How is the photocell different from the neon tube?

68 **S:** the photocell instead of bumping electrons up actually kicks electrons off in order to create an electric current, i learned this after the test, I think I got that one wrong

69 **I:** 16:23 Is there any amount of energy that wouldn’t light the bulb?

70 **S:** 16:28 anything that's below the energy required to bump it up to the first orbital, in that case it just won't do anything

71 **I:** 17:02 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table] Where are the energy levels?

72 **S:** [starts drawing an "absorption spectra" like plot with levels plotted horizontal]so going from left to right you go to increasing energy. um, lowest one will be 4 right here, easiest to kick off. Will this be like.. oh wait never mind. n=4, n=3, n=2 and n=1 is waay out here

73 **I:** sp why don't we flip it vertical and have energy going up?

74 **S:** so, I was kinda curious about the x axis of this would be

75 **I:** in the energy level diagram ,the x-axis really doesnt' mean anything

76 **S:** 20:01 go ahead and put the energies in the table next to those also

77 **I:** so what energy is n=1?

78 **S:** -1312

79 **I:** where is the electron in the hydrogen atom?

80 **S:** 21:23 in a regular unexcited atom, ground state, s1 ,

81 **I:** what energy is the electron at?

82 **S:** I guess this would be the IE, once you've gotten here [gestures zero], you've kicked off all the electrons

83 **I:** 22:10 How much energy is needed to ionize Hydrogen?

84 **S:** 1312

85 **I:** So hydrogen has one electron, but this is 4 levels, so how does that make sense?

86 **S:** I guess this is the energy required to bump it up or the difference between the 2 energies is the energy required to bump it up to a certain level or do something to it once it reaches that level

87 **I:** can you calculate how much is needed to bump up the electron to different levels?

88 **S:** 22:57 so from n1 to n2 you have 984, 1166 to go from 1 to 3, 1230 to go from 1 to 4

89 **I:** so what does it mean when it gets excited?

90 **S:** it will temporarily go up,, it will go farther away from the nucleus

91 **I:** for the H-atom, this example, what energies of light will get absorbed?

92 **S:** pretty much 984, 1166, and 1230

93 **I:** 24:31 So let's say I shine light of 985 kJ - what happens?

94 **S:** the electron gets bumped up with… exactly 985?

95 **I:** exactly 985.

96 **S:** nothing will happen -because of the whole discrete packet theory.. it says that uh it has to be this energy. you can't bump an electron up cause i t's not the same frequency, you can't bumpan electron up and have a little extra energy leftover to go, have a fraction of it go over, it has to be this discrete packet, so nothing is going to happen. If you shine something a little less intense, like 984, then it will get bumped up

97 **I:** so let's say 983 - what happens at 983?

98 **S:** nothing still, cause it's not high enough... at 984 gets excted, nothing again until 1166, and then it gets bumped up again

99 **I:** what happens at 1312?

100 **S:** 1312, the electron pretty much gets kicked off of the atom and at that point any extra energy that you have becomes kinetic

101 **I:** let's say you have 1313, then what happens?

102 **S:** the electron's gonna leave the atom with 1kJ of KE

103 **I:** 26:39Now think about an emission spectrum, how is emission different from absorption?

104 **S:** emission is the light given off when the electron goes back to ground state, you're going to have different specta because it's gonna be any combination of coming back down, it could be from, 4-3, 4-2, 4-1 or any combination of those, so you're gonna have a lot of lines in emission spectrum, generally they might fall in between like say this chart, it's going to have one here, one here, one here, one here, so there's going to be lines in between the chart

105 **I:** can you draw it on there?

106 **S:** this is your absorption, your emissions are generally going to fall somewhere like this

107 **I:** why?

108 **S:** cause when it jumps from here to here the energy is going to be the difference between these two, so it's going to be a little more than this, and a little less than this, so it will be this

109 **I:** Can you calculate for me what one possible emission energy could be?

110 **S:** energy would be this is 82, you're jumping from 82 to 146, you've got 64, which is going to be way back out here, oops... yeah

111 **I:** 29:47 can you just tell me all the emissions that can happen?

112 **S:** ok, so it's gonna go 4 to 3, 4 to 2, 4 to 1, and then it's gonna go 3 to 2, 3 to 1 and 2 to 1, because it won't jump back up

113 **I:** ok, there's like six possible differences that you can calculate

114 **S:** [nods yes]

Student No: 57

	Evidence	Code
Probabalist/ Determinist	01:22 well I visualize it as a nucleus in the middle with a proton inside of it and one electron circling around the nucleus I'm guessing the attraction from the nucleus on the outer electron as they are circling the nucleus, I guess that's just the shape it gets (path of electron) no, I think they.. they say that they don't actually know where the electron is traveling like at one time, but they can like estimate like where it is within that orbital	2
Discrete/ Continuous	18:36 (500?) it wouldn't do anything. Because the least you need is like 1312 -328 =984 (so what if 984?) then you can excite it from the first one to the second one (990?) no, it would just stay at n=2 (so it can get extra, it just has to get enough?) yeah. to give it enough energy to break through to the outer shell	1
Interpreting Spectra Code	15:07 of H? these lines .. I think I dropped some but yeah… there needs to be more… but these lines over here, the height of them represent how many electron are being excited and as you move to the right they are increasing in energy (why these energies) that's because it's written right here	1
Energy/Force Code	06:40 then the atom has enough energy to eject an electron and that excess energy that excess energy is going to be turned into KE (how?) it vibrates… ok so the light wave comes hits the electron then the electron vibrates and breaks free 08:25 uh, the electron being excited to another orbital and then as they are coming back down the light comes out. The.. When you shine the light onto something then the electron can move from let's say.. They can move from the ground state, so they can move from the s-orb to the p-orb and then on their way down that's when they give off the heat Why are Ne and He tubes different colors? because some of them just have higher effective nuclear charge so higher IE would be and the other ones just have more shielded electron which lowers the IE	4

Line No. **Transcript**

1 **I:** 01:22 Describe how you visualize the atom

2 **S:** well I visualize it as a nucleus in the middle with a proton inside of it and one electron circling around the nucleus

3 **I:** 01:50 How would you describe oxygen?

4 **S:** oxygen has it's first shell filled, so it has… first of all oxygen's nucleus has 8protons and then it has 2electron in its first shell and six in its outer shell

5 **I:** shells?

6 **S:** I think it depends on the orbital that they are in

7 **I:** What's an orbital?

8 **S:** there's the… I'm not pretty sure what the orbitals are or i know that the orbitals are where the electron are and I know there is an s, a p, a d, and a f orbital

9 **I:** do those letters mean anything to you?

10 **S:** [shakes head no] that there's different ones, yeah... because each shell can only fit a certain amount of electron, so they can't all fit

11 **I:** 03:42 how are the shells?

12 **S:** I don't know how to describe it but like here's a shell, and then here's another shell [farther out] and another shell

13 **I:** are they all circles?

14 **S:** no that's only an s orbital. the p-orb is shaped liked a dumbell, the d-orb is shaped like sorta like a clover, and the f orb is shaped in a weird way

15 **I:** why those shapes?

16 **S:** I'm guessing the attraction from the nucleus on the outer electron as they are circling the nucleus, I guess that's just the shape it gets

17 **I:** is it the path of the electron?

18 **S:** no, I think they.. they say that they don't actually know where the electron is traveling like at one time, but they can like estimate like where it is within that orbital

19 **I:** 05:42 Describe how you visualize light

20 **S:** well now I visualize it as certain wavelengths and now I visualize it as certain wavelengths passing through or tramsmitting through or reflecting off of certain objects. Um, there's they look like white ilght until they get absorbed by some object

21 **I:** 06:40 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

22 **S:** then the atom has enough energy to eject an electron and that excess energy that excess energy is going to be turned into KE

23 **I:** how?

24 **S:** it vibrates… ok so the light wave comes hits the electron then the electron vibrates and breaks free

25 **I:** why is it a wave?

26 **S:** or photons

27 **I:** what does that mean to you?

28 **S:** I don't know

29 **I:** 07:50 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

30 **S:** nothing happens to the electron at least. Nothing like the light hits it and the electron in the atom just stays still

31 **I:** 08:25 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

32 **S:** uh, the electron being excited to another orbital and then as they are coming back down the light comes out. The.. When you shine the light onto something then the electron can move from let's say.. They can move from the ground state, so they can move from the s-orb to the p-orb and then on their way down that's when they give off the heat

33 **I:** Why are Ne and He tubes different colors?

34 **S:** because He can only go up to a certain orbital and Ne can go up to a higher orbital

35 **I:** for Ne and He,is the 2s orbital the same energy?

36 **S:** I don't think so.

37 **I:** why not?

38 **S:** I don't know but.. I think...I'm not sure but I think I saw.. because the IE for every atom is very different, they are not the same so, it could take 1200 kJ to eject an electron from He, or the first electron could take like 4000 in Ne

39 **I:** why do you think that is?

40 **S:** or sorry if I coud just go back, I think that it would be the other way around He would be 4000 and Ne would be 1200

41 **I:** Why different?

42 **S:** because some of them just have higher effective nuclear charge so higher IE would be and the other ones just have more shielded electron which lowers the IE

43 **I:** 11:32 Over time, would the tubes change color?

44 **S:** no,
45 **I:** where would they change color?
46 **S:** somtimes light bulbs they just begin to like fade and and eventually they go out
47 **I:** Is there any amount of energy that wouldn't light the bulb?
48 **S:** some energy that's less than the IE, actually I don't know I don't think it has to do with that
49 **I:** what do you think are the key things to know?
50 **S:** how much energy is required to excite the electron from one orbital to another.
51 **I:** 14:32 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
52 **S:** this is.. How it takes however much energy that.. To excite the electron from the first orbital to the second orbital
53 **I:** 14:54 How much energy is needed to ionize Hydrogen?
54 **S:** 1312 kJ
55 **I:** 15:07 Can you draw the absorption spectrum of Hydrogen?
56 **S:** of H? these lines .. I think I dropped some but yeah… there needs to be more… but these lines over here, the height of them represent how many electron are being excited and as you move to the right they are increasing in energy
57 **I:** why these energies?
58 **S:** that's because it's written right here
59 **I:** 17:37 if I had an electron in n=1, describe what scenarios could happen…
60 **S:** it could go to here up to there or up to there.
61 **I:** if it goes up to n=4 what could happen?
62 **S:** it could come back down, it could go from 4 to 3, 3 to 2, 2 to 1
63 **I:** 17:11 How is this different from an emission spectra?
64 **S:** I don't know
65 **I:** 18:18 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?
66 **S:** then it just kicks the electron off and the electron goes to infinity
67 **I:** 18:36 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?
68 **S:** it wouldn't do anything. Because the least you need is like 1312 -328 =984
69 **I:** so what if 984?
70 **S:** then you can excite it from the first one to the second one
71 **I:** 990?
72 **S:** no, it would just stay at n=2
73 **I:** so it can get extra, it just has to get enough?
74 **S:** yeah. to give it enough energy to break through to the outer shell

Student No: 58

	Evidence	Code
Probabalist/ Determinist	the electron are in a cloud I guess, this probability like cloud around the nucleus, they are not in orbits I guess We don't know where in the p-orb they are, but they are there.	3
Discrete/ Continuous	It can't take like half that amount of energy and go halfway between 1 and 2 . it can only go from 1 to 2 to 3 to ..., or 1 to 4 or 1 to 3 , but not in between. Let's say you need 10 kJ of energy to get from 1 to 2, and say you put in 5, it won't go here , it will just absorb that energy , but nothing will happen to the e-, it won't go higher, cause it needs more. it's like stepping up on a ladder , if you don't put enough energy to get to the next rung, you're not gonna be halfway between the ladder you'll just be in the first step yeah, I want to take back what I said, let's say you shine whatever 500kJ, the atom doesn't absorb it, the light just gets shined right through	3
Interpreting Spectra Code	This is all for a ground state atom, or a ground state electron (points to 1-2, 1-3, 1-4, 1-IE) (4 energies?) yeah, beyond 1312 works too	3
Energy/Force Code	I think the electron can go outside the sphere if you put energy into it I guess the way I thought about it for the longest time - if you like climb up onto a step and you jump down, like you are releasing all that energy that you have built up from that higher step. so when you jump back down you are releasing all that energy you've gained, kind of	2

Line No. **Transcript**

1 **I:** 00:30 Describe how you visualize the atom

2 **S:** so as in like it's structure and everything? So the atom itself, the nucleus… there is a lot of space surrounding the nucleus, but the nucleus has a lot of stuff in it, so it has like the electron, the protons, the electron are in a cloud I guess, this probability like cloud around the nucleus, they are not in orbits I guess. I guess they take up these densities that you can only figure out the probability of where you find these electron. and then there's obviously protons which are within the nucleus, and yeah surrounding the nucleus is just a cloud of empty space.

3 **I:** 01:33 How about the orbital in hydrogen?

4 **S:** 1s. Based on the shape of the orbital, it's spherical. It doesn't have any nodes, a node is where you won't find any electron, and in the 1s orbital, there are no nodes.

5 **I:** 02:02 Can the electron leave the sphere?

6 **S:** I think the electron can go outside the sphere if you put energy into it, like if H absorbs energy, the electron can move to higher states. But currently, if you are just talking about the H atom, without any energy put in or anything, the electron is found in the sphere.

7 **I:** Is it equally likely to be found in sphere?

8 **S:** yeah.

9 **I:** 02:25 How would you describe oxygen?

10 **S:** so an oxygen atom, so it's 1s2,2s2,2p4, so it has a 1s orbital, a 2s orbital, and a p orbital as well. And the p orb is shaped like a dumbell, the s's are spheres, . Oxygen has more electrons and protons than H. The electrons in oxygen, the prob of finding the electrons are in the 1s , the 2s and the 2p.

11 **I:** 03:15 Can you draw the 1s and 2s?

12 **S:** 2s has 1 node. so like it will probably be like here is like the node so you won't find any electron here. So maybe it depends on how you look at it. For this one, you find the electron here, for this one you find it here and here, or it can be you don't find the electron there and you find it here, but I think it's this way.

13 **I:** 04:18 Do 1s and 2s overlap?

14 **S:** I know there is overlapping. I'm not exactly sure if it's between the s's, or the p's. I know there is p-overlaps... yeah there is overlap.

15 **I:** 04:30 Can you draw the 2p?

16 **S:** well, it's like dumbell shaped. but like i can't. I was gonna draw it the way I was drawing it here, but I'm trying to think. I think it's pretty much like this, like there and like there, and there's like some node. for the 2p, there is one node. so I think it would be like here and here, like this is considered a node

17 **I:** What do you mean by node?

18 **S:** it just means, it's just an area where you can't find an electron, I guess what they used in lecture was like, they used the analogy of taking a string, and it's pinched right here , and the nodes are where... the nodes are like here and here and here . so you'll find electron here and there and there, you won't find electron there

19 **I:** 05:45 Can the p electron move from one side to another?

20 **S:** yeah, i think so. We don't know where in the p-orb they are, but they are there.

21 **I:** 06:00 Describe how you visualize light

22 **S:** so light can be looked at as like a particle or a wave, they talk about that a lot. The duality of them both because in certain experiments we say that like the electron were like quantized, like they can move from energy level to energy level and then when they fall they emit light, in like packets called photons, but then light can be seen as a wave, because if you take black body radiation , like if you have a black body and you heat it up , and you took the graph of intensity vs i think it was not temperature, i think it was wavlngth, like it was continuous. and because it was continuous it shows it was not just like packets of light. and so there's both

23 **I:** 06:55 What do you mean by quantized?

24 **S:** I guess like discrete levels of energy. Like let's say you have n=1 energy level and n=2 energy level, you can't find .. If electron were absorbing energy , they have to absorb a certain amt, a certain number, like a certain level of energy it needs to have to get to . It can't take like half that amount of energy and go halfway between 1 and 2 . it can only go from 1 to 2 to 3 to ..., or 1 to 4 or 1 to 3 , but not in between.

25 **I:** 07:49 what happens between 1 and 2?

26 **S:** between 1 and 2 .. like this is the amount of energy the electron needs to get to 2. Let's say you need 10 kJ of energy to get from 1 to 2, and say you put in 5, it won't go here , it will just absorb that energy , but nothing will happen to the electron, it won't go higher, cause it needs more. it's like stepping up on a ladder , if you don't put enough energy to get to the next rung, you're not gonna be halfway between the ladder you'll just be in the first step

27 **I:** 08:44 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

28 **S:** [draws] so ground state is here.

29 **I:** What is the ground state?

30 **S:** this is the amount of energy from here to here to completely ionize, like remove the electron from ground state

31 **I:** 09:34 How much energy is needed to ionize Hydrogen?

32 **S:** 1312 kJ/mol

33 **I:** 09:44 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

34 **S:** then it'll, so the electron will get kicked off , but then the rest of the energy is going to be used for the KE of the electron, so like how fast it moves

35 **I:** 10:00 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

36 **S:** nothing happens. Basically you just do -1312 plus you said how much energy?

37 **I:** 500

38 **S:** so -1312 + 500 would be -812 , and -812 is not one of these numbers , so because it's not one of those numbers it would be like here [points to in between] it's not enough energy to go to the next energy level, nothing happens, light goes through, so transmitted, light is transmitted, nothing happens to the electron

39 **I:** 11:20 before you said absorbed?

40 **S:** yeah, I want to take back what I said, let's say you shine whatever 500kJ, the atom doesn't absorb it, the light just gets shined right through

41 **I:** 11:34 What happens idf you shine 984 kJ/mol?

42 **S:** yeah, so the electron will move from the first energy level to the second energy level. the light is absorbed.

43 **I:** Can you describe what happens.

44 **S:** the electron is getting "excited" is what they said. the electron is absorbing that energy so it can move up to the second energy level

45 **I:** Is it physically moving farther from nucleus?

46 **S:** yes

47 **I:** What does excited mean?

48 **S:** i think it just means moving to higher energy levels and moving away from the nucleus

49 **I:** 12:25 how about 985?

50 **S:** ok, yeah, nothing is going to happen, when I mean nothing,light is just gonna get transmitted through

51 **I:** why not n=2?

52 **S:** because like I said about the quantized energy, you need discrete amounts of energy for the electron to move between energy levels. if you do anywhere below, anywhere above, the light is just transmitted

53 **I:** 13:08 so what energies are absorbed?

54 **S:** between there and there, there and there [points to different levels] not really there and there. This is all for a ground state atom, or a ground state electron [points to 1-2, 1-3, 1-4, 1-IE]

55 **I:** those 4 energies?

56 **S:** yeah, beyond 1312 works too

57 **S:** 13:41 [draws] that would be -1312, then this right here is 984 and then we subtracted 984 to get there... 1166, and then ...

58 **I:** 15:05 How is this different from an emission spectra?

59 **S:** emission and absorption, I'm trying to think here, so it's the same thing, but what happens is like for absorption, this is how much energy we are absorbing and this is… for emission what happens is like these lines become like bright, and everything else becomes dark, or it's one or the other. for one of the it's like thes lines become dark and everythign else is lighter or the opposite one is these lines become light and everything else becomes dark. I'm pretty sure in emission, these ones get light

60 **I:** so why is that?

61 **S:** 15:58 basically in emission, there is going to be like, basically draw the same thing. an emission in different because let's say an electron gets to like n=4, it can go frm n=4 to n=3 , n=4 to n=2 or 1 , but it can also go from 3 to 2, 3 to 1, and from 2 to 1, so you have more lines

62 **I:** why is light emitted?

63 **S:** because when electron fall from higher energies to lower energies this causes like let's see, there is higher PE up here, and when you fall you are going to release energy

64 **I:** why?

65 **S:** why do you release energy? I know this.. I guess the way I thought about it for the longest time - if you like climb up onto a step and you jump down, like you are releasing all that energy that you have built up from that higher step. so when you jump back down you are releasing all that energy you've gained, kind of

66 **I:** 17:47 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

67 **S:** so if you put an electric current through it the electron are gonna get excited, so absorb all that energy, move up to a higher discrete energy levels and then when they fall back down, they emit light. The color of the light depends on the change in energies and where it falls from. so if we falingl with a higher energy, you're gonna see like purples and stuff , if you fall with a lower energy, you're gonna see like reds

68 **I:** 18:46 Why are Ne and He tubes different colors?

69 **S:** because Ne has more outer valence shells , so it means it has more energy levels that the electron can go to so if it goes to the highest energy level that it has.. He only has 1s2 so when those electron fall they are not going to be emitting as like high frequency of light as the Ne

70 **I:** why?

71 **S:** energy levels correspond to like ... like for He a greater frequency has a shorter wvlength...

72 **I:** 20:15 Over time, would the tubes change color?

73 **S:** yeah, because they are not always gonna be at that high energy state falling, let's say n=4, they are not always gonna be falling for three days from n=4, as they start emitting light, they are losing energy , they are not going to be at that excited state forever

74 **I:** but what if you supply an external current?

75 **S:** yeah, then it would still glow orange

76 **I:** what would need to happen for color change?

77 **S:** the electron when they move to higher energy states, might have to move to different energy levels , and if its falling from different energy levels, it emits different colors

78 **I:** 21:27 Is there any amount of energy that wouldn't light the bulb?

79 **S:** yeah, if you put in energy that's not enough to move it to the 1 the 2 the 3 the 4, like those exact amts of energy, then it won't

80 **I:** How about for H?

81 **S:** let's say we put in like 200kJ , it won't light the neon

Student No: 59

	Evidence	Code
Probabalist/ Determinist	it's just in a cloud, a spherical orbital. You have the proton, and it's just around it, I have no idea where it is…	3
Discrete/ Continuous	990kJ, it would move to n=2, and then it would have extra KE, but it won't move to n=3, would just stay in n=2. 500? it would stay in n=1 shell	1
Interpreting Spectra Code	990kJ, it would move to n=2, and then it would have extra KE, but it won't move to n=3, would just stay in n=2. 500? it would stay in n=1 shell	1
Energy/Force Code	04:29 you can excite the electron from the 1s to like another orbital and then once it goes back down, it releases energy. When the electron drops from the excited state back to the ground state. Excited means higher than 1s, into the 2s	2

Line No.		Transcript
1	**I:**	00:22 Describe how you visualize the atom
2	**S:**	like basically a proton. It has an electron just around the atom, the nucleus, it's in the 1s orbital, it's right around the nucleus, it's just in a cloud, a spherical orbital. You have the proton, and it's just around it, I have no idea where it is…
3	**I:**	01:36 How would you describe oxygen?
4	**S:**	has more electrons, 1s2, 2s2, 2p4. that means that the first s orbital is completely filled, so is the second one, and the p-orbital has 4 electron in it [draws] would have a node. I have no idea how to draw the p-orbital, it's a dumbell shape.
5	**I:**	02:52 Describe how you visualize light
6	**S:**	um, it's complicated. I think of like the EM spectrum, and energy, and I think of spectroscopy and the spectrometer. I guess visible light, light you can see. You can't see IR, microwaves, xrays, gamma rays
7	**I:**	04:29 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
8	**S:**	you can excite the electron from the 1s to like another orbital and then once it goes back down, it releases energy. When the electron drops from the excited state back to the ground state. Excited means higher than 1s, into the 2s. Ionization is the amount of energy it takes to eject or release an e-.
9	**I:**	What happens if you shine light of an energy greater than the IE?
10	**S:**	the leftover energy becomes KE, and the electron just keeps going
11	**I:**	what is KE?
12	**S:**	like the energy for it to travel, I don't know. KE is the energy for the electron to move. I remember then talking about 1312, so then if you add 1512, the extra 200 is the KE of the electron that just keeps traveling at that speed.
13	**I:**	06:38 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
14	**S:**	I think it was absolute values, I didn't think they had negatives, but I don't remember…
15	**S:**	[struggles throuhg drawing]
16	**S:**	… you mean from 1 to 2, is it ionizing? I don't know…
17	**I:**	What energies will get absorbed?
18	**S:**	I don't know
19	**I:**	How about to get to n=2?
20	**S:**	[struggles]
21	**I:**	How about energy of 900 kJ?
22	**S:**	for 900kJ, it will stay in the =1 shell. The light just goes through the atom.
23	**I:**	How about 990kJ?

24 **S:** 990kJ, it would move to n=2, and then it would have extra KE, but it won't move to n=3, would just stay in n=2.

25 **I:** how about 500?

26 **S:** it would stay in n=1 shell

27 **I:** 10:50 What is an absorption spectra?

28 **S:** I don't remember? I remember hearing about emission spectra, but I don't remember

29 **I:** what energies would be absorbed?

30 **S:** 11:26 oh that's the.. Ok… it absorbs a certain wavelength of light and that's what we see, I got confused with absorption and transmission and reflection, I can't explain it…

31 **I:** 17:12 How much energy is needed to ionize Hydrogen?

32 **S:** - 1312 kJ/mol

Student No: 60

	Evidence	Code
Probabalist/ Determinist	kinda like a cloud around it of where the electron could be. The cloud its just possibility of where it could be, it's an s orbital, it's spherical.	3
Discrete/ Continuous	(in between?) no, because it's quantized it means that there is no in between energy levels you shine a light that isn't exactly correct for this, then it just is transmitted it doesn't do anything and the electron stays out here. quantization means that it can only be in certain levels, just because it works	3
Interpreting Spectra Code	12:57 absorption is when you shine light on a sample of H and certain wavelengths are absorbed. Certain wavelegnths would be - there would only be 1 line, because there is only 1 electron to move around (confusing with PES?) oh, are we just talking about these 4 energy levels? (yes) so then it could be 6 lines?? (calculate?) so 1312 will, 328... 15:40 actually like I was saying before to get it from n=1 to n=2 you need this much energy. absorption there are only 4! 1312-146 and 1312-82 16:38 the sharp lines are that...i'm not sure why they are thin, I know they are thin....	2
Energy/Force Code	it absorbs it. the absorption gives it more energy so it jumps up.	2

Line No.		Transcript
1	**I:**	00:55 Describe how you visualize the atom
2	**S:**	um, after this unit, I see it as a proton in the middle and kinda like a cloud around it of where the electron could be. The cloud its just possibility of where it could be, it's an s orbital, it's spherical. Orbital is just possibility of where it can be based on the periodic table. so the H atoms has a config of 1s because its the very first element and it has an electron in the 1s orbital and it's a sphere
3	**S:**	01:58 the sphere is the probability of where the electron could be.
4	**I:**	02:13 How would you describe oxygen?
5	**S:**	O has 2 inner sphere I was just talking about and then it has 6, so then there is 2 more subshells, one is the 2s subshell which is another sphere and the 2p subshell which is they are wings. Oh no they are the dumbells! [draws] so this is the p orbital and this is the probability of where the other 4 electrons will be because they are like subshells. The inner circle is the 1s or 2s subshell. they are subshells they are a little distinct but not completely.
6	**I:**	04:08 Describe how you visualize light
7	**S:**	light is a bunch of photons at different wavelengths, or depending on which wavelength it is. They can have amount of energy, wavelength, freq, the intensity determined by the amplitude of the wavelength
8	**I:**	04:46 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?
9	**S:**	if the light has the correct amount of energy, it will excite the electron and allow it to, it will get it to a higher energy level, but it has to be the right discrete amount of energy level for each shell, and then the electron will de-excite and move back down to the ground state, and depending on which shell it was bumped up to, it will emit a certain energy of photon. it absorbs it. the absorption gives it more energy so it jumps up. For H, jumps up to here, another subshell n=2.
10	**I:**	how about in between?

11 **S:** no, because it's quantized it means that there is no in between energy levels you shine a light that isn't exactly correct for this, then it just is transmitted it doesn't do anything and the electron stays out here. quantization means that it can only be in certain levels, just because it works

12 **I:** 07:44 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

13 **S:** it's ionized. If less than IE, it won't be ionized, and if it's a correct amount for excitation, it will be excited and if not then it will be transmitted

14 **I:** 08:11 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

15 **S:** the deexcitation causes color. For H when it jumps back down to n=2 that's when light is emitted [draws] Balmer lines, I think. It's the excitation, they're excited and when they drop back down to say the n=2 level they shoot off a photon, not shoot off but like emit a photon. Color depends on the level of energy the deexcitation happens. So this would be a higher energy, so it would be redder, nope I'm so bad at these proportionalities.

16 **I:** 10:19 Over time, would the tubes change color?

17 **S:** stay the same, because the same process is happening over and over again

18 **I:** Is there any amount of energy that wouldn't light the bulb?

19 **S:** yeah, the energy if you don't get the excitation, then it can't excite and can't emit

20 **I:** 11:58 How much energy is needed to ionize Hydrogen?

21 **S:** 1312 - because there is one electron , and to get it to E=0 or basically n=infinity, you need that much energy. N= infinity means the electron and proton are no longer associated with each other

22 **I:** 12:57 Can you draw the absorption spectrum of Hydrogen?

23 **S:** absorption is when you shine light on a sample of H and certain wavelengths are absorbed. Certain wavelegnths would be - there would only be 1 line, because there is only 1 electron to move around oh, are we just talking about these 4 energy levels?

24 **I:** yes

25 **S:** so then it could be 6 lines??

26 **I:** calculate?

27 **S:** so 1312 will, 328...

28 **I:** 15:40 actually like I was saying before to get it from n=1 to n=2 you need this much energy. absorption there are only 4! 1312-146 and 1312-82

29 **S:** 16:38 the sharp lines are that...i'm not sure why they are thin, I know they are thin....

30 **I:** 17:17 how about 983?

31 **S:** no. it's because it's discrete jumps and you have to have it's quantized energy levels

32 **I:** 17:55 How is this different from an emission spectra?

33 **S:** Emission is the same thing but these are colors, and everything else is black

34 **S:** 18:08 this is where you would jump from here to here, here to here… lots of pretty lines going down, 6 this time

Student No: 61

	Evidence	Code
Probabalist/ Determinist	kinda like where the... the possibility, the probability of where the proton is, I mean the electron is, cause you can't really like "see" it	**3**
Discrete/ Continuous	15:33 (500) nothing will happen because the energy required to move from 1 to any of the others is greater than 500 so you need more than that 15:50 (984?) it would go to the, it would be able to move the electron to the second energy level which then would return to the ground state and emit light (990) no, this was in lecture, I want to say nothing happens cause it's not to an orbital, it's too much for number 2 and not enough for number 3, 4 (why exact?) because these are like specific energy levels and if you go over it won't really work out it's gonna stay where it is	**3**
Interpreting Spectra Code	15:33 (500) nothing will happen because the energy required to move from 1 to any of the others is greater than 500 so you need more than that 15:50 (984?) it would go to the, it would be able to move the electron to the second energy level which then would return to the ground state and emit light (990) no, this was in lecture, I want to say nothing happens cause it's not to an orbital, it's too much for number 2 and not enough for number 3, 4 (why exact?) because these are like specific energy levels and if you go over it won't really work out it's gonna stay where it is	**3**
Energy/Force Code	06:32 well if it has enough energy that it could move the electron to a different orbital then the electron will move up and then when it returns it will release the light. Or it just doesn't have enough so it doesn't do anything (define enough) if it doesn't have the energy required to move the electron to a different orbital because they are different distances from the nucleus so the closer it is the more attracted it is to the nucleus (so is 2p always the same distance, like in any atom?) no, maybe... I want to say no because the protons are different but then I don't remember if it's a no, so I'm gonna go with the no 09:33 (change color?) no, I would vote no, cause to change color you would have to change the amount of energy to shift electron, and that would require changing the actual effective nuclear charge on the atoms which I don't think would happen...	**4**

Line No.		Transcript
1	**I:**	01:29 Describe how you visualize the atom
2	**S:**	well now that we've learned the quantum model, there's like clouds of electron, different orbitals, um, if it's the same quantum number, it's like inter… there's like 1 and there's more around it, there's like different layers. There's like an area where like it's "very probable" the electron is, so like p's are are the...d's are like clover leaves, s is like a circle, p's are like 2...
3	**I:**	02:30 what do those represent?
4	**S:**	kinda like where the... the possibility, the probability of where the proton is, I mean the electron is, cause you can't really like "see" it
5	**I:**	what are the electrons doing?
6	**S:**	moving around, various movements
7	**I:**	like would it stay in 2p?
8	**S:**	I would think like 2p has three things, it would jump in either one of those
9	**I:**	why would it stay in the p's?
10	**S:**	because the s is filled? cause it can't really have like 3 electron, cause it's too much repulsion... it's like pulled in by the [inaudible] of the electron

11 **I:** 03:58 why is energy important?

12 **S:** because whatever energy you give it can move electron to different shells eventually completely ejected

13 **I:** why are different shells different energies?

14 **S:** because they are different distances from the nucleus so the closer it is the more attracted it is to the nucleus

15 **I:** so is 2p always the same distance, like in any atom?

16 **S:** no, maybe... I want to say no because the protons are different but then I don't remember if it's a no, so I'm gonna go with the no

17 **I:** 05:00 Describe how you visualize light

18 **S:** little packets of energy going from the source to whereve it hits and then... yeah and particlelectronish things. So these packets have.. They contain energy from the light source which shoot them out and when they hit an object they can either be absorbed or reflected or transmitted

19 **I:** 05:47 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

20 **S:** it would eject the electron with a KE equal to the excess. Like if it hits the atom it could be any of the electron but then the energy is different because it could be a core electron, an outer electron a shielded electron

21 **I:** 06:32 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

22 **S:** well if it has enough energy that it could move the electron to a different orbital then the electron will move up and then when it returns it will release the light. Or it just doesn't have enough so it doesn't do anything

23 **I:** define enough

24 **S:** if it doesn't have the energy required to move the electron to a different orbital

25 **I:** 07:31When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

26 **S:** the wavelength of the light emitted when the electron comes back down to the relaxed state. Well there is a specific energy required for the electron to jump to the different orbitals and once it goes there it can go either straight back down to different lower orbitals and whatever the energy difference between the orbitals will produce the wvlngth, produce a wave...eject like energy of a certain wavelength and that would be either visible or non-visible

27 **I:** 08:29 Why are Ne and He tubes different colors?

28 **S:** because they have different electron and they are different atoms, um the energy required for each to move to orbitals is different so the energy released when the electron come back to the rest state, relaxed state, ground state, there you go, is different, so the wavelength of light which would be different also

29 **I:** would an electron from 1s to 2s in Neon and Helium be the same?

30 **S:** yes

31 **I:** 09:33 Over time, would the tubes change color?

32 **S:** no, I would vote no, cause to change color you would have to change the amount of energy to shift electron, and that would require changing the actual effective nuclear charge on the atoms which I don't think would happen...

33 **I:** 10:21 Is there any amount of energy that wouldn't light the bulb?

34 **S:** like we can't see it [inaudible]

35 **I:** 10:50 any electrons ejected?

36 **S:** um it's possible they are ejected it depends on the voltage, cause if a lot of high energy goes through, certain electron could be ejected, um but I think most of them would stay within the levels, because if it's ejected you would lose electron

37 **I:** 12:47 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

38 **S:** so these are like the energy levels, and this is the energy required to reach, um… the PE at each of these levels I want to say…

39 **I:** 13:03 How much energy is needed to ionize Hydrogen?

40 **S:** you would need the difference between 1 and 4 and anything higher than that would shoot it out of the 4 orbital, eject that

41 **I:** how much would that be?

42 **S:** 1230

43 **I:** ok, so the different between 1 and 4

44 **I:** 13:49 Can you draw the absorption spectrum of Hydrogen?

45 **S:** so it would be… hmm… so you would have a couple of lines here, I would say it's… red for hydrogen with black lines

46 **I:** why would the black lines be there?

47 **S:** so it would be where the electron would drop down energy levels, so it's like something red and blue

48 **I:** 14:35 How is this different from an emission spectra?

49 **S:** the emission spectrum shows you lines and the rest of it is totally black, I know for this it's all colored with some sort of lines when the light is absorbed

50 **I:** how can you tell which colors get absorbed?

51 **S:** you can look through the little spectroscope thing and then see which lines are emitted, the wavelength of colors...

52 **I:** 15:19 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

53 **S:** the electron is ejected. Because it's greater than the IE

54 **I:** 15:33 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

55 **S:** nothing will happen because the energy required to move from 1 to any of the others is greater than 500 so you need more than that

56 **I:** 15:50 984?

57 **S:** it would go to the, it would be able to move the electron to the second energy level which then would return to the ground state and emit light

58 **I:** how a bout 990?

59 **S:** no, this was in lecture, I want to say nothing happens cause it's not to an orbital, it's too much for number 2 and not enough for number 3, 4

60 **I:** why exact?

61 **S:** because these are like specific energy levels and if you go over it won't really work out it's gonna stay where it is

Student No: 62

	Evidence	Code
Probabalist/ Determinist	like the possibility of where the electron will be, so it's not guaranteed like where the electron are gonna go but like through the eqns whose names I don't remember they like figured out like the likelihood that it will be in certain areas in atoms	3
Discrete/ Continuous	06:30 (discrete?) it's like a fixed exact number like it's not continuous like say if it was 3, which it wouldn't be, but if it was 3, it's not like if you do 4 like then you're ok, or if it was 2 it's halfway up, like it has to be exactly on the mark 20:27 (if you put it enough energy to jump to number 1, what happens to that energy?) it gets transmitted, I think (transmitted?) It means it just passes through the atom (exactly enough to get to level 1) then it would move to level 1 (1 kJ more?) well, if I'm gonna be consistent i'd have to say that it wouldn't go, yeah, cause I know with the... ionization, then the excess energy is KE, but that's when like the electron is all the way ejected, so when it's like traveling between the orbitals or whatever I mean it has KE but it's still like in the orbital	3
Interpreting Spectra Code	it just makes the full jump to like whichever level and on the way down it can travel more easily between the indiv one instead of necessarily like falling all the way 17:21 uh, 1312 kJ (what do those numbers in the chart tell you?) I think it has to do with the distance traveling between the energy levels and how much energy, well I mean it's negative so.. I'm not sure…	1
Energy/Force Code	like each one has a different value assigned to it and you have the atom and stuff um and so in order for them to like travel between orbs like that's how much energy they require yeah and so like the energy has to be put in and I guess the energy is great enough to break the attraction between that electron and the nucleus uh, different charge onthe nucleus could be like drawing the electron closer or not depending on like how they are interacting	4

Line No. **Transcript**

1 **I:** 01:09 Describe how you visualize the atom

2 **S:** well its funny I still don't really think about it in like the visual 3D terms, I just have a jumble of like different 2D pictures like depending on what we know… like there's the circle with the valence shell and now we've had like the electron cloud and yeah I guess like the most simplest way is to think of it as like circles cause we always draw them I guess they're not really, but that's like the most.. the thing that naturally comes to mind, like atom, sphere

3 **I:** 02:27 Can you draw the 2p orbital in Oxygen?

4 **S:** 2p orbital... um, ok..well I'm trying to remember now, I remember like the shapes, I'm trying to remember what I would attribute to that... would that be a spherical one? well I think the number is 2 so the the number of nodes should be minus 1, which is 1, wo I think it would be spherical with one node, so like the one node, however they have those pictures like that

5 **I:** 04:20 what do these orbitals represent to you?

6 **S:** like the possibility of where the electron will be, so it's not guaranteed like where the electron are gonna go but like through the eqns whose names I don't remember they like figured out like the likelihood that it will be in certain areas in atoms

7 **I:** 04:54 would the electron stay in the sphere? orbital?

8 **S:** well, they don't have to like depending on what's going on like we looked at some in, I don't know what those little video things are called, but the thing that they show like if you are exciting electron they can travel between the orbitals like and absorb different energy and also like emit different energy just like depends on the travel between orbitals that they are going through

9 **I:** why do they need energy to go between?

10 **S:** well the orbitals are, what's the word, discrete energy like levels and uh so like each one has a different value assigned to it and you have the atom and stuff um and so in order for them to like travel between orbs like that's how much energy they require yeah and so like the energy has to be put in

11 **I:** 06:30 what do you mean by discrete?

12 **S:** it's like a fixed exact number like it's not continuous like say if it was 3, which it wouldn't be, but if it was 3, it's not like if you do 4 like then you're ok, or if it was 2 it's halfway up, like it has to be exactly on the mark

13 **I:** 07:09 Describe how you visualize light

14 **S:** wavelength and photons…

15 **I:** why sometimes wavelngth and sometimes photons?

16 **S:** uh well I think they like start out with the wavelengths and then like as they are like going along there are some things that they didn't that didn't make sense, so kinda like with the discrete and like energy and stuff like wavelengths don't entirely describe that and so like photons are like essentially discrete energy packets themselves

17 **I:** 08:09 is one model better?

18 **S:** i think it just depends on what you're talking about like what you're.. what aspect of light that you are looking at, yeah, cause both of them provide diff, just different approach ... I was gonna say that I feel like we dealt with wavelengths more often, especially when we were looking at the spectrum and stuff, but then we were getting into absorbance and going between the orbitals and stuff we did particles too, so I guess we talked about both of them

19 **I:** 09:06 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

20 **S:** uh, if it's greater than the IE then the electron is ejected from the atom and the excess energy is converted into KE for the electron that has been ejected.

21 **I:** how does it eject an electron?

22 **S:** um, good question… I guess I don't really know, if I had to guess, which I probably shouldn't, but um like it's enough energy so that goes past all of the orbitals that are on that atom and I guess the energy is great enough to break the attraction between that electron and the nucleus

23 **I:** 10:44 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

24 **S:** um, well it could then it could be absorbed depending on the atom, um, but it also if it is less and it doesn't like match up to the absorbance values it could just be transmitted like pass through the atom

25 **I:** 11:19 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

26 **S:** um, so I think that like the current is like.. Can you say that again?

27 **I:** sure, when you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

28 **S:** so in the gas the electrons get excited to higher orbitals, but it's like a temporary excitement and so they return to their orig state and the excitement when they are going up, or like away from the nucleus, is when it's absorbed and when it returns to its original state it's emitting a wavelength of light and uh whatever wavelength the light is emitted at, like depending on where it falls in the visual spectrum, that's the color that we see

29 **I:** 12:45 why different colors?

30 **S:** uh, just that they might be emitting different wavelengths cause there's... well like Ne has more orbitals or shells so there's more opportunity to go like instead of like go up 1 or 2 or whatever and come back down

31 **I:** so for He, Ne, from 1 to 2, is it the same color?

32 **S:** uh, I don't know, it's possible, I could see it going either way, uh cause I feel like we only looked at H and He, like they had different values, like the n values, I forget what it's called.. but then like He and Ne are noble gases so they might be similarly configured

33 **I:** why are energy levels different in every atom?

34 **S:** uh, different charge onthe nucleus could be like drawing the electron closer or not depending on like how they are interacting

35 **I:** 15:05 Over time would the tubes change color?

36 **S:** like change an entirely different color? um, I don't think so but I don't know

37 **I:** 15:28 Is there any amount of energy that wouldn't light the bulb?

38 **S:** yeah, probably, like I don't know the amount but if it wasn't enough to excite the electron from their ground state then nothing would happen

39 **I:** 16:35 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

40 **S:** I don't remember which like diagram it is.. In my mind thinking of oh, what's that called, we just studied, a MO diagram…

41 **I:** 17:21 How much energy is needed to ionize Hydrogen?

42 **S:** uh, 1312 kJ

43 **I:** what do those numbers in the chart tell you?

44 **S:** I think it has to do with the distance traveling between the energy levels and how much energy, well I mean it's negative so.. I'm not sure…

45 **I:** 18:32 what are some possible absorptions?

46 **S:** like where can the electron go from the ground state? Um… well I mean it could go to any of these levels I think…

47 **I:** can it jump from 1 to 2?

48 **S:** yeah

49 **I:** 1 to 2?, 2 to 3?

50 **S:** I think like it, I think prof Majda was talking about how like we don't really count it as doing that because like the time that it would spend at 2 on it's way to 3 is so brief that like it doesn't even register so like on the way up so to speak it just makes the full jump to like whichever level and on the way down it can travel more easily between the indiv one instead of necessarily like falling all the way

51 **I:** 20:27 if you put it enough energy to jump to number 1, what happens to that energy?

52 **S:** it gets transmitted, I think

53 **I:** transmitted?

54 **S:** It means it just passes through the atom

55 **I:** exactly enough to get to level 1?

56 **S:** then it would move to level 1

57 **I:** 1 kJ more?

58 **S:** well, if I'm gonna be consistent i'd have to say that it wouldn't go, yeah, cause I know with the... ionization, then the excess energy is KE, but that's when like the electron is all the way ejected, so when it's like traveling between the orbitals or whatever I mean it has KE but it's still like in the orbital

Student No: 63

	Evidence	Code
Probabalist/ Determinist	the model doesn't say that the electron is definitely there but it's telling you of the probability of the atom being there and it also tells you where the nodes are, and the nodes are like where the electron are like there's a zero percent chance that there's an electron in that area	3
Discrete/ Continuous	07:37 I think the light is just transmitted, I think if I remember correctly, I don't think it's absorbed , because it's not enough energy so the light just passes through; 19:08 (what causes light to be emitted?) once the electron falls back to the n1 shell , depending on which one it's already on , then that's what determines what color it's going to be. because if it's falling from n4 to n1 that's going to be more energy than if it's falling from n3 to n1 because you put in more energy to begin with so when it falls back it's releasing that energy back , and if it's from n4 to n1 it will be like blue, and n2 o n1 will probably be like red (draws arrows on diagram); 22:38 (so can an electron have an energy in between 2s and 2p for example?) I don't think so. I think that would be a node. A node is a region in the atom where there is no probability that the electron will be there	3
Interpreting Spectra Code	17:40 (can it move from 1 to the other levels?) yes. if you add enough energy, if you excite the electron to another level (if you excited it to the 2nd energy level, how much energy would that take?) 328 kJ	1
Energy/Force Code	06:06 I'm not sure why it happens, but I do know that because it does take energy to move to a higher orbital, I'm guessing that when the light does come in that's the energy that's provided to make it jump to a higher orbital. I'm not sure if it's moving faster or slower, but if it's at a higher energy and it's farther away from the nucleus, I guess that atom is holding less onto it , I guess I would imagine it's going faster, but it's also closer to the atom, it has a shorter distance to travel, so I'm not too sure because it takes energy to get it farther away from the nucleus that's sort of how the light comes in , the light energy , it's that energy that is used to make it jump and if it's enough energy then you can make the you can ionize the electron and the excess enrgy is used as goes converts into KE	4

Line No.		Transcript
1	**I:**	00:15 Describe how you visualize the atom
2	**S:**	an atom? Starting from the inside out, you have your protons and your neutrons in the nucleus. And the electron I mean you have different models, you have the, what is it, the plum pudding, and you have the … throughout the course I've learned that you have the subshells and each, I believe this is the way i understood it, you have your orbitals, different orbitals and it depends on which subshell it is and one will be spinning one way, and the other will be spinning the other way. and it's not necessarily like the the electron is, like the model doesn't say that the electron is definitely there but it's telling you of the probability of the atom being there and it also tells you where the nodes are, and the nodes are like where the electron are like there's a zero percent chance that there's an electron in that area
3	**I:**	01:27 describe orbitals
4	**S:**	H would only have one orbital and that would be in the n=1 or the 1s , and He would be the same except with 2 electron
5	**I:**	Describe the 1s?

6 **S:** I believe the 1s has no nodes which means the electron because it's close to the nucleus there is a high chance that is going to be somewhere close to the nucleus but I'm not exactly sure like

7 **I:** what shape is it?

8 **S:** I think it was just like, I don't remember , I know the p has the different crazy ones, but I think the 1s was just like a ball around it

9 **I:** How about p?

10 **S:** I think the p has horizontal ones and vertical orbitals, and once you start getting into the d's you start having not horizontal, diagonal

11 **I:** 03:05 How would you describe oxygen?

12 **S:** Oxygen, 8? Then it would have 2 in its first shell and then it would have 2 in the 2s2 shell or 2s shell and then it would have 4 in its 2p shell

13 **I:** Are they distinct areas or overlap?

14 **S:** I think they are distinct regions, I mean I know that if you shine light on it then you can make an electron jump from one orbital to another one but I believe that they are distinct regions

15 **I:** what does that mean, jump?

16 **S:** I mean if you add enough energy which in this case would be light, if you shine light on a metal you can make one electron go from a lower energy, from like n=2 or n1 which is closer to the nucleus to like a higher orbital like n4 because it takes energy to get it farther away from the nucleus that's sort of how the light comes in , the light energy , it's that energy that is used to make it jump and if it's enough energy then you can make the you can ionize the electron and the excess enrgy is used as goes converts into KE

17 **I:** 04:45 what do you think happens when light hits the electron?

18 **S:** well, like I imagine light as a photon which would be a massless little particle , then if it has enough energy when it hits the atom then um, let's see, I remember seeing this demo in the class where I think it was electron spectroscopy and it even showed that you were just like shining light on it and I think it measured the energy that the electron flew off with and that would also tell you how many electron were in each orbital because you would just compare the ratio of each one

19 **I:** so, why does this happen?

20 **S:** 06:06 I'm not sure why it happens, but I do know that because it does take energy to move to a higher orbital, I'm guessing that when the light does come in that's the energy that's provided to make it jump to a higher orbital. I'm not sure if it's moving faster or slower, but if it's at a higher energy and it's farther away from the nucleus, I guess that atom is holding less onto it , I guess I would imagine it's going faster, but it's also closer to the atom, it has a shorter distance to travel, so I'm not too sure

21 **I:** 07:37 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

22 **S:** I think the light is just transmitted, I think if I remember correctly, I don't think it's absorbed , because it's not enough energy so the light just passes through

23 **I:** 07:10 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

24 **S:** then the electron is pulled off and the remainder energy is converted to KE of the electron , so that's what used in electron spectroscopy, I think it measures the KE of the electron

25 **I:** 08:03 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

26 **S:** I believe it depends on the.. Because when an electron is excited it moves up to a higher energy level, once it moves back down, then energy is released and that's light energy, so it depends on which orbitals it's coming from , if it jumps from like a 4 to a 1 , then that's going to be a lot of energy, like it probably will be glowing blue, or if it's jumping from 2 to 1 then it will probably be glowing red because it's less energy so it's less frequency

27 **I:** 09:03 Why are Ne and He tubes different colors?

28 **S:** well He has less energy, or not energy, less electron , and you said Neon, Ne is 9? 10 Ne is also a , what's it called Noble Gas. Well, for He it's valence electron are in the 1s shell and for Ne it would be on the p shell so it would be 2p6 and I think because the electron are already on another energy level then when it comes back down , and He I guess has a wider range of energy levels it could jump to and that would affect it, i think

29 **I:** 1s of He and Ne at same energy?

30 **S:** what do you mean? I know that because Ne has more protons, it would take more energy to remove an electron

31 **I:** how do IE compare?

32 **S:** Well He is the one that requires the most energy because it has a filled valence shell and it's closest to the nucleus , and Ne even though it has more electron the valence electron aren't as close to the nucleus as He would be , so He would require more energy to ionize

33 **I:** 12:24 Over time, would the tubes change color?

34 **S:** I don't think so. because if you are just exciting the electron and it's not reacting with anything else then it's just falling back to it's original state or shell, I means it's not changing and it is a noble gas so so it's not gonna be reacting with anything else the exciting and falling of the electron in the subshells

35 **I:** 12:58 Is there any amount of energy that wouldn't light the bulb?

36 **S:** if you don't have enough energy to excite the first electron, then the energy would just be transmitted , I don't think it would do anything it's not absorbed, it's not enough

37 **I:** 13:28 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

38 **S:** I don't know how to do these

39 **I:** what does n=1234 mean

40 **S:** well this is the one closest to the nucleus, and this one is farthest from the nucleus, if it's farther it requires less energy to ionize it. So if this is neg and this is pos that means that n4 would be up here, so this would be like n4, and then n3 then n2 and n1, I didn't really like know how to do these

41 **I:** 14:54 How much energy is needed to ionize Hydrogen?

42 **S:** ionize would be just to pull one electron off? Well if it's pulling off from n4 then it would be 82. but I think it's actually 1312

43 **I:** why?

44 **S:** you're pulling an electron from the first shell. Is ionization just any electron that you are pulling off? Or does it have to be from a specific shell?

45 **I:** in H, where is electron?

46 **S:** in n1. so it would be 1312

47 **I:** 15:57 Can you draw the absorption spectrum of Hydrogen?

48 **S:** the frequecy of light that is absorbed

49 **I:** look at diagram, what energies of light would electron absorb?

50 **S:** 1312

51 **I:** why

52 **S:** because it's using that energy to ionize the electron so because if you add 1312 the electron is ionized but it just falls back because it doesn't have any KE

53 **I:** 16:38 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

54 **S:** then the electron now would be ionized but it would fly off because it would have KE, it would have 200 kJ

55 **I:** are there other energies are absorbed?

56 **S:** 17:01 well if the electron is in any other shell then it would absorb these also. Wel I believe the electron is in the first shell, but if it's actually in another shell , I think then that would be the IE of that shell, I'm not sure..

57 **I:** 17:40 can it move from 1 to the other levels?

58 **S:** yes. if you add enough energy, if you excite the electron to another level

59 **I:** if you excited it to the 2nd energy level, how much energy would that take?

60 **S:** 328 kJ

61 **I:** 18:24 How is this different from an emission spectra?

62 **S:** emission I believe is the opposite of absorption so it tells you which one it's not absorbing, like which frequency is not being absorbed and which one's actually passing through , so if you look at something through a filter and it's emission spectrum . if you look at something through a red filter you'll see that it's letting red light through

63 **I:** 19:08 what causes light to be emitted?

64 **S:** once the electron falls back to the n1 shell , depending on which one it's already on , then that's what determines what color it's going to be. because if it's falling from n4 to n1 that's going to be more energy than if it's falling from n3 to n1 because you put in more energy to begin with so when it falls back it's releasing that energy back , and if it's from n4 to n1 it will be like blue, and n2 o n1 will probably be like red [draws arrows on diagram]

65 **I:** 20:11 can it fall between levels?

66 **S:** yes, that would be the sub-orbitals. well it would be like like 1s or like 2s and 2p lthose are the sub orbitals.

67 **I:** how do n=1234 relate to orbitals?

68 **S:** well I think the n1 would be like s because it's only one , there's only one s but if you have the n2 or the n3 you have the 3s,3p,3d. actually I remember also from the electron spectroscopy there was a couple that were like this that was showing there is actually like a sub energy level so

69 **I:** 22:02 draw 1s,2s, which one is higher in energy 1s or 2s?

70 **S:** 1s.

71 **I:** 22:38 so can an electron have an energy in between 2s and 2p for example?

72 **S:** I don't think so. I think that would be a node. A node is a region in the atom where there is no probability that the electron will be there

Student No: 64

	Evidence	Code
Probabalist/ Determinist	01:56 there is a probability the electron is going to be in a circle right around the nucleus	2
Discrete/ Continuous	it still wouldn't do anything cause it has to be 10, also if you put in like 11 it also doesn't do anything either. the um it has to be that exact amount of energy	3
Interpreting Spectra Code	16:34 so there's gonna be what did I say, 986? well here... 984, 1166, so that one's 1312-146, so that's gonna be the energy it absorbs when it goes from n=1 to n=3; 1312 - 82 = 1230. So these are gonna be high, the rest are going to be low	3
Energy/Force Code	19:51 - energy released when moving down an energy level - 4-1, 4-2, 4-3, 3-3, 3-1. light is energy, when electrons move down, they will lose energy, and emit light so that's the distance away from the nucleus because the distance away from the nucleus determines the force that you have to put on it.. or sorry the force that the nucleus attracts on it and so the farther away it is the less force, attractive force there is and yeah, and so when it emits it's gonna have it's gonna take lower energy to emit a higher level electron, higher quantum number	4

Line No.		Transcript
1	**I:**	01:40 Describe how you visualize the atom
2	**S:**	there is one proton in the center and then there is one electron in the s orbital, so it's in a circular motion around the... it's going to ... i think what it is is there's a probability that it's going to be somewhere in that circle right around the central nucleus, and it's unpaired as well
3	**I:**	02:03 How is it moving?
4	**S:**	it's.. depending.. i think it's going to be spinning.. it's spinning upwards I think it's got a positive spin on it.. I'm not sure
5	**I:**	and what is an orbital?
6	**S:**	an orbital is a circular thing around the.. well not necessarily circular actually, but it's just a distance away from the central nucleus where the protons are paired up
7	**I:**	circular? or not circular? how are you visualizing it?
8	**S:**	well the s-orbital is circular, is spherical in nature, but p-orbitals are an infinity sign, and d-orbitals are like 2 infinity signs
9	**I:**	03:05 so in a p-orbital, how is the electron in that?
10	**S:**	there's gonna be.. there's a probability that.. there's a positive and negative side, so the electrons travel in pairs I believe, but they're gonna.. there's a chance they're gonna be on either side of the thing in a shape like that [gestures 2 circles]
11	**I:**	so is that shape a limit on where the electron is? or..
12	**S:**	well that electron pair I guess, cause there is gonna be 3 p-orbitals around the nucleus
13	**I:**	can electrons go close to the nucleus or beyond the shape, the dumbell shape
14	**S:**	oh well, also the distance away from the nucleus depends on which level of n quantum number it is I think
15	**I:**	so what does that mean?
16	**S:**	so that's the distance away from the nucleus because the distance away from the nucleus deermines the force that you have to put on it.. or sorry the force that the nucleus attracts on it and so the farther away it is the less force, attractive force there is and yeah, and so when it emits it's gonna have it's gonna take lower energy to emit a higher level electron, higher quantum number
17	**I:**	04:25 -So now, how about oxygen? Describe to me oxygen and what's going on

18 **S:** oxygen has um, 6 oh so it's got the first orbital filled up, s orbital, and then the second s orbital also filled up, and then then the first p orbital, the 2p orbital is going to have 3, no 4 electrons in it

19 **I:** so if you look at 1s and 2s, are those orbitals overlapping? or are they distinct

20 **S:** it's like, the 1s is right next to the nucleus and then the 2s is like a circle around that one and there is a radial node in between them I think it's called

21 **I:** how about the 2p?

22 **S:** what is the question?

23 **I:** are the 1s and 2s overlapping or distinct?

24 **S:** yeah, they're distinct

25 **I:** and then so 2p?

26 **S:** the 2p are distinct too cause they're all on different axes

27 **I:** so the 2p and the 2s are they overlapping?

28 **S:** i guess they could be overlapping.. i think that's where.. no hybridization comes in.. never mind.. I guess they could be overlapping

29 **I:** 06:04 So how are you thinking about light? So you said it was like a wave and a particle - so in your mind, how are those 2 things related?

30 **S:** In nature, wave is energy traveling, the particles, matter you would say, but obviously photons don't have any mass or matter, it's pure energy but they act like particles which is weird

31 **I:** so tell me more - how do they act like particles?

32 **S:** so it's like when we saw the diagram of electrons absorbing photons, there was like, a particle would hit the electron and it would shoot out

33 **I:** and then how is a wave useful?

34 **S:** well, there's different wavelengths of light so wavelength we automatically assume it has a wave nature goes all the way from UV to IR and those are all just different wavelengths of light

35 **I:** 07:15 If you have a hydrogen atom you have light coming in, what happens?

36 **S:** uh, well if it's enough to eject it or move it up to the n=2 levle, then the atom will emit a special frequency of light I believe, and that is when the electron moves back down from the excited state which I think happens pretty rapidly, and if you also look at the absorption spectrum of the light, if the light is the right frequency to move it up, then it will have an absorption spectrum on that

37 **I:** tell me more about the right frequency. What determines this "right" frequency?

38 **S:** there is a certain amount of energy necessary to move it from ny electron orbital to another orbital, from a lower to higher, and so when you move it from 1 to 2 let's say, you have to have a certain amount of energy and energy is determined by frequency so you have to have the right frequency

39 **I:** so can it move in between 1 and 2?

40 **S:** uh, no, there's discrete amounts of energy that have to be put in

41 **I:** so when you first learned this, did that seem odd to you in any way?

42 **S:** well, when we first learned this in high school, we just learned the discrete amount of photon packet, i don't know it was confusing then

43 **I:** so what does discrete amount of energy mean?

44 **S:** so there's only like , let's say it takes like 10 kJ to move it up, if you put in like light that has like 5 kJ it's not going to do anything

45 **I:** ok, what if you put in 9 kJ?

46 **S:** it still wouldn't do anything cause it has to be 10, also if you put in like 11 it also doesn't do anything either. the um it has to be that exact amount of energy

47 **I:** 09:19, so what happens if you put light that is greater than the IE?

48 **S:** then it would eject the electron from the atom and the amount of energy you put in would also determine the speed the electon exits at
49 **I:** in what way? Let's say you put in more energy than the IE
50 **S:** then, you would take the energy of the photon, and subtract the IE from that, and everything left over would be KE of the electron
51 **I:** 10:11, When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?
52 **S:** oh, ok, so i think it's that the probably the electron, an electron is moving from one orbital to another so that's gonna emit light of the certain color that the electron is getting excited
53 **I:** what does that mean, get excited?
54 **S:** it moves up in energy level, i think so
55 **I:** so why do we see orange?
56 **S:** oh, because it moves back down from the excited energy level, it emits the orange color
57 **I:** and why does it do that?
58 **S:** I'm not exactly sure, but in all the models that we looked at, that's what it did
59 **I:** So, why are Ne and He tubes different colors?
60 **S:** so the atoms are different, there's a different effective nuclear charge, so it's different energy levels between n=1 and n=2, so it's going to emit a different wavelength of light
61 **I:** So how does Zeff relate to the energy level differences?
62 **S:** well, it's just if the nucleus has more charge, it's going to pull an electron more and so then if it's pulled in more then that means that the energy required to move it up a level is going to be more
63 **I:** Over time, would the tubes change color?
64 **S:** um, I don't think so - if you pass the same current through it
65 **I:** let's say we do
66 **S:** I wouldn't say it will change color because the same process keeps on happening over and over again, so..
67 **I:** what would need to happen in order to change the color?
68 **S:** you would put a different level of current or energy through it and so that the elecrons would either be excited to a different energy level or not excited at all and then there wouldn't be any color or if they weren't excited at all, cause it if it was one of those discret numbers then they wouldn't be excited, or if you put in like let's say a different energy level to move it to a different n number then it would show different wavelength of light
69 **I:** Is there any amount of energy that wouldn't light the bulb?
70 **S:** yeah, not one of those discrete numbers, either between n1 adn n2, n3 and n2, it just has to be.. an electron has to be moving from one level to another to emit light
71 **I:** 13:16 this table shows the energy levels of hydrogen. Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]
72 **S:** [draws]
73 **I:** 14:17 ok, so why did you draw it that way? what does the zero mean?
74 **S:** zero is the ejected electron, and then this way this is the amount of energy required or like required to eject the electron from each level, and it's better to coneptualize it like this when you draw it like this cause that way like the electron moves upward instead of downward, cause it's moving upward in real life too
75 **I:** 14:49 so how much energy is needed to ionize hydrogen?

76 **S:** uh, hydrogen is gonna have an electron in only the n=1 so it's going to take 1312 kJ/mol

77 **I:** So H has one electron, but we have 4 levels here, so how come there's more levels than the electrons

78 **S:** cause there are those levels, those levels exist for the electron to move up to it's just that it doesn't have any electrons to fill those but let's say you would do 1312-328 [calculates] let's say you have 984 kJ, then it would move up to n=2 and then when it moved back down it would emit a photon

79 **I:** 15:46, So what is an absoprtion spectrum, what would that show you?

80 **S:** An absorption spectra is gonna show you the energies, like 984.. It would either be 1312, 984, do you want me to list the lines?

81 **I:** actually draw me an absorption spectrum

82 **S:** um, this is gonna be frequency or energy...

83 **S:** 16:34 so there's gonna be what did I say, 986? well here... 984, 1166, so that one's 1312-146, so that's gonna be the energy it absorbs when it goes from n=1 to n=3; 1312 - 82 = 1230. So these are gonna be high, the rest are going to be low

84 **I:** So what happens if you shine light of 985 kJ?

85 **S:** it wouldn't do anything because.. oh sorry I forgot the 1312, cause it's gonna absorb 1312 too...

86 **S:** 985 wouldn't do anything because it has to be one of these discrete levels or anything above 1312

87 **I:** so what happens if you shine energy of 1512?

88 **S:** then it would eject the electron and you would have it a KE of 200

89 **I:** past 1312, what energies of light get absorbed?

90 **S:** anything

91 **I:** 19:37 -So what does the emission spectrum of hydrogen look like?

92 **S:** Ok,

93 **I:** so what causes an emission spectrum?

94 **S:** emission spectrum are gonna be the energy released from moving down an energy level - so there's going to be 1,2,3,4,5 lines...

95 **I:** what are those 5 lines caused by?

96 **S:** ok, so there's going to be the 4-1, 4-2, 4-3, 3-1, 3-2. and then 2-1

97 **I:** so each of those would cause the emission? why does light get emitted when you are going down?

98 **S:** cause light is energy basically, when the electrons move down, I guess energy levels, that makes sense, when it moves down energy levels they will lose energy so...

Appendix C: Interview Transcripts of 10 students (for Chapter 3 & 4)

Student No: 09

	Evidence	Code
Probabalist/ Determinist	and it's not like there is a specific one area that can be pinpointed hands down every single time , there's like a 99% chance that an electron is gonna be around this energy proton within the 1s subshell, 1 orbital and so...	3
Discrete/ Continuous	18:47 (985?) then there would be some KE associated with the electron and it would start moving (still move to n=2?) yes. (and what would the 1kJ of KE do?) I don't really know what it would do representatively. the way that I see it it moves up and then it can start moving around and like jiggling around in it's little subshell (not moving before?) if there is just enough energy to move it up a subshell then it wouldn't move. I remember Prof Stacy saying that it could potentially be reabsorbed into like a lower subshell but I think that had to do with IE , so I don't know if it's true on a subshell	1
Interpreting Spectra Code	13:58 starts drawing horizontal line, so this is the IE so if this much energy were inputted into the H molecule it would eject i entirely and ionize it. And then this one would be to switch from the n=1 to the n=4 shell.18:47 (985?) then there would be some KE associated with the electron and it would start moving (still move to n=2?) yes. (and what would the 1kJ of KE do?) I don't really know what it would do representatively. the way that I see it it moves up and then it can start moving around and like jiggling around in it's little subshell (not moving before?) if there is just enough energy to move it up a subshell then it wouldn't move. I remember Prof Stacy saying that it could potentially be reabsorbed into like a lower subshell but I think that had to do with IE , so I don't know if it's true on a subshell go from the n=1 to the n=2 subshell (so why not on spectra) I remember drawing it this way, I really don't know.	1
Energy/Force Code	No because there are different forces pointing on the electrons. Like the number of protons in the middle of an oxygen molecule or atom excuse me is greater than the number of protons in the center of a hydrogen, the attraction is gonna be different. There is the same number in the 1s subshell but there is not the same attraction 11:26 (diff colors?) because there is diff energy associated with the movement, because it has to do with effective nuclear charge, i think, i don't actually know any of this so, just kidding, I feel like I have a basic knowledge of all physical chemistry, but there is a diff energy associated with moving from subshell to subshell because it requires diff energy because there is diff attractions between He and Ne and Ar and ...	4

Line No.		Transcript
1	**I:**	Describe how you visualize the atom

2 **S:** 01:29 far more complicated than I thought before. When I was studying on Tuesday night I remember you had asked this question, so I was thinking like what would I say now so it's kinda interesting that you ask me that. So the thing that really sticks in my mind, one of the really interesting images in my mind is the model of the orbitals in which an electron can exist, like there are fixed, like statistically fixed and they exist on every atom and so I think it's interesting every atom can exist just based on where the electron fall. and the protons are holding the electron together in this set statistical probabiility and so that's actually the image I have of the model now, far more complicated, and it's not like there is a specific one area that can be pinpointed hands down every single time , there's like a 99% chance that an electron is gonna be around this energy proton within the 1s subshell, 1 orbital and so...

3 **I:** 02:59 What does 1s mean to you?

4 **S:** that I spend a lot of time thinking about them! it means like, it's an imagining of an atom, to me it's like I have a very simple version in my head with like a sphere around like this little tiny pocket of positive energy and that's what a subshell looks like to me and like an orbital , well, that's what an orbital looks like and then there's like the subshells inside of it

5 **I:** 03:40 Do the shells overlap?

6 **S:** I see them as discrete in my head, like they don't touch, i mean like there is energy level overlap which is evident in the subshells, but the overall n whatver orbital itself is like you have this one and you have one around it [gestures concentric] 2-dimensionally it doesn't quite see it as clearly

7 **I:** 04:23 How does energy play a role in this?

8 **S:** the natural state of things is to go to an energy state that is like lower in energy because that's more stable and less reactive. for example, an example of something physical we do is like when we're drawing out the models of the atom or something especially in the MO theory when you have the sigma and the pi stuff you...the things that have the lower energy like the sigma bonds and the non starred bonds or electron those are gonna like get filled up faster because they are less reactive , and so energy has a really big role because electron and atoms in general want to be at the lowest energy state they can be so that they are as non reactive as possible I think that's just the way nature is

9 **I:** How would you describe oxygen? Would Oxygen 1s shell be at the same energy level?

10 **S:** 05:28 No because there are different forces pointing on the electrons. Like the number of protons in the middle of an oxygen molecule or atom excuse me is greater than the number of protons in the center of a hydrogen, the attraction is gonna be different. There is the same number in the 1s subshell but there is not the same attraction

11 **I:** Describe how you visualize light

12 **S:** 06:09 it's hard to think about again. So we had a lecture on pigments through the ages, and I was just reading through my notes on it and he was discussin how movement from shell to shell generates energy and then energy generates wavelength, I know when you asked me the first time I said 'oh it has something to do with wavelength', so it does sort of have something to do with the wavelengths of the visible light, cause visible light is between 400 and 700 nm in wvlngth give or take, but there was a zinc solution that was colorless , and there was still like energy playing into the changes in the atoms and the subshells and stuff , but it was colorless because the energy was generating wvlnghts that were non visible light, so they were like UV or microwave light which is outside of the 400 to 700 range, and I thought that was really interesting that's it's always happening, like the things that we imagine as color is always happening but it's not always visible to us and I think that' s really interesting...

13 **I:** 08:08 view it as a wave?

14 **S:** not really, it's not like natural to me other ways? like the wave model and the particle model , those are diff imaginings of how light is emitted and how light happens

15 **I:** 08:34 why multiple ways?

16 **S:** there is different, so for example there is the diff between absoprtion and reflection... like it's conceptual, when a wave hits something, it spreads out like waves in an ocean. When a particle hits something it can like go into it depending on energy or it could bounce back off and so there is like different .. when you see things like that happening at a macroscopic level that would theoretically explain like little parts of light and energy and how those play out

17 **I:** What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

18 **S:** 09:33 so an electron is removed from the atom and it gains some KE, I just have this idea that it goes from like the center to "whoosh". Peaces out. I don't know if that's too simple, but that's how like I see it

19 **I:** What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

20 **S:** 10:11 less than the IE? so then, an electron would not be removed but some of the light would be absorbed. If there is other subshells it would be the light that woud change electron from subshell to subshell, cause there is an energy that is like required to go from one subshell to the next

21 **I:** When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

22 **S:** 10:45 it has to do with like , cause Ne and He are both Noble gases right? So it has to do with the amount of energy that's transmitted from the electron moving from shell to shell, because the addition of energy, like you are making the electron do something, move shells, and that would release energy, and that energy is transmitted visibly

23 **I:** 11:26 Why are Ne and He tubes different colors?

24 **S:** because there is diff energy associated with the movement, because it has to do with effective nuclear charge, i think, i don't actually know any of this so, just kidding, I feel like I have a basic knowledge of all physical chemistry, but there is a diff energy associated with moving from subshell to subshell because it requires diff energy because there is diff attractions between He and Ne and Ar and ...

25 **I:** 12:05 Over time, would the tubes change color?

26 **S:** no idea, probably? most likely. because you have a finite amount of He or Ne present, and if you are constantly ejecting electron by the addition of energy or just making the electron move , then eventually the chemical structure is going to change if you are going to manipulate it chemically and that's going to yield a different atom

27 **I:** 13:07 Is there any amount of energy that wouldn't light the bulb?

28 **S:** no energy. um, energy that wouldn't allow the electron to move from shell to shell

29 **I:** Can you draw an energy level diagram of Hydrogen? hand piece of paper with table

30 **S:** 13:58 [starts drawing horizontal line], so this is the IE so if this much energy were inputted into the H molecule it would eject i entirely and ionize it. And then this one would be to switch from the n=1 to the n=4 shell. The absorption spectra is gonna like show you where the most energy would be absorbed by the addition of energy to a H molecule, atom, atom, and so it's gonna have a peak at which energies would be absorbed and graphed against, I don't know what it's graphed against

31 **I:** why only those 2 absorptions?

32 **S:** because that's the way I remember it happening

33 **I:** How is this different from an emission spectra?

34 **S:** 16:40 it would be like the emission spectra would be what we see. The absorption would be what we don't see there would be these peaks, and emission would be the converse of the absorption that's like what we would physically be able to observe, so in our case it could potentially be color or I think sound

35 **I:** What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

36 **S:** 17:15 so then the electron is ionized cause it's enough energy for it go to fully ionized to go from the n=1 subshell or orbital to infintity.

37 **I:** How about 500 kJ/mol?

38 **S:** 500kJ/mol it woud only be able to move … then… nothing, nothing would happen.

39 **I:** why?

40 **S:** cause there wouldn't be enough energy to overcome the barrier between any of the subshells

41 **I:** So how about if it was enough to get to the next one, 984 kJ?

42 **S:** then you would be able to move up a subshell at least. go from the n=1 to the n=2 subshell

43 **I:** so why is this not on the spectrum?

44 **S:** I remember drawing it this way, I really don't know.

45 **I:** 18:47 how about 985?

46 **S:** then there would be some KE associated with the electron and it would start moving

47 **I:** still move to n=2?

48 **S:** yes.

49 **I:** and what would the 1kJ of KE do?

50 **S:** I don't really know what it would do representatively. the way that I see it, it moves up and then it can start moving around and like jiggling around in it's little subshell

51 **I:** was It not moving before?

52 **S:** if there is just enough energy to move it up a subshell then it wouldn't move. I remember Prof Stacy saying that it could potentially be reabsorbed into like a lower subshell but I think that had to do with IE , so I don't know if it's true on a subshell

Student No: 10

	Evidence	Code
Probabilistic/ Determinist	it's not like y'know the normal proton in the middle and it's like one ring around it it's more like a fuzzy orbital where like the electron can be like anywhere but it's most likely gonna be like in this one spot the 1s orbital. It's kinda like I guess like a fuzzy sphere, but I guess like if you were to look at it it would be like one ring around each proton. and that one ring is pretty close to it but not like so close to it, because there is some like shielding. 05:10 I guess like the fuzziness, it's the same, if the 1s is like a fuzziness, then the 2s is a fuzziness that goes around it and same with 2p, kinda builds up on top of each other. (overlap?) . I think they overlap, It's not like you have 1s and then empty space and then 2s. It doesn't mean there is like empty space between the 2, like it's kinda like fuzzy here as well	2
Discrete/ Continuous	so levels are discrete, you can't, it's like a step ladder basically, so it can only be in one step or another, it can't be really in between, so if you have enough energy though you can push the electron up another step, and even if you have a lot of energy, it can push the electron off the step and into a new area 11:44 (doesn't match diff?) then basically the light kinda bounces off, nothing happens the electron just doesn't move. Either you have enough light or you don't, nothing in between. 15:25 (less than 1312?) well depending on how much energy, like say it's enough energy to move from 1 to say like 2, then the light gets used up to move from 1 to 2, but if it doesn't then the light gets reflected or transmitted, or it just moves somewhere else (calcs 984 kJ) 16:51 (990?) then I think the electron gets excited and whatever is left translates into KE (math?) well it wouldn't end up at 3 because that's too little, most likely it would end up at 2. the extra energy would probably translate into KE, you don't want to waste energy at all (how about to get to 3?) 1166 kJ	2
Interpreting Spectra Code	17:56 (which energies of light are absorbed?) so you've got 1312, and then like crap, is this the absorption spectrum? you have like 1312 and 328 - am I drawing that right? (what do you think? why 328?) because that's where the second energy level is. I don't know if I'm doing this right, hmmm I'm mixed up for some reason	1
Energy/Force Code	greater than the IE, then all that energy translates into KE, it's not really gonna go to waste. cause you can't really excite any more electron in Hydrogen, cause there's only one., so all that energy goes into making the H molecule move faster or the KE essentially 16:51 (990?) then I think the electron gets excited and whatever is left translates into KE (math?) well it wouldn't end up at 3 because that's too little, most likely it would end up at 2. the extra energy would probably translate into KE, you don't want to waste energy at all when it moves down, because it's at a lower PE level and when you do that energy is released.	2

Line No.		Transcript
1	I:	00:56 Describe how you visualize the atom

2 **S:** ok, so hydrogen atom consists of one proton and one electron, and um the way the atom is really like like it's not like y'know the normal proton in the middle and it's like one ring around it it's more like a fuzzy orbital where like the electron can be like anywhere but it's most likely gonna be like in this one spot the 1s orbital. Like it could be somewhere else but it's most likely gonna be in the 1s orbital

3 **I:** Can you describe the 1s orbital?

4 **S:** It's kinda like I guess like a fuzzy sphere, but I guess like if you were to look at it it would be like one ring around each proton. and that one ring is pretty close to it but not like so close to it, because there is some like shielding. like the electron is not gonna go like instantly connect with the proton. you'd think it would but it's not because of like the effective nuclear shielding, like shielding

5 **I:** Can it go outside of the ring?

6 **S:** yeah, it can, but it's like the spot it's most likely to be found

7 **I:** 02:42 How would you describe oxygen?

8 **S:** So oxygen, so that has 8 electron and 8 pro, and that's one's different because it's paramagnetic, when like the electron are filled in the subshell, the 2p subshell, not all the electron are paired up with each other in such a shell, so that makes it kinda magnetic, so that's why if you were or have like regular oxygen gas, you can't really tell exactly, it's kinda hard to describe I guess

9 **I:** How about the orbitals of oxygen?

10 **S:** you have a 1s orb, then you have a 2s orb and then you have 2p orb [draws] If you were to look at it this is the 1s orb, and then this is the 2s like usually when people draw like electron configurations it's like that, but it's really kinda more like that, where this makes up the one line that people usually make, like a region, so this is 2p and this is 2s, and these 2 these represent rings or areas where the electron would most likely be in the 2s orbital, and this kind of orbital can only have 2 electron occupying it, but for 2p you can have up to 6, but since oxygen has only 4, these 2 are like paired with each other, and what I mean by paired is like um I guess they exist in the same orb of the subshell.

11 **I:** Do they overlap? Or are they distinct regions?

12 **S:** I think they overlap, It's not like you have 1s and then empty space and then 2s. It doesn't mean there is like empty space between the 2, like it's kinda like fuzzy here as well

13 **I:** How about the 2s and the 2p?

14 **S:** 05:10 I guess like the fuzziness, it's the same, if the 1s is like a fuzziness, then the 2s is a fuzziness that goes around it and same with 2p, kinda builds up on top of each other.

15 **I:** 06:16 Describe how you visualize light

16 **S:** Light consists of photons and waves and rays too. But you can't rely on one model to describe. Like lights made up of waves cause there are like incidences where it shows that it's not just a wave. You can't say lights are photons because there are incidences where light isn't a photon strictly. like shadows basically. shadows show that lights are rays because if there weren't for then shadows would be really fuzzy. but then again there was that one example IE that is a case where light is not just a wavelength but a series of photons I suppose

17 **I:** 07:09 What do you mean by photon?

18 **S:** photon is kinda a particle of light, but it doesn't really have a shape per say... it either goes really fast or it doesn't. but that doesn't mean it is bigger or larger if it goes faster or smaller. I mean it's kinda like an abstract thing, the way to look at light, by looking at it as a particles that move around really fast.

19 **I:** 07:47 how is each model useful?

20 **S:** I suppose you look at light as a wave model when you, now I'm trying to think of examples from what I remember from the lecture slides they were talking about like if you were to look at light through a tunnel I guess it's not really fuzzy around it it's more like one distinct. that that's the light and stuff so I guess you would use the wave model for that. Photon model - IE, I think that would be something like that

21 **I:** 08:54 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

22 **S:** um, so let's say there is a light with a short wavelength which means it has a lot of energy. If it has enough energy then it can excite the electron so the electron can jump to a different energy level

23 **I:** What do you mean by excite?

24 **S:** basically it has enough energy to move it up a level, so levels are discrete, you can't, it's like a step ladder basically, so it can only be in one step or another, it can't be really in between, so if you have enough energy though you can push the electron up another step, and even if you have a lot of energy, it can push the electron off the step and into a new area

25 **I:** What are these "steps" in the atom? what is the electron doing in the atom?

26 **S:** I guess sometimes it emits light when it comes back down from a level for example and depending on what level they are on it also tells you what color too because of the wavelength

27 **I:** 10:25 how about in terms of orbitals?

28 **S:** I think that it means it can jump from a 1s to a 2s, because it's not restricted to 1s but that's where it's most likely to be found. but I suppose with light it jumps into the 2s orbital, or even 2p and then it can come back down.

29 **I:** 11:00 What happens when light hits a Hydrogen Atom with energy greater than the Ionization energy?

30 **S:** greater than the IE, then all that energy translates into KE, it's not really gonna go to waste. cause you can't really excite any more electron in Hydrogen, cause there's only one., so all that energy goes into making the H molecule move faster or the KE essentially

31 **I:** 11:25 What does ionizing mean?

32 **S:** ionizing means like basically removing an electron from the atom itself

33 **I:** 11:44 What if it doesn't match that difference?

34 **S:** then basically the light kinda bounces off, nothing happens the electron just doesn't move. Either you have enough light or you don't, nothing in between.

35 **I:** 12:27 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

36 **S:** ok so that's the energy and that's zero… for the sake of the energy level diagram you state that this is zero and the electron is ionized

37 **I:** So what does ionized mean again?

38 **S:** from what I guess, it's where the electron is excited and all the way off of H. [draws n=1, 2,3,4] and they are not evenly spaced out either

39 **I:** Why are there 4 levels? Even though H has one electron?

40 **S:** that doesn't mean there are other electron that occupy it, but it just means like sometimes the H is not as stable than it usually is, the electron is not... if it's most stable, it's here[n=1]

41 **I:** 14:00 How much energy is needed to ionize Hydrogen?

42 **S:** 1312 kJ

43 **I:** 14:07 What energies of light does H absorb?

44 **S:** I think it can absorb regular light, uv, IR, , well in terms of numbers, it can either absorb say, let's say the electron is down here, so it can absorb either like 1312 kJ or more, then this electron gets ionized because it goes all the way up to zero

45 **I:** 17:56 so can you draw the absorption spectrum of H?

46 **S:** so you've got 1312, and then like crap, is this the absorption spectrum? you have like 1312 and 328 - am I drawing that right?

47 **I:** what do you think? why 328?

48 **S:** because that's where the second energy level is. I don't know if I'm doing this right, hmmm I'm mixed up for some reason

49 **I:** 19:09 talk it out, what energies are absorbed

50 **S:** it absorbs energy levels that are like at 1312 kJ, but then... past 1312 it absorbs them too, but not past a point, it doesn't go to infinity per say there is a limit, and that's why most of it translates into KE, and that's why this one the graph is down

51 **I:** How about before 1312?

52 **S:** the absorption climbs up basically

53 **I:** 15:00 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

54 **S:** then what happens is the electron gets ionized, and all the excess energy, the 200kJ left translates into KE , the energy of a moving object

55 **I:** 15:25 how about less than 1312?

56 **S:** well depending on how much energy, like say it's enough energy to move from 1 to say like 2, then the light gets used up to move from 1 to 2, but if it doesn't then the light gets reflected or transmitted, or it just moves somewhere else [calcs 984 kJ]

57 **I:** 16:04 so if light of 984 kJ shines on the sample, what happens?

58 **S:** then basically it goes from 1 to 2, the electron just jumps up to here

59 **I:** 16:17 how about 982 kJ?

60 **S:** then it's not enough to jump from here to here, so it like remains at this level

61 **I:** is it reflected?

62 **S:** it bounces off the electron. like it doesn't do anything to it, the electron just like reflects it. I know for some substances, the light bounces off atoms, it will even make colors too

63 **I:** 16:51 how about 990?

64 **S:** then I think the electron gets excited and whatever is left translates into KE

65 **I:** can you do the math?

66 **S:** well it wouldn't end up at 3 because that's too little, most likely it would end up at 2. the extra energy would probably translate into KE, you don't want to waste energy at all

67 **I:** how about to get it to 3?

68 **S:** 1166 kJ

69 **I:** 16:04 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

70 **S:** then basically it goes from 1 to 2, the electron just jumps up to here

71 **I:** 20:00 How is this different from an emission spectra?

72 **S:** for H, this would be 1312, and then this would be if you were to shine a light on an atom the likely place for electron to come off so this is the probability of electron where it would be emitted, but since you only have one electron for H, you only have one line, and this is the amount of energy needed to emit the electron, basically to kinda like ionize it

73 **I:** so what energies of light would be emitted?

74 **S:** 24:17 I think it would emit like not high energies, because it's lowest PE level isn't particularly low, I don't even know if it has color

75 **I:** 24:39 Can you put some numbers to that diagram?

76 **S:** it would either emit, like 116, or if it were at n=2 it would emit 984

77 **I:** 21:07 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

78 **S:** so I guess the electricity, the electron will be able to bounce to certain levels, and when it comes back down it emits a color, but for Ne it emits a certain color because it has a certain emission spectrum, they have certain wavelengths in which the light bounces off of because of the energy levels and it's very discrete

79 **I:** comes back down?

80 **S:** like if it was at the n=2 level it would go to n=1, and so energy is released and that translates into light

81 **I:** why?

82 **S:** when it moves down, because it's at a lower PE level and when you do that energy is released.

83 **I:** what is that called when an electron moves down and energy is released?

84 **S:** umm.. emission I think

85 **I:** 22:34 Why are Ne and He tubes different colors?

86 **S:** because it's got different energy levels. like energy levels for each atoms, they are not all like at 1312, 328 - they are at different, say like He would be a lot lower, so their first energy level would be at like 2000, and emits a certain color because it has it's own certain energy levels in which the electron can jump up to and come back down and that's what makes it distinct and a different color, and Ne would have different positions for it's energy levels too, so it has it's own discrete energy of ionization or for going from one level to another and vice versa, Like a small gap would be red, a larger one would be purple

87 **I:** 25:09 Over time, would the tubes change color?

88 **S:** I think no. because it's not like an electric cell , yknow like electric cells after a while start to decrease . but for tubes I think it doesn't change color because this is like the same property of the atom, it's the same

89 **I:** what would need to happen to change?

90 **S:** maybe if it combined with another atom or reacted in a weird way

91 **I:** 26:13 Is there any amount of energy that wouldn't light the bulb?

92 **S:** if you don't have enough energy then it won't light the bulb, there's not enough energy to first excite the electron to another energy level, so then if it's not excited, then it doesn't move and nothing comes out of it

Student No: 18

	Evidence	Code
Probabalist/ Determinist	can the electron go outside the sphere? Yeah, I think so , but I guess 90% of the time it's going to be found inside	3
Discrete/ Continuous	So if you give it this much energy [points to in between N=1 and N=2], would it go to n=1? 25:02 I think it would, but I'm not really sure because it's "quantized", so what does that mean? it can only like only certain levels of energy like.. it will do nothing, nothing, nothing, and then it will like go to the next energy level if you do 1000 then nothing's going to happen	2
Interpreting Spectra Code	so before 1312, take your best guess so if you do here 984, that's absorbed, then 180 is the next one that's here and then. so then 66 I guess. No wait, maybe it's just.. if you put in 1312 then it's going to be ejected, but if you put in 328, I'm getting confused with the negatives... if you put in 328 kJ, nothing would happen, you haven't put in 984 yet... now I'm confused as to what to add... so maybe i do 1312-180, or 1312-148, no I don't know what I'm saying	2
Energy/Force Code	07:24 I imagine like.. because light is a form of energy, and so then you are putting energy into the atom to excite the electron, so i imagine that it goes "whoop" and goes up, and once..that energy, something needs to come back down eventually and that makes color I think so why does it emit light when it moves down? well, something has to happen to the energy cause of conservation of energy and so I think that it would just come back yeah like the energy that comes.. ok, so it's at a higher energy and it goes to lower energy, and that difference in energy something has to happen to that so I guess it comes out as light ok, then if you keep going, what's the next transition? uh, so let's see, so you have to shine yeah so you have to shine 180 kJ to get to the next level, and the energies get like smaller because you are farther away from the nucleus so there is less attraction I think it has a bigger IE because it has a bigger charge on the nucleus and then it has one more electron, but the charge on the nucleus is a lot, like the pull from the nucleus on the electrons is a lot stronger, cause you are adding one more electron and it's like the first valence shell so like it's really really close	4

Line No.		Transcript
1	**I:**	01:00 Describe how you visualize the atom, what does it look like to you?
2	**S:**	um, well there is one, ok well there is a nucleus, and then there's one electron, so that would be, since that'st like the first valence shell, it's a 1s orbital, so it's just a circle, but it doesn't like go in a circle it's just like a cloud of where it might be like 90% of the time I guess, it's what the orbitals are
3	**I:**	so tell me a little more about that, what exactly is an orbital?
4	**S:**	I think it's just like a region of space around the nucelus where the electron is mostly likely to be, like usually
5	**I:**	So for hydrogen - 1s, what does that look like?
6	**S:**	um, it's just a circle around the nucleus, or like a sphere I guess
7	**I:**	can the electron go outside the sphere?

8 **S:** Yeah, I think so , but I guess 90% of the time it's going to be found inside, so yeah

9 **I:** and then inside the sphere, is it equally likely to be anywhere?

10 **S:** I think so, I'm not quite sure, I know that it's like in pictures it's like the darker shading is where it's more likely to be, but I'm not really sure.

11 **I:** 02:13 then, how about oxygen?

12 **S:** ok, so oxygen has 6 valence electrons, so then there is a s2 orbital, and then there would be 2 2p orbitals I guess

13 **I:** Can you draw me a picture?

14 **S:** [draws] probably not [laughs] and then the hybrid orbital think I really still don't understand.. Ok, so there's 6 electrons so then you have a 2s which I think is a circle and then uh [inaudible] and then the p's look like this, um like a dumbell shape and then this is like a node I think where uh you won't find the electron, so then like so each of these have 2 electrons and then somehow they are put together where this is like this or something and then so like this is one orbital and this is another orbital , so there are like 2 electrons found somewhere in here 2 electrons found somewhere in here and then i don't know how this one goes with that

15 **I:** if you had to guess, what would you say?

16 **S:** I'd say like it goes like around or something, but I'm having issues [laughs]

17 **I:** 04:04 So now let's talk about light, how are you thinking about light now ?

18 **S:** well, there are different ways you can look at it, like the photons or like little particles or the waves and so I guess it just depends on what you are trying to demonstrate, which one

19 **I:** So what types of things would you demonstrate with the wave and with the particele?

20 **S:** ok, so I think like with the particles, you would do, I don't know like you have an atom or a molecule and you like shoot particles at it, then I think like when it so like excites the electron and the electrons come back down it makes the spectrum, oh absorbance spectrum is like particles of light like what but then like if you do wavelength,it's like which wavelengths are absorbed, adn that's the absorbance spectrum for that spectrum, so that probably didn't really answer your question a tall [laughs]

21 **I:** are there any other areas where waves are useful to think about?

22 **S:** um, oh i know like i guess something to do with this is like the electrons are in a wave or something, but that's not relevant I guess.

23 **I:** can you tell me more about that?

24 **S:** I think like, it kinda has to do with the different like I know Prof. Stacy did in class I think with the rope and then that is like one kind of wave and then this is another kind and there's like a node right here so I think it's kinda having to do with matching these up, there's some sort of comparison, yeah...

25 **I:** 06:18 So let's put these together now, you have a hydrogen atom and you shine light on it, what are some things that can happen?

26 **S:** Ok, well it can it goes up to different.. Ok if you shine light on it it will like excite the electron

27 **I:** what does that mean?

28 **S:** so it's at the 1s normally and it can go up to the next level

29 **I:** so what does that look like?

30 **S:** what does it look like? I would just think that it like It shoots up a little bit,and the radius, the distance between the nucleus and the electron increases

31 **I:** So what does the light have to be in order to get the electron excited?

32 **S:** 07:07 well there is like a specific energy that is has to reach before it will go up

33 **I:** so if you zoomed in on this and saw the light coming in and the electron getting excited, what do you imagine happening? Why does that happen?

34 **S:** 07:24 I imagine like.. because light is a form of energy, and so then you are putting energy into the atom to excite the electron, so i imagine that it goes "whoop" and goes up, and once..that energy, something needs to come back down eventually and that makes color I think

35 **I:** so why when it comes down does that make color?

36 **S:** uh, because it emits a certain energy and so like it emits a certain wavelength, and so that's the light that you see whatever wavelength it is is the color

37 **I:** so why does it emit light when it moves down?

38 **S:** well, something has to happen to the energy cause of conservation of energy and so I think that it would just come back yeah like the energy that comes.. ok, so it's at a higher energy and it goes to lower energy, and that difference in energy something has to happen to that so I guess it comes out as light, but I don't get why it doesn't just come out as heat or something

39 **I:** so it comes out in some form?

40 **S:** in some form of energy

41 **I:** 08:56 so what happens if you hit the H atom with light of an energy greater than the IE?

42 **S:** I think well, once you get past the IE, that will just eject the electron,and it won't be in the atom anymore, and so you have like H+.

43 **I:** So let's say you put in more energy than the IE, what happens to like that extra energy?

44 **S:** we learned in class, i think this is what we learned, it was kinda a model that wasn't realistic but like if it was exact ionization energy, it would like eject the electron and then the electron would just sit there still but that's not actually true, if you hit the atom with more than the IE, then so it takes a certain amount of energy to get the electron away from the atom, or from the nucleus, and then after that, that goes into KE

45 **I:** ok, what does that mean?

46 **S:** so the electron will just move around

47 **I:** so what do you think you understand least about the stuff we just talked about?

48 **S:** um, probably like this stuff, the orbital stuff and then I'm still kinda, well aside from everything, I'm kinda fuzzy on the like absorbance spectrum like what it actually is, like we have questions to relate it to the IE kinda, like we had the energy level diagram with the different levels and then which absorbance spectra corresponds, and I have some issues with that cause I'm not quite sure like what is going on

49 **I:** ok, that actually leads in nicely to my next question [laughs]

50 **S:** ok [laughs]

51 **I:** 11:11 so this has energy levels for hydrogen, so can you draw me an energy level diagram, kinda just what you mentioned [hand piece of paper with table]

52 **S:** ok [draws] n=1, should be.. then

53 **I:** 12:22 so what does that zero mean? That you drew

54 **S:** so the zero means is like the agreed level for potential... like this is potential energy and then uh the zero means that the electron is completely ejected

55 **I:** so what does that mean if it's ejected?

56 **S:** so it's not part of the atom any more

57 **I:** so how much energy is needed to ionize hydrogen?

58 **S:** uh, so ionize means completely ejected from the atom, ok, so, I don't know I feel like I was confused on the MT too. I know like to get it up to the next energy level it would be 1312 kJ, no! that was a like, oh I got that question wrong! ok, so this is zero and this is 1312, If you put in 1312 it will go all the way up, so 1312 is needed

59 **I:** so why is the electron at n=1?
60 **S:** because it's a hydrogen atom and it's at like the lowest level
61 **I:** so let's say we shined different energies of light on hydrogen, what will happen?
62 **S:** I think if you shine a light that's in between like somewhere in this region, nothing will happen
63 **I:** why?
64 **S:** because it's "quantized",
65 **I:** so what does that mean?
66 **S:** it can only like only certain levels of energy like.. it will do nothing, nothing, nothing, and then it will like go to the next energy level if you do 1000 then nothing's going to happen
67 **I:** So did you have some idea of that you can relate it to?
68 **S:** you mean quantization? I just kinda thought of it like, I don't know if this is correct when we were first learning about the different electron shells kinda, if this was the nucleus [draws] you have the first shell and you have like 1s and then like there are other shells around it too, I just thought about it as it just kinda goes up to the next one and so if it's somewhere in here it's not going to do anything because it hadn't reached that energy level actually, it's kinda how I picture it in my head

69 **I:** so almost like, there's nothing in between, either one or the other?
70 **S:** yeah, and then if you shine this number minus that number
71 **I:** actually you can use that calculator and tell me the exact value for that
72 **S:** oh, ok, so I guess you would do -1312 minus, oh wait, no, so you have to shine 984 kJ to get it to the next energy level
73 **I:** 16:30 so if you shine 984 kJ of light, what happens to the light?
74 **S:** um, what happens to the light? I think that energy gets changed to PE of the electron and it goes up here
75 **I:** so, does it get absorbed, transmitted
76 **S:** so it would be absorbed
77 **I:** so what if you shine like 982 kJ?
78 **S:** Then I think it just stays here.
79 **I:** Ok, then what if you shine 986 kJ?
80 **S:** it would go to this one, and then that's it, and I guess the other 4 kJ I don't know I kinda imagine it would just pass along through, but I'm not sure if that's even right

81 **I:** ok, then if you keep going, what's the next transition?
82 **S:** uh, so let's see, so you have to shine yeah so you have to shine 180 kJ to get to the next level, and the energies get like smaller because you are farther away from the nucleus so there is less attraction
83 **I:** 18:05 So then from this, can you tell me what energies of light will hydrogen absorb?
84 **S:** ok, so I guess it would absorb 984, and 180 kJ, and this difference
85 **I:** you were saying 990 would absorb as well?
86 **S:** I think like it absorbs part of that, now that doesn't make sense cause when you look at a absorbance spectra it's just like line line...
87 **I:** can you draw me an absorbance spectrum?

88 **S:** [draws absorbance spectra] So I know this is absorbance [points to y-axis] I think this is energy, this is energy and then when you get to a certain energy level, I guess this would be zero or something, when you get to a certain levels it's all dark because the electron is ejected

89 **I:** so at what energy will the electron be ejected?

90 **S:** so like 1312

91 **I:** so 1312 gets absorbed?

92 **S:** yeah

93 **I:** how about 1313?

94 **S:** I guess it does because when you are looking at the ionization thing it's all dark because 1312 falls here, then 1313 would be it's all dark

95 **I:** does that make sense?

96 **S:** Yeah, but I can never remember if the big number should be over here or over here

97 **I:** so if I shine 1512 kJ/mol, what happens

98 **S:** the electron will leve the atom, the light will be in this region and then yeah I guess the extra energy goes to the electron as KE

99 **I:** so before 1312, take your best guess

100 **S:** so if you do here 984, that's absorbed, then 180 is the next one that's here and then. so then 66 I guess. No wait, maybe it's just.. if you put in 1312 then it's going to be ejected, but if you put in 328, I'm getting confused with the negatives... if you put in 328 kJ, nothing would happen, you haven't put in 984 yet... now I'm confused as to what to add... so maybe i do 1312-180, or 1312-148, no I don't know what I'm saying

101 **I:** can you show me some arrows, if it starts here [n=1] where would it go to if it absorbs light?

102 **S:** it would go to this one, and if you put in more energy it would go to this one

103 **I:** anything else?

104 **S:** i guess you could just keep going and go here and here

105 **I:** So if you give it this much energy [points to in between N=1 and N=2], would it go to n=1?

106 **S:** 25:02 I think it would, but I'm not really sure

107 **I:** 25:22 How is this different from an emission spectra?

108 **S:** emission is the light that passes through that gets reflected. So I think if you're looking at it in terms of the hydrogen atom it's like if this got like went up to this level and then when it went back down, the energy given off would be what was emitted.

109 **I:** So if hydrogen is in the ground state, do you see an emission spectrum? Can light be emitted?

110 **S:** I didnt' think so because there's nowhere for it to go you have to put in energy first.

111 **I:** So, can you show me some more arrows? what emissions would you see?

112 **S:** well, if it went all the way up to 4, well I guess it could go here or here or here , or if it only went up to 3 it would do this one this one this one

113 **I:** any other possible transitions down?

114 **S:** not that i know of

115 **I:** 27:34 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

116 **S:** I think, this is what I put on the midterm, you put an electrical current through it so that is energy, it's the electrical energy, so the electron of Neon gets to excited state I geuss and then when it comes back down, it emits light.

117 **I:** How does that link to orange, or the color that you see?
118 **S:** I guess the wavelength, whatever wavelength is associated with orange is the wavelength that is emitted.
119 **I:** Why are Ne and He tubes different colors?
120 **S:** 28:27 cause each element has it's own specific energy level cause the electrons go to.
121 **I:** so what determines how each atom has their own energy levels?
122 **S:** Related to the charge on the nucleus, the atomic radius and stuff like that.
123 **I:** So if Hydrogen has these levels, how does He's IE compare with H?
124 **S:** I think it has a bigger IE because it has a bigger charge on the nucleus and then it has one more electron, but the charge on the nucleus is a lot, like the pull from the nucleus on the electrons is a lot stronger, cause you are adding one more electron and it's like the first valence shell so like it's really really close
125 **I:** 29:39 So if you looked at this neon tube over time, would it change color?
126 **S:** I guess I would think that it would it stop being neon after a while, because all the electrons would eventually go back to the ground state , but that doesn't really explain why some elements have a color always, unless they are never in their ground state or something.
127 **I:** so for Ne, if all the electrons go back to the ground state, is it still neon?
128 **S:** I would think no, because it's not emitting energy anymore, so there are no wavelengths coming out, but that doesn't really make sense
129 **I:** so what makes Neon Neon? or He He
130 **S:** The number of protons and electrons

131 **I:** 31:00 so if we constantly feed the current in, over a couple of days what would happen?
132 **S:** I think if you are constantly feeding the current in, it would stay neon because if the electrons fall back down there's going to be energy that will eventually hit it to go back up
133 **I:** and then is there any amount of energy that won't light the bulb?
134 **S:** I guess if you put in energy that's like less than the energy required to get it up to the next level then I don't think that will light it.

Student No: 23

	Evidence	Code
Probabalist/ Determinist	yes, it can because of schrodinger… because an electron exist in a wave as well, that's essentially how it travels and exists, in 3D in x-y-z one of the coord where it can exist, in that case when you square the function it gives the probability where it exists, so the 1s orbital is the 90% probability of it being there, but there's also a 10% probability that it will be outside	3
Discrete/ Continuous	08:17 if it doesn't match then nothing happens, and that kinda supports the idea that light exists as a particle (990?) that also would pass through because it once again when we excite electrons it has to be a certain amount of energy	3
Interpreting Spectra Code	so the idea that a light of at 1312 kJ/mol; 328, 146, 82, and then it would be the energies of light that fit in between the differences of these levels	3
Energy/Force Code	in that case, that would have enough energy to completely remove the electron away from the atom and the excess energy,cause energy must be conserved, would be converted into KE. it means that the electron it has enough energy to increase one orbital and just move away from the nucleus because it's the idea that that's the most stable. So we learned sorta about coulomb's law of kq1q2/r, and sorta like going back to the PE diagram,it was the whole idea that as atoms.. because it's sort of stuck in between the ideas that it doesn't have enough energy to completly leave the nucleus so it can still feel that attraction, so it will be pulled back	4

Line No.		Transcript
1	**I:**	0:29 Describe how you visualize the atom
2	**S:**	in this case a hydrogen atom I imagine is a very small nucleus in the center with 1 proton and 1 neutron, outside is sorta like a cloud, it's like there is an electron but it can exist in the 1s orbital,there's like a spherical shape it can be in
3	**I:**	so tell me more about that, can it leave that shape?
4	**S:**	yes, it can because of schrodinger… because an electron exist in a wave as well, that's essentially how it travels and exists, in 3D in x-y-z one of the coord where it can exist, in that case when you square the function it gives the probability where it exists, so the 1s orbital is the 90% probability of it being there, but there's also a 10% probability that it will be outside
5	**I:**	so what is the function or the wave behavior?
6	**S:**	01:43 wavefunction that sorta - I think it takes into account the effective nuclear charge and there is also a rydberg constant
7	**I:**	02:06 How would you describe oxygen?

8 **S:** O in this case would have I believe 8 protons and neutrons, that's its' nucleus and around it are essentially it's electrons and it would have 8 electrons as well. And the electron they exist sorta in… different electron exist in different shells, the first 2 electrons in a 1s orbital, also has its 2s electronswhich are around the 2s orbital are themselves another spherical orbital but larger, and then it has a 2p4, p orbital which means that essential it's got.. because the p orbital itself is shaped like dumbells, and so you have 2 electrons existing in each, and so in the case of I believe Pauli's exclusion principle it's the idea that electrons essentially when they first go in , when electrons fill up the orbitals, they are not likely to be paired up so if you just consider the first 3 they each go into one orbital, one lobe, and the last one gets paired up

9 **I:** Can you draw for me the 1s and the 2s? show me how they are?

10 **S:** [draws picture] and then there's a space in between where the electrons don't exist

11 **I:** so where is that space located?

12 **S:** it's just in between the 1s and the 2s

13 **I:** so you were saying the 1s is a sphere, a cloud where the electron can be, for the 2s just describe to me where the electron can be

14 **S:** 04:12 the 2s by itself is also spherically shaped, but in this case the electron can be slightly outside of 2s or within the 2s, there is this node essentially in-between the 1s and 2s where the electron can't exist

15 **I:** ok,and how about the 2p? can you draw that on here too?

16 **S:** the 2p orbital, like I'm not quite sure how it would fit on, but I know that it's got different orientations, so you put it as a 2px, or a 2py or a 2pz

17 **I:** so where is the nucleus in those pictures?

18 **S:** the nucleus is right here

19 **I:** If you think about the 2s and the 2p, how are they kinda related? If you had to draw the 2p on this diagram, just one of them...

20 **S:** it would probably just be like this

21 **I:** and where is the electron located?

22 **S:** the electrons would mainly be around here

23 **I:** 05:33 Now let's think about light, how are you visualizing light or thinking about light?

24 **S:** light I'm still thinking about sorta as a waves, but when we keep thinking about color in solutions I keep thinking back to that absorbance lab

25 **I:** In class they takled about 3 models, the wave model, the ray model, particle model, for the wave and particle models, where is the wave most useful and the particle view most useful

26 **S:** 06:06 the wave view is most useful in general when thinking of light, like if you look at something and you see colors reflected or soemthing, you're supposed to think of it as light, but when we start talking about light as energy, that's when I think thinking about it as a particle is really helpful

27 **I:** why?

28 **S:** because we learned about the photoelectric effect which is the idea that.. and they also cited a lot of examples sorta the idea that if you had a red wavelength even if you increase its intensityit's not going to have energy per say to knock off an electron, in that case the wave model doesn't really work. when you consider it as a particle, like a photon, you can give that photon enough energy then it can knowck off the electron

29 **I:** 07:01 So, now kinda putting these 2 things together, you have this hydrogen atom and you are shining light on it, what are some things that can happen?

30 **S:** depending on the intensity or energy of light, the light can either pass through it if it doesn't meet the specific energy level requir ements, or if we do manage to meet the n1-n2 requirement we can excite the electron from the first orbital to its second shell.

31 **I:** so what does that mean - to excite?

32 **S:** 07:33 it means to give the electron enough energy. that it can essentially.. because there is sorta like an energy barrier from in residing in the 1s subshell in order to get to the 2s subshell

33 **I:** So let's say the light comes on and matches that difference to excite the electron, what does that look like, or what does that mean - the electron can be excited

34 **S:** it means that the electron it has enough energy to increase one orbital and just move away from the nucleus

35 **I:** what happens if the light doesn't match the difference?

36 **S:** 08:17 if it doesn't match then nothing happens, and that kinda supports the idea that light exists as a particle

37 **I:** 08:30 how about if you shine light with an energy GREATER than the Ionization energy?

38 **S:** in that case, that would have enough energy to completely remove the electron away from the atom and the excess energy,cause energy must be conserved, would be converted into KE.

39 **I:** what does mean, KE?

40 **S:** it means sorta like the random motion of the electron in this case

41 **I:** 08:52 If you flip that page over, there is a table there, this shows the first 4 electron energy levels in hydrogen what I want you to do is draw me an energy level diagram of H

42 **S:** [drawing]

43 **I:** 09:19 so what does that zero mean?

44 **S:** the zero is sorta like… it's like a standard that we set for an infinite separation of the electron to the nucleus

45 **I:** 09:34 How much energy is needed to ionize Hydrogen?

46 **S:** 1312kJ.

47 **I:** How do you know that?

48 **S:** Ionizingan electron means that we completely remove it, so it's like we are moving it from n=1 to n=infinity, and in this case it's the energy required to move it from essentially this the most bottom level to the energy equals zero.

49 **I:** So why does it stay at the bottom level?

50 **S:** because it's the idea that that's the most stable. So we learned sorta about coulomb's law of kq1q2/r, and sorta like going back to the PE diagram,it was the whole idea that as atoms... yeah as those 2 atoms get closer their PE increases, so they get more stable.. there is a point where they're both like bonded and that's the most stable energy, and then as you push them closer, repulsions come into play

51 **I:** So H only has 1 electron, but there is four energy levels here - so what do those mean? How come there is 4?

52 **S:** 10:49 essentially.. it kinda doesn't matter how many electrons H has, the idea is there are they always exist these subshells always exist, it's the idea whether its essentially feasible or not to keep moving that electron up, because I know that as the electron increases sorta, like if it gets into this n=3, n=4, it's not going to be stable enough that it will most likely almost immediately fall back

53 **I:** why is it not stable?

54 **S:** because it's sort of stuck in between the ideas that it doesn't have enough energy to completly leave the nucleus so it can still feel that attraction, so it will be pulled back

55 **I:** 11:51 so can you tell me what energies of light will be absorbed? which light will excite the electron

56 **S:** so the idea that a light of at 1312 kJ/mol; 328, 146, 82, and then it would be the energies of light that fit in between the differences of these levels

57 **I:** can you do some quick calculations and tell me what those are [hand calculator]

58 **S:** [calculates difference between levels]

59 **I:** So, go through and tell me what happens to the electron when it absorbs these energies

60 **S:** 13:12 the electron is in the stable state is down here, so when it absorbs an energy 984 kJ/of mole, it will get excited into sorta like - because each of these energy levels corresponds to a different shell, so in that case it will get excited to the n=2 shell, and n=3, and n=4

61 **I:** so for the n=3 shell, how much energy will it absorb?

62 **S:** 13:53 182kJ - transitioning from n=1 into n=4 182 is the difference... wait hold on... this is n=2 to n=3

63 **I:** Um, so can you draw an absorption spectrum? I'm shining light on, tell me which energies of light get absorbed?

64 **S:** [draws] so 182, [inaudible]

65 **I:** so for that 182, what transition is that?

66 **S:** It's transitioning from n=1 to n=4

67 **I:** so how did you get the number 182?

68 **S:** it's the difference between.. wait, hold on... so in that case it's transitioning from n=1 to n=3 because the 182 difference it's when it's already excited to n=2 and then it's excited yet again to n=3

69 **I:** So I'm just going to give you some scenarios and you tell me what happens

70 **I:** 15:15 what happens if I shine light of 983 kJ/mol? Just under that 984

71 **S:** the light would just pass through

72 **I:** ok, why?

73 **S:** because it doesn't have that necessary amount of energy the idea that in this case light should act like a photon so it needs that specific amount of energy to hit that electron to excite it

74 **I:** how about 990? a little bit above?

75 **S:** that also would pass through because it once again when we excite electrons it has to be a certain amount of energy

76 **I:** When you were first learning this, did that seem odd to you or was it hard to understand?

77 **S:** This was difficult to understand at first

78 **I:** why do you think?

79 **S:** it was the ideas that I always thought that essentially I was imagining almost like ionization energy the idea that like if you gave it excess energy then it would just converted into sort of random motion

80 **I:** 16:20 So actually if I put in 1512 kJ/mol, what would happen?

81 **S:** 1512 in that case would exceed the amount required to ionize it, 1312 of that energy would go into ionizing that electron and then the other 200 will be converted into KE

82 **I:** 16:47 So now let's think about emission spectra, describe to me what an emission spectrum is

83 **S:** Emission spectra is wegraph it against the amount of energy versus the number of electrons that are ejected so it's just that at different energies or like we subject the atom to different amounts of energy and if that energy correlates or matches the energy required to excite that electron sthat you can see that it will be charted on the emission spectrum so that way we can observe the energies required and how many electrons exist in certain subshells

84 **I:** So for hydrogen for example, what would some emissions be?

85 **S:** 17:42 you would see the emission spectra required to ionize it and it's possible that you would see the line from n=1 to n=2

86 **I:** so for an emission can you draw me an arrow, how is the electron moving when it emits light?

87 **S:** 18:01 when an electron emits light it's being excited up to another level and then it's falling back down, and it's the energy that it releases when it falls back down

88 **I:** so for H in its ground state, if we don't excite it do we see an emission spectrum?

89 **S:** no

90 **I:** so what would you have to do to the sample in order to see an emission spectrum?

91 **S:** you need to test many different amounts of light

92 **I:** 18:47 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

93 **S:** would it be the idea that electrons because they can conduct a current, then you would sorta see the energy in the light flowing through the electrons?

94 **I:** what do you think?

95 **S:** I think that might be possible, I can't think of another reason

96 **I:** If you think of 2 tubes, a Ne tube and a He tube, and they are different colors, what do you think causes those different colors between different atoms?

97 **S:** I think what causes those different colors is sorta the idea of IE. Because He tubes are usually, I want to say that they are blue but then hydrogen ones are sort of I think they are violet and that sorta related to the idea that H tubes they need to absorb a greater frequency of light.

98 **I:** So between He and H, which one has the greater IE?

99 **S:** actually He has a greater IE

100 **I:** and why?

101 **S:** because in that case it's sorta the idea that there are 2 electrons in helium now and they are being attracted in this case to 2 protons and the amount of enery needed to ionize essentially the last electron is very great because instead of H where there is only one proton, there are 2 now

102 **I:** So you were saying H and He, blue and violet, which color would correspond to which IE?

103 **S:** So it would be violet for He and blue for H

104 **I:** 20:54 Over time, would the tubes change color?

105 **S:** I'm not sure...

106 **I:** 21:11 Is there any amount of energy that you think wouldn't light the bulb?

107 **S:** I suppose most energies should light the bulb...cause I'm pretty sure for the H tubes that we saw in the lab they were just plugged into the wall and turned on and so I don't know if it would be feasible if we were to say oh we can only have a hydrogen gas tube if so and so energy was available

Student No: 26

	Evidence	Code
Probabalist/ Determinist	01:30 I just think of it as randomly like there so it's not always like at a specific place but it would be like constantly in motion, so you don't know always where it is, but it's always in a specific general area	3
Discrete/ Continuous	I don't think it would reach all the way to the third level because it's not enough energy - it would probably reach the n=2 but it would still like remain there, the remaining energy would be transferred to KE, but like I said, I'm not sure what that means	1
Interpreting Spectra Code	I'm not sure if that concept is right, if it actually is the difference. cause like the way I see the numbers is that the numbers would be the energy it takes to actually remove the electron if it was in these levels, and so I'm not really sure about the concept if the difference in these energies is actually the energy it takes to excite it	2
Energy/Force Code	um, I think it's saying like this is the energy - like if it is excited, if there is energy put in, like if the - like if this is like s or the first one - the electron is moved outwards more, so it's like in an excited state, like say it reaches n=4, then this amount of energy would be needed to actually remove it like to ionize it 04:40 I'm not sure, I know I just accepted that as a fact. but if I had to like take a stab at it I would say something about like the energy, just like pulling away, like coulomb's law, the charge that's between the nucleus and electron, , it takes energy to break a bond, so kinda like that concept, you put in energy to take away that attraction. 05:13, i think it's like when you put in energy, this one you are not breaking it, the molecules they like vibrate, I don't know if you increase the vibration or not but like the electron is pulled farther away, you still have an attraction but it's not as strong, so that's what the vibration, when you put in the energy it causes the vibration 10:53 If it's in the first energy level, I think it - cause usually generally it's in cause it's only one, it's in the first one - so close to the protons the attraction is so strong so it takes, it should take 1312 to remove it	4

Line No.		Transcript
1	**I:**	00:50 Describe how you visualize the atom
2	**S:**	I think it's just like now considering the orbitals, there is a nucleus, and an electron cloud around it and the cloud is shaped according to the orbitals, so that's where you would find the electron surrounding the H atom.
3	**I:**	So what is an orbital?
4	**S:**	is like an energy level, like a probability of finding the electron circling the nucleus, different orbitals have different levels of energy.
5	**I:**	and how is the electron moving?
6	**S:**	01:30 I just think of it as randomly like there so it's not always like at a specific place but it would be like constantly in motion, so you don't know always where it is, but it's always in a specific general area
7	**I:**	and for the 1s - what does that general area look like?
8	**S:**	the 1s would be like the spherical one so for 1s it would be closer to the nucleus, then there would be that node where you wouldn't find the electrons then there would be the 2s where like more, the radius is greater but it's still like in a spherical shape

9 **I:** So my next question is for oxygen, you do have 1s and 2s electrons, the 1s and the 2s - do they overlap or are they distinct regions

10 **S:** 02:19 I feel like they are like distinctthere is a node in between, it's just showing the probability of finding it is either closer or there is the space and then farther out

11 **I:** 02:32 and then oxygen also has 2p, so how are the 2p and the 2s kinda compared to each other?

12 **S:** I think I see it like there's this sphere .. I kinda see it like dumbell overlapping it so there is the sphere there and there is also a dumbell that exists around the nucleus

13 **I:** 02:52 ok, and then a question about light - how are you thinking about light now?

14 **S:** I think of it more as of particles, when you shine light, I guess, there is just like a certain amount of photons going through, and that determines how much light you see and what color you see.

15 **I:** So how is color related to photons?

16 **S:** um, I think it's the frequency, cause I know that the amount of photons that you see determines if it's bright or not, and then like the wavelength determines the energy of the photons and the energy of the light and also what color it is

17 **I:** 03:34 ok, so now kinda putting these 2 together, you have a hydrogen atom and you shine light on it, what happens

18 **S:** it depends on the energy, the frequency. So like the there is a certain energy that is necessary to either remove the electron, to ionize or remove it or to excite it to another orbital. If the light energy is not enough, nothing's gonna happen to that electron, but if there is enough energy inthe light, then it will either be excited or it's gonna be pulled off.

19 **I:** So what does it mean to be excited?

20 **S:** I think of it like it goes from one orbital to you'd more likely find it in a higher orbital that it wouldn't normally exist in, and then gives it like different properties, I think I'm not sure about that part

21 **I:** what do you think is happening with the light hitting the electron, or why does it excite to a different orbital?

22 **S:** 04:40 I'm not sure, I know I just accepted that as a fact. but if I had to like take a stab at it I would say something about like the energy, just like pulling away, like coulomb's law, the charge that's between the nucleus and electron, , it takes energy to break a bond, so kinda like that concept, you put in energy to take away that attraction.

23 **I:** so when you take away that attraction, how is that kinda related to excited?

24 **S:** 05:13, i think it's like when you put in energy, this one you are not breaking it, the molecules they like vibrate, I don't know if you increase the vibration or not but like the electron is pulled farther away, you still have an attraction but it's not as strong, so that's what the vibration, when you put in the energy it causes the vibration

25 **I:** So if you go up in orbital energy, does that mean it's further from the nucleus?

26 **S:** like the radius is greater so there's um it takes less energy to pull away to the electron than if it was closer to the nucleus

27 **I:** 06:05 are there only certain energies of light that get absorbed?

28 **S:** 06:16 I guess like there is a certain, I guess like there is a certain level, threshold where the light is enough, like say like you need 1000 to ionize it or remove it, then anything above 1000 would also work, but it has to like reach that level

29 **I:** 06:48 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color, like orange. What causes this color?

30 **S:** not really sure. but I would say something about like the Neon getting excited, and that causes a - I know there was a concept about this that it releases energy, and so that energy is based on - the frequency of that energy will determine the color, I guess, so that's why that's orange cause it's releasing that energy, it glows, gives off light

31 **I:** Is there any amount of energy that wouldn't light the bulb?

32 **S:** I think it's the amount of energy that's like uh the energy necessary to cause the electron to be removed and then Neon giving off the energy and if that energy isn't enough like it's not high enough then it's not going to shine light

33 **I:** 08:03 So this question has Hydrogen energy levels - Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

34 **S:** [drawing] I think it would be like - -1312, -328 [inaudible]

35 **I:** So how many electrons does hydrogen have?

36 **S:** has 1 electron

37 **I:** so one electron but this has 4 energy levels, so how are those related?

38 **S:** um, I think it's saying like this is the energy - like if it is excited, if there is energy put in, like if the - like if this is like s or the first one - the electron is moved outwards more, so it's like in an excited state, like say it reaches n=4, then this amount of energy would be needed to actually remove it like to ionize it

39 **I:** How much energy does it take to excite it? n=1 to n=4?

40 **S:** 09:57 I'm not really sure, i think it's the - I'm not sure about this

41 **I:** how about n=1 to n=2?how much energy does that take?

42 **S:** I feel like it would be the difference between n=1 and n=2, but I'm not too sure... so it would be the difference between these two levels would be the amount of energy needed to move the electron from the n=1 to the n=2 level

43 **I:** what are you not sure about?

44 **S:** I'm not sure if that concept is right, if it actually is the difference. cause like the way I see the numbers is that the numbers would be the energy it takes to actually remove the electron if it was in these levels, and so I'm not really sure about the concept if the difference in these energies is actually the energy it takes to excite it

45 **I:** 10:52 How much energy is needed to ionize Hydrogen?

46 **S:** If it's in the first energy level, I think it - cause usually generally it's in cause it's only one, it's in the first one - so close to the protons the attraction is so strong so it takes, it should take 1312 to remove it

47 **I:** 11:10 so what happens if I shine 1512 kJ/mol?

48 **S:** it would still be the same, like it would still ionize it, cause it's greater than it

49 **I:** what happens to the extra?

50 **S:** I know it becomes KE but I'm not sure like what it means

51 **I:** KE of what do you think? if you had to guess

52 **S:** not sure, I think it would be the KE of the hydrogen molecule? but I'm not too sure

53 **I:** 11:56 What if you shine light that is this difference, this happens to be 984?

54 **S:** I think it excites it, and it would probably go to n=2 energy level, yeah but the concept I'm not sure so it's just like me taking a stab at that

55 **I:** that's totally fine, what if - if you had to guess, what if I shined 986, so it doesn't quite match that energy level difference, a little but above, what would you think happens then?

56 **S:** I don't think it would reach all the way to the third level because it's not enough energy - it would probably reach the n=2 but it would still like remain there, the remaining energy would be transferred to KE, but like I said, I'm not sure what that means

57 **I:** 12:44 what is an absorption spectrum? what does that mean?

58 **S:** um, so like it's just like showing like which light is - so this is the wavelengh,[draws] and then this is the absorption, and it would be like this, and because this is close , because this is increasing, if the wavelength is increasing this way then this would be red and this would be violet, And so if its if the spectrum is high there that means that it's absorbing the light energy at this, you wouldn't see this because it's being absorbed , the ones that's not being absorbed is the one that probably we would see

59 **I:** and what is that called, the light that is not absorbed?

60 **S:** um...

61 **I:** or what is the opposite of absorption

62 **S:** oh, transmission

63 **I:** So for the H atom, what would the Absorption spectra look like?

64 **S:** 13:48 um, not quite sure about that one.

65 **I:** or how about this - what energies of light would Hydrogen absorb? if you had to guess

66 **S:** so because I know that the Hydrogen electron is generally close to the proton then the energy should probably be relatively high, so I'm not sure how it connects to the absorption spectrum. So if it absorbs high energy then um hmmm I'm not too sure

67 **I:** can the electron be in between n=1 and n=2?

68 **S:** um, I don't think so i think it's either at n=1 or n=2 and I'm not sure it relates but when I think about the orbitals the energy levels I kinda also think about the orbitals, so i feel like if it was in between it would be in one of the nodes where you wouldn't find it, I'm not sure though [laughs]

69 **I:** 14:59 so when you were first learning this, did that seem odd to you, that it couldn't be in between n=1 and n=2? or had you seen this before? what do you think about that concept?

70 **S:** I hadn't seen this before, I don't know I generally just like accept it as fact. Cause I used to think that it would be a proton and just like this cloud around it and you can find it anywhere so I knew that there were s,p,d orbitals and I knew they had a certain shape but I don't think I ever really understood what the shapes meant so i just assumed that like the electron could be found anywhere around the proton

71 **I:** So now do you think you have a good understanding of what the shaped mean?

72 **S:** um, I think so it just tells you the probability of finding like where the electron will be and then there's spaces where the electron for sure won't be found

Student No: 28

	Evidence	Code
Probabalist/ Determinist	and then it would have 1 electron zooming around it in an orbital kinda magnified. (orbital?) um. It.. I'm pretty sure it's schrodingers it would be like a wavelike pattern of electron just kinda around the neutron where it would be attracted enough to keep it going around it but then it would be repulsed enough to keep it like not really close and it would just be kinda this cloud 05:15 it kinda moves around the outside of that, inside the dumbell I guess is where the electron is not very likely to be found, it's only around the outside (why diff energy levels?) because each electron repulses the other electron to an extent where it kinda keeps them at diff levels so that they are at a certain distance from the nucleus they are separate from each other	2
Discrete/ Continuous	then it causes the molecule or the particles to kinda wiggle a little more , like IR radiation, that's like heat 19:36 I don't think it would do anything just because it's not one of the specific energies (928 kJ?) I think this was one the test, it's a good question and I think I got that one wrong (any energy below 1312 do anything?) I feel like if it was below then it could send an electron up an energy level but not eject it (example?) like maybe the 328? but then I feel like that's not right either, I don't really know. (so if 328? magic number?) maybe I feel like really not sure about any of this	1
Interpreting Spectra Code	15:42 so the absorption spectrum would look like this… so these would be the lines that are the energies that would be absorbed so these are just the black lines and the rest of them are colors so that difference is that amt of energy that you would need.	2
Energy/Force Code	and I'm pretty sure it takes energy to move the electron from one orb to the next but first thee electron has to be excited or ionized for another electron to move up. cause it's the IE and the rest is absorbed or put into the KE i don't really think that's the case but I'm not really sure. (why not?) just because I know that the excess energy outside would go to the emitted electron for KE, but then I'm not sure if the excess energy would also go to sending the electron up, and I also remember the excess energy is also absorbed I think , I never really thought about this lecture that much!	2

Line No.		Transcript
1	**I:**	01:21 Describe how you visualize the atom
2	**S:**	would have a very very small nucleus with only one proton and one neutron, and then it would have 1 electron zooming around it in an orbital kinda magnified.
3	**I:**	so what is an orbital?
4	**S:**	um. It.. I'm pretty sure it's schrodingers it would be like a wavelike pattern of electron just kinda around the neutron where it would be attracted enough to keep it going around it but then it would be repulsed enough to keep it like not really close and it would just be kinda this cloud
5	**I:**	Would it stay in the same orbital?
6	**S:**	as you add more electron they go up to bigger orbs that hold more and more electron and then they move between orbs if light is absorbed or if the electron are excited up to the next orb
7	**I:**	tell me about this excitation

8 **S:** it takes a certain.. or the ionization energy is the energy needed for the electron to go completely away from the atom for the atom to be ionized and then but then also and then anything past the IE leads to KE of the electron and I'm pretty sure it takes energy to move the electron from one orb to the next but first thee electron has to be excited or ionized for another electron to move up. cause it's the IE and the rest is absorbed or put into the KE.

9 **I:** can you explain more?

10 **S:** The one that goes up, moves up and then it kinda shoots back down after that and stays there

11 **I:** how about the vacant spot?

12 **S:** I'm guessing that another electron takes it's place from a higher orbital?

13 **I:** 04:30 Can you describe the 2p orbital?

14 **S:** the 2p orbital is kinda looks like a dumbell shape and since there is 2 subshells there would be one node, well if there is only one subshell it would have to be an s orbital anyway - 1s22s22p6. so then it's like in this little bow shape I guess and then it has a node in the middle where the electron is not usually found and then it kinda moves in a general p orbital

15 **I:** So how is it moving?

16 **S:** 05:15 it kinda moves around the outside of that, inside the dumbell I guess is where the electron is not very likely to be found, it's only around the outside why different energy levels? because each electron repulses the other electron to an extent where it kinda keeps them at different levels so that they are at a certain distance from the nucleus they are separate from each other

17 **I:** 06:13 Describe how you visualize light

18 **S:** dual... wave particle duality, it moves it a wave or it kinda a photon would be like a particle and so it's just these little teeny tiny things so that's the particle aspect the photon and then it kinda moves in a like a little wave[gestures]

19 **I:** what do these different models tell you?

20 **S:** so the particle model or photons it tells us what exactly excites electron that there is something that like hits them and it has the energy transfer and everything and then the wave is just like the motion that it goes in so it tells us how like light moves through space

21 **I:** 07:25What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

22 **S:** then if it's greater than the IE, then the electron will like shoot off because it's ionized, and then when it shoots off the excess energy that it was shot off with kinda like lends to the KE of the electron so that's why some things are brighter than others, it's because.. no not brighter, that's why some things show different colors because it shoots off with greater frequency and greater energy and shorter or longer wavelengths and then then some of the excess energy is also absorbed so that's what brings up the other electron.

23 **I:** which is the light we see?

24 **S:** I'm not really sure, that's the only part I was kinda confused about, cause I know that when the 1s is excited in the atom, when it drops down it emits light because that is what causes the emission spectrum but then I also think that it could be the 1s that shoots off but I never really got that clarified

25 **I:** 08:52 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

26 **S:** then nothing happens. The light it doesn't cause any electron to shoot off but then it causes the molecule or the particles to kinda wiggle a little more , like IR radiation, that's like heat

27 **I:** 09:44 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

28 **S:** um it's from the electron being excited to the next state and coming back down to the state they started at

29 **I:** Why are Ne and He tubes different colors?

30 **S:** because He… I'm not really sure other than just like looking at the electron move… since there is 2s shells in He it's 1s2, then the electron can move between the 1s1 and 1s2 in He so I think that has to do with it and since there is only 1s1 for H it can't like move

31 **I:** are all 1s orbitals for all atoms at the same energy?

32 **S:** I remember hearing that no 1s orb is the same for every atom but I don't know why

33 **I:** 11:03 Over time, would the tubes change color?

34 **S:** I can see them becoming dimmer just because maybe the electron, I'm not really sure why but I can see them becoming dimmer

35 **I:** also would the electrons be ionized?

36 **S:** I'm guess that they would just because that would cause the emission more, but I'm not sure exactly why

37 **I:** If you increase the energy transfer to tube, would there be a color change?

38 **S:** no, I don't think so, it might just be a little more brighter because that would just be more photons. because they would still have the same orbitals, the atoms. because the colors are caused by how far the electron fall down from the other orbitals

39 **I:** 13:06 Is there any amount of energy that wouldn't light the bulb?

40 **S:** if it was low energy it would not light it or it might be really really dim.

41 **I:** why?

42 **S:** not as many electron would be excited because there is not as many photons to hit the electron, because only one electron moves with each photon hitting it, it doesn't hit multiple electron

43 **I:** 14:30 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table] what does that mean?

44 **S:** this is the minimum amount of energy, cause this is the IE of H, so this would be the minimum amount of energy needed to eject an electron so the electron could like so let's say this amount was given , the amount added to the electron or the atom then the electron would move from this to level to this level and would fall back down after that and then so that difference is that amount of energy that you would need.

45 **I:** so, how does this relate to picture of atom?

46 **S:** these are all subshells of the orbitals

47 **I:** 15:42 Can you draw the absorption spectrum of Hydrogen?

48 **S:** so the absorption spectrum would look like this… so these would be the lines that are the energies that would be absorbed so these are just the black lines and the rest of them are colors

49 **I:** 16:23 How is this different from an emission spectra?

50 **S:** the emission spectrum would be the opposite of this where these would be the colors are emitted, and the rest would all be black

51 **I:** would there be lines between these two?

52 **S:** I don't know I never considered that…

53 **I:** what is the emission spectra representing?

54 **S:** the electrons that are emitted.. or I wanna say the wavelengths that are emitted, I know it has to do with wavelengths but I'm not really sure if it's the electron that are emitted or I think the electron stay and then they drop down I'm thinking it's just energy of different wavelengths.

55 **I:** 17:35 How much energy is needed to ionize Hydrogen?

56 **S:** 1312, I just remember it from lecture.

57 **I:** How does it relate to the H atom?

58 **S:** That it has a fairly high IE so it would need a lot of energy per photon that hits it to excite the electron or emit it

59 **I:** 18:04 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

60 **S:** then I would say that that would be greater so then it would I think that in that case, the electron would just go off completely.

61 **I:** would any other electron move?

62 **S:** I don't know, now I'm confused. I know that would be the energy needed to eject the electron but then I'm not like back to that thing where I said like when one electron moves off another one goes up to take it's place i don't really think that's the case but I'm not really sure.

63 **I:** why not?

64 **S:** just because I know that the excess energy outside would go to the emitted electron for KE, but then I'm not sure if the excess energy would also go to sending the electron up, and I also remember the excess energy is also absorbed I think , I never really thought about this lecture that much!

65 **I:** 19:36 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

66 **S:** I don't think it would do anything just because it's not one of the specific energies

67 **I:** any energy below 1312 do anything?

68 **S:** I feel like if it was below then it could send an electron up an energy level but not eject it

69 **I:** can you give me an example?

70 **S:** like maybe the 328? but then I feel like that's not right either, I don't really know.

71 **I:** so what if it was 328? That magic number?

72 **S:** maybe I feel like really not sure about any of this

Student No: 40

	Evidence	Code
Probabalist/ Determinist	well these are the these don't really exist instead they are our way of mapping where the electron could be at any point in time and usually we draw one at the point of 90% probability in diagrams I looked at where the electron has a 90% chance of being somewhere in this blob	3
Discrete/ Continuous	20:45 (how about 985?) kJ? that's not the right.. that's again you are in the intervening space it can't absorb it, you can't just get rid of 2 kJ/mol. that's.. I don't think it works like that! It seems unfair, like it ought to but I don't think it does	3
Interpreting Spectra Code	If the light by some nice coincidence has exactly the right amount to, exactly equal to the difference between energy levels it can move	3
Energy/Force Code	and the specific color corresponds to the specific amt of energy that each electron is gaining because then when it returns to ground state it emits the light with the wvlngth and the freq corresponding to that amt of energy and it gives the electron enough energy to overcome its attraction to the nucleus and get out of there it seems like they would except that there are different charges in the nucleus and so the attractions between the nucleus and the electron will be different necessarily because in the eqn for determining the attraction radius and charge are the main things we need to worry about 09:58 then it can hit any electron in the atom and it gives the electron enough energy to overcome its attraction to the nucleus and get out of there 1312 kJ/mol. Because the convention is that you represent zero as no interaction at all with the electron and the nucleus	4

Line No.		Transcript
1	**I:**	01:49 Describe how you visualize the atom
2	**S:**	it's very very very small as in unimaginably small but if I'm inflating it several thousand times I see it sort of as a tiny nugget with clouds around it which is not really the way to describe it but the shapes are fuzzy.
3	**I:**	So, describe these clouds.
4	**S:**	well these are the these don't really exist instead they are our way of mapping where the electron could be at any point in time and usually we draw one at the point of 90% probability in diagrams I looked at where the electron has a 90% chance of being somewhere in this blob
5	**I:**	So, what's going on with the electron?
6	**S:**	electrons are moving around but we can't really know where they are exactly and so it's useful for us to deal with them as though they are just moving around in a blob even though they are not because that way we can work with the blob as where the electron could be. So it's not always there but it's there most of the time and it's not through the whole place but it's gotta be somewhere
7	**I:**	03:35 how are these blobs different?
8	**S:**	because that's what fits best we know that because in this unit we discovered as ones who have discovered before us that when an atom when an electron is when an atom is discharging energy from an electron when an electron is going back to the ground state it always releases a certain amount of energy, the energy that comes out comes out in discrete units and packages
9	**I:**	06:59 anything else?

10 **S:** that not all blobs are created equal, there's more than one shape of blob and blob isn't the right term cause really it's a fuzzy region in space. If you have a very small atom like He or H it's a sphere a fuzzy sphere around the nucleus and as you get more electron the shapes end up getting more and more complicated with lobes and more lobes as you get to have more electron and more orbital shapes , so the shapes are not constant

11 **I:** 04:10 what do you mean by discrete units and packages?

12 **S:** um, can I draw something?, so if we're, so we've seen.. I'm not going to draw it as I think of it I'm going to draw it much much simpler, but if this is the nucleus and these are the various levels it doesn't of course look like this but it's how we represent it and if something is going from here to here and if we didn't have certain places from which it can only go from here to here instead of going from here to here to here then when looking at the energy emitted you would see a whole spectrum you would see a whole wide range of energies, but instead we only see a few discrete lines only a few specific amounts of energy which shows you that there has to be more than one that it's not just a whole region that it has to be more than one defined levels where the electron can be

13 **I:** 05:24 is the second level in N and O the same?

14 **S:** both in the sp, but that's irrelevant... they don't have the same number of electron assuming we are still looking at the atom

15 **I:** is the difference between 2 and 3 the same for 2 atoms?

16 **S:** it seems like they would except that there are different charges in the nucleus and so the attractions between the nucleus and the electron will be different necessarily because in the eqn for determining the attraction radius and charge are the main things we need to worry about and charge would be different so I'm guessing no they won't be exactly the same even though it seems like they ought to be!

17 **I:** 07:40 Describe how you visualize light

18 **S:** this is one I completely messed up last time! Light is actually tricky because I'm not sure how to think of it, sometimes I think of it as this stream of particles pelting at me from the light which works sort of especially in the spectra if you think of it as each particle is a sort of packet of light energy hitting me and I interact with it and some bounce off. but that doesn't always work, sometimes I'm supposed to think of it a wave coming at me and this image is more problematic for me cause I'm not as good as visualizing it, but I try

19 **I:** 08:30 what do these ways get us?

20 **S:** they get us different wys of thinking about light each of which explain different ways we've seen light behave. so for example the particle theory is really good at explaining these discrete packages but it's not as great at explaining some other things about light, let's see I'm trying to remember what the wave model explains, I've kindo f been avoiding it it's not as intuitive for me! But like a shadow isn't sharp edged, it's fuzzy and if light only were particles no matter how small we were looking still they are sharp edged but instead you get blurs which implies there is something else going on

21 **I:** 09:34 is one model better than the other?

22 **S:** that depends on what you are trying to do. They are each useful for different things, we may eventually find some coherent way of thinking about light which would be really cool, but until that happens there is no value in it

23 **I:** 09:58 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

24 **S:** then it can hit any electron in the atom and it gives the electron enough energy to overcome its attraction to the nucleus and get out of there, that's where electrcity comes from

25 **I:** 10:24 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

26 **S:** then it depends very precisely on how much energy the light has. If the light by some nice coincidence has exactly the right amount to, exactly equal to the difference between energy levels it can move, it can excite an electron , move one electron from one energy level to the next

27 **I:** what if it didn't hit exactly?

28 **S:** then nothing then there's nothing it can do

29 **I:** 11:14 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

30 **S:** oh um so the electric current is exciting the electron and the specific color corresponds to the specific amount of energy that each electron is gaining because then when it returns to ground state it emits the light with the wvlngth and the freq corresponding to that amount of energy

31 **I:** 11:49 Why are Ne and He tubes different colors?

32 **S:** because the distance between energy levels is different. in fact closer, He is a different color from H even though you think they should be the same because of their distance would be the same cause nuclear charges and because 2 electron make things more complicated, they're different.

33 **I:** 12:17 Over time, would the tubes change color?

34 **S:** assuming a constant supply of electricity? no. no they won't because for every electron you excite you only get light when it's returning to ground state so it's a complete cycle

35 **I:** 12:34 Is there any amount of energy that wouldn't light the bulb?

36 **S:** yes, less than, let me think about it. If you don't put in enough to excite the electron nothing is gonna happen and if you put in way too much to completely ionize everything, then I bet the tube becomes a much better conductor but you don't get light

37 **S:** 13:23 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

38 **I:** you mean like the lines we saw? Each energy level and the IE's in between? I can try.

39 **S:** 15:04 it's showing that as the energy levels get higher they get farther apart. It's showing this kind of messily because I don't have anything that looks like a scale but approximately that, this is actually an n even though it looks like an m, it's in disguise

40 **I:** 16:06Can you draw the absorption spectrum of Hydrogen?

41 **S:** I could, I can't accurately here with my feeble attempt at scale, but this would absorb, until we get up to 1312, it would absorb light of exactly this minus this

42 **I:** 984, what other peaks would you see?

43 **S:** Let's see so absorption means I'm exciting electron so electron are always going to start at the ground state which means I can go from 1 to 2; 1 to 3 or 1 to 4. So I would have a line at 984, I'd have a line at about 1200 for that, that's how I understand it, it's possible we learned that that's wrong, but I don't remember

44 **I:** 17:41 How is this different from an emission spectra?

45 **S:** there it's the opposite, there I'm sure we have lines from each of them to 1 because when you emit you can go from n=2 to the ground state, but you can also go from n=3 to n=2 and from n4 to n3 and n4 to n2, so you would have… yes, your lines would be different

46 **I:** would you have more lines?

47 **S:** yes you would. especially if I'm wrong about it not being able to go from 1 to 3

48 **I:** what are your reasons for that?

49 **S:** because it seems like if it could go from 1 to 3, it seems vaguely as though if it go from 1 to 3 it would...hmm... I need to think about this for a while, it's pretty obviously not going to crash into any intervening electron because there is so much space in proportion to anything, um would the charge be a problem? I don't think so because again there is tons of space, so if it got the right amount of energy I can't think why it couldn't! maybe it can ..

50 **I:** How much energy is needed to ionize Hydrogen?

51 **S:** 1312 kJ/mol. Because the convention is that you represent zero as no interaction at all with the electron and the nucleus, zero is the point of complete ionization which means that you would need that amt, that because the first energy level is at -1312 you would need 1312 to get up to zero from there

52 **I:** 19:37What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

53 **S:** ionization

54 **I:** 19:41 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

55 **S:** not much. 500 kJ/mol here not enough to ionize and not the right amount to do anything else. It couldn't absorb it, basically the electron could not absorb that energy of light

56 **I:** how about 984?

57 **S:** you will… assuming you are interacting with an electron , the electron you will remove it to the next energy level, and that would be a n=2 electron until H decides to emit energy ... oh wait! of course you can go to higher energy levels because that's the only way you are going to get more than one line in your emission spectrum so yes! it can get up higher.

58 **I:** 20:45 how about 985?

59 **S:** kJ? that's not the right.. that's again you are in the intervening space it can't absorb it, you can't just get rid of 2 kJ/mol. that's.. I don't think it works like that! It seems unfair, like it ought to but I don't think it does

Student No: 52

	Evidence	Code
Probabalist/ Determinist	00:46 I think of just a nucleus and then an electron really close to it just going around. 01:26 well a shell is like.. A shell is orbitals with pairs of electron, one is spinning one way, one is spinning the other way, and sometimes it's unpaired. 2 electron fit in one orbital. s an p represent the general area where you can find the electron, and if you go in that area you will find one but they will be going around the whole time.	2
Discrete/ Continuous	07:00 well it's not like riding a bike up a hill… I think of it as like a piecewise function, not a nice linear one… the electron can't be in between 2 levels 16:15 (H-atom absorbs?) anything between these numbers. It takes whatever this is...(calculates) 984kJ. So if you don't have enough energy to get to the next energy level, then whatever you have left over is what is absorbed. like if you have more than enough to get to one energy level but not enough for the next one, then whatever you have left over in there is what is absorbed. it takes 984kJ to go from there to there. and if you have more, let's say to 1000, you would get to here, not to here and whatever energy you have left over is absorbed. so like 16kJ will get absorbed. (other absorptions?) maybe.. it can go from n=1 to n=3, and if it has enough energy to go to n=3, it gets there. If it has more than enough to get there but not enough to get to n=4, then the electron is not gonna stay in between n=3 and n=4, instead the extra energy gets absorbed.	1
Interpreting Spectra Code	16:15 (H-atom absorbs?) anything between these numbers. It takes whatever this is...(calculates) 984kJ. So if you don't have enough energy to get to the next energy level, then whatever you have left over is what is absorbed. like if you have more than enough to get to one energy level but not enough for the next one, then whatever you have left over in there is what is absorbed. it takes 984kJ to go from there to there. and if you have more, let's say to 1000, you would get to here, not to here and whatever energy you have left over is absorbed. so like 16kJ will get absorbed. (other absorptions?) maybe.. it can go from n=1 to n=3, and if it has enough energy to go to n=3, it gets there. If it has more than enough to get there but not enough to get to n=4, then the electron is not gonna stay in between n=3 and n=4, instead the extra energy gets absorbed. 18:51 Nothing at 500. It doesn't have enough energy to go anywhere. The light - I guess it gets reflected? It could get absorbed and the atom would get KE and move faster	2
Energy/Force Code	I don't know, it was more KE. If it's excited, it just has more energy and so it jumps, that's why it's excited. 05:30 (describe this process of jumping) It takes the energy from light and uses that to go to higher orbitals. I think it moves, just further away from the nucleus, so it's easier to be separated..	2

Line No.		Transcript
1	**I:**	00:46 Describe how you visualize the H atom
2	**S:**	I think of just a nucleus and then an electron really close to it just going around.
3	**I:**	01:03 How would you describe oxygen?
4	**S:**	still think of a nucleus, and then think of different shells around, and electron in those shells, it's hard for me to visualize p-orbitals vs s-orbitals, so I just think of concentric spheres

5 **I:** So, what is a shell?

6 **S:** 01:26 well a shell is like.. A shell is orbitals with pairs of electron, one is spinning one way, one is spinning the other way, and sometimes it's unpaired. 2 electron fit in one orbital. s an p represent the general area where you can find the electron, and if you go in that area you will find one but they will be going around the whole time.

7 **I:** Can you describe the shapes?

8 **S:** S is like a spherical, p is dumbell shaped. the area where you fins an electron is dumbell shaped, it would be inside the sphere area

9 **I:** 3:23 Describe how you visualize light

10 **S:** think of it as a squiggly line with a little photon in front of it. The squiggly line means that it can be thought of as a wave. But the photon behaves as a particle also. Sometimes it displays properties of a wave, and sometimes it displays properties of a particle so you have to like combine the two to get all of what it can do.

11 **I:** how about when light hits atom?

12 **S:** I think about particles more because they have to hit the atom.

13 **I:** 4:33 So, what happens when light hits the atom?

14 **S:** Depending on how much energy it has, an electron can move up orbitals or it can just leave the proton. Go from like the n=1 to n=2 to n=3 and it just gets excited and gets further away from the nucleus.

15 **I:** why?

16 **S:** I don't know, it was more KE. If it's excited, it just has more energy and so it jumps, that's why it's excited.

17 **I:** 05:30 describe this process of jumping.

18 **S:** It takes the energy from light and uses that to go to higher orbitals. I think it moves, just further away from the nucleus, so it's easier to be separated..

19 **I:** 06:24 When can it go up to energy levels?

20 **S:** when there is like the exact amount of energy needed in order to move from one energy level to the next energy level, because it's all "quantized". That means that the levels are discrete energies, so that if [gestures] you are here, and you have to enough energy to get to the next one, and like it won't move up unless it has enough energy to get to the next one, and anything between that it's just gonna stay at the same one that it's at

21 **I:** 07:00 what does quantized mean?

22 **S:** well it's not like riding a bike up a hill… I think of it as like a piecewise function, not a nice linear one… the electron can't be in between 2 levels

23 **I:** 07:56 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

24 **S:** it's because the electron are absorbing energy, so like the differences between where they move are certain wavelengths, and based on that

25 **I:** Why are Ne and He tubes different colors?

26 **S:** 08:33 well, because the energy is making different wavelenths, and it has to do with electron moving and what kinds of energy they need.. I really don't know....it has somethingto do with electron moving to different levels, and it gives off specific wavelengths, and each element has specific wavelengths it gives off to give different colors

27 **I:** Over time, would the tubes change color?

28 **S:** 10:03 i don't think so it's not like it's gonna run out and it's not like you are ejecting color. i guess if you put too much energy into it it will change color, or the intensity, the amount of electron that are going in there, the amount of energy going in

29 **I:** Is there any amount of energy that wouldn't light the bulb?

30 **S:** 11:06 i think there is a certain amount it needs to make it really dim, and then it grows brighter and brighter. i think you need a certain amount to get the process going... it would go from black filaments, then to red when it's really dim and then to bright white

31 **I:** 13:22 These are the 4 energy levels of H. Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

32 **S:** [draws] I guess it just shows like the difference between individual orbitals and the energy you need to get it to that level. H has 1 electron but if it's really excited it can move to the furthest away orbital I guess. In the groud state, it's in n=1

33 **I:** 14:01 How much energy is needed to ionize Hydrogen?

34 **S:** um, ionize means you remove electron, like n=infinity. Would it be 1312 kJ. Because that's the biggest one there. [draw n=infinity, above n=4] when the electron is just removed completely. The infinity energy level is when it's just gone, has an energy of zero

35 **I:** What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

36 **S:** That would get it to n=1… oh! It would get removed. Ugh, maybe I'm thinking about this backwards.. Cause they are negatives - it takes that much energy from the surroundings to get to those energy levels?? I don't know..

37 **I:** 15:18Can you draw the absorption spectrum of Hydrogen?

38 **S:** I always forget if it's the one with the graph and the straight lines, or the graph with the curve with different types of wavelengths at the bottom, and it shows what wavelengths are absorbed.

39 **I:** 15:45 what does absorption mean?

40 **S:** where there is a peak in the absorption spectrum, that's one that's getting absorbed, and that you don't see. But everything else that is smaller, that you will see.

41 **I:** 16:15 So what energies would the H-atom absorb?

42 **S:** anything between these numbers. It takes whatever this is...[calculates] 984kJ. So if you don't have enough energy to get to the next energy level, then whatever you have left over is what is absorbed. like if you have more than enough to get to one energy level but not enough for the next one, then whatever you have left over in there is what is absorbed. it takes 984kJ to go from there to there. and if you have more, let's say to 1000, you would get to here, not to here and whatever energy you have left over is absorbed. so like 16kJ will get absorbed.

43 **I:** any other absorptions?

44 **S:** maybe.. it can go from n=1 to n=3, and if it has enough energy to go to n=3, it gets there. If it has more than enough to get there but not enough to get to n=4, then the electron is not gonna stay in between n=3 and n=4, instead the extra energy gets absorbed.

45 **I:** 18:51 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

46 **S:** Nothing at 500. It doesn't have enough energy to go anywhere. The light - I guess it gets reflected? It could get absorbed and the atom would get KE and move faster

47 **I:** 20:31 How is this different from an emission spectra?

48 **S:** emission is.. It happens when an electron moves from a higher energy level to a lower energy level, and it gives off wavelengths Like n=3 to n=2. [calculates]. 408?

49 **I:** if H is in the ground state, will there be emission?

50 **S:** no, because it's at the lowest possible level, can't go anywhere...

Student No: 65

	Evidence	Code
Probabalist/ Determinist	orbital.. I still think of it as like a solar system except that instead of being on a defined track it can just be like anywhre roughly near the track and the density is like closer to the middle of the track I would assume would be more electron, higher probability of it existing there even though there is only one	2
Discrete/ Continuous	Um, but I guess the only one I really liked, or understood was how light in that instance behaves like a wave, and there are certain nodes in which it can exist, so I guess that would kinda explain why there are specific differences 14:55 (500?) nothing would happen, the light would just pass right through (why?) because it's not enough to ionize and it doesn't meet any of these energy differences (pass right through?) if it isn't the appropriate amount of energy, it can't excite any of these because none of the electron can go in this empty space, and you can't really split a photon, it's just like at one energy, so like it would just go right through the atom, and it wouldn't interact with any of the electron in the atom	3
Interpreting Spectra Code	13:24 yeah, so you would have a lot of different spectra , so basically for every possible energy difference that it could drop down that would be one type of, one absorption, so like 4 to 3; 4 to 2; 4 to 1; 3 to 2; 3 to 1; and then 2 to 1	3
Energy/Force Code	06:47 I would imagine you would have an atom, a nucleus, and electron around it spinning, and then this wave comes in, or photon, comes in and hits that exact electron and basically the photon kinda gets absorbed into the electron and the electron takes that KE energy and is able to jump just farther away from the nucleus and it just keeps going up until it gets to a certain point for which the nuclear charge doesn't have any pull on it and then instead of pulling it back, it just keeps going Neon would have more electron shells than I guess He and then because of that it's nucleus would also be larger so therefore the pull on the inner electron would be greater than the outer ones and since they have more electron, the discrepency I guess would be bigger up until it gets to a certain point for which the nuclear charge doesn't have any pull on it	4

Line No.		Transcript
1	**I:**	01:19 Describe how you visualize the atom
2	**S:**	I guess I still visualize it kinda like sphere, that's how I see it because I know the atom at the very center is very dense, with the protons and neutrons and between that and the electron there is a lot of space, and the electron are just kinda like a cloud, but like from far away I think it would still appear as a sphere, especially since you have all the different orbitals, and when yu put them all on top of each other it's like a [gestures a sphere]
3	**I:**	01:53 So, what are orbitals?
4	**S:**	I guess the electron.. you would probably see like certain densities of electron in certain patterns I guess. I guess for me like an orbital.. I still think of it as like a solar system except that instead of being on a defined track it can just be like anywhre roughly near the track and the density is like closer to the middle of the track I would assume would be more electron, higher probability of it existing there even though there is only one I feel like from our point of view it's really a bunch cause it's moving really fast

5 **I:** are they round? circular?

6 **S:** I guess they are kinda close to that, like the s is spherical all around whereas the p is in a dumbell shape, and d is clover shaped

7 **I:** 03:19 are they the same distance out?

8 **S:** it's depends on which energy level you are looking at, cause they kinda tell you how much energy each electron has, cause each energy level is progressively farther away and thus the electron must have more energy to be that far away and so like I feel like it's all these orbitals, densities, whatever on the atom, and for each energy level it's the same thing but each additional shell that gets bigger

9 **I:** 04:04 would 2p on 2 different atoms would be the same distance out?

10 **S:** I would imagine they are at different distances. um, mainly because I guess the different properties of each atom so like um Neon would have more electron shells than I guess He and then because of that it's nucleus would also be larger so therefore the pull on the inner electron would be greater than the outer ones and since they have more electron, the discrepency I guess would be bigger

11 **I:** 05:00 Describe how you visualize light

12 **S:** I think I still see light the same way , I don't remember how I've answered it but basically the class made it really precise for me but I've always kinda understood that light is basically a ray at a macroscopic level, and therefore this class they really hammered it down at a microscopic level it behaves like a wave which is why there is diffraction and stuff like that

13 **I:** so, why these different ideas?

14 **S:** because kinda like classify things as a wave or a particle, that's our classification not really necessarily how things work, and so light is kinda both, it doesn't easily fit, so we just say it's both rather than making another category for it

15 **S:** 06:22 for light, definitely, for the photoelectric effect, it's defintely a lot easier to think of it as particles so that would explain why the intensity doesn't matter whereas for diffusion or whatever it's nice to think of it as waves

16 **I:** 06:47 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

17 **S:** I would imagine you would have an atom, a nucleus, and electron around it spinning, and then this wave comes in, or photon, comes in and hits that exact electron and basically the photon kinda gets absorbed into the electron and the electron takes that KE and is able to jump just farther away from the nucleus and it just keeps going up until it gets to a certain point for which the nuclear charge doesn't have any pull on it and then instead of pulling it back, it just keeps going

18 **I:** 07:26 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

19 **S:** then it would depend on how much less or the exact number, cause in an atom for each energy level there is specific differences between each one, that's unique to each atom, and that.… And it can only absorb that difference

20 **I:** why?

21 **S:** like I guess in class they explained it in different ways like how it's like a ladder, so you have step, they also explained how it's a probability , and you take the formula, and there is a certain probability of being between. Um, but I guess the only one I really liked, or understood was how light in that instance behaves like a wave, and there are certain nodes in which it can exist, so I guess that would kinda explain why there are specific differences

22 **I:** 09:00 When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

23 **S:** I would imagine it's because you are exciting electron to a certain level, and they are falling back down and that specific different between the 2 energy levels - they emit that, just that amount of energy, a wave I guess, and that amount of energy would correspond to a certain freq which determines a certain wvlngth which produces the color. I guess in the same way that each one is unique and its orbitals are spaced differently, so Ne and He would have differently spaced orbitals, so therefore when it falls down the different in energy and the energy that would be emitted would be different

24 **I:** 09:46 Over time, would the tubes change color?

25 **S:** Like would the Ne tube turn into a different color? I don't think so. Hmm, well I'm not sure but I think it wouldn't ever change color mainly because you would always have Ne gas inside and even if you excited an electron a certain amount to get it to a higher state, it drops back down, um, as long as it drops back down, you would always have the same Ne with the same stable state, the electron would be in the same spot as you started

26 **I:** 11:06 Is there any amount of energy that wouldn't light the bulb?

27 **S:** um, I'm pretty sure like the lights only work at specific energies , even if you plug it into the wall, the light itself is sensitive to certain energies

28 **I:** 12:05 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

29 **S:** wait is energy level diagram the one that goes like this? Or this one?

30 **S:** 12:56 like it pretty much tells you like.. I guess how much energy is needed to take the electron out from each different level, and it tells you like the relationships between each level in terms of how far apart they are

31 **I:** 13:13How much energy is needed to ionize Hydrogen?

32 **S:** 1312 kJ/mol

33 **I:** 13:24 Can you draw the absorption spectrum of Hydrogen?

34 **S:** yeah, so you would have a lot of different spectra , so basically for every possible energy difference that it could drop down that would be one type of, one absorption, so like 4 to 3; 4 to 2; 4 to 1; 3 to 2; 3 to 1; and then 2 to 1

35 **I:** 13:54 How is this different from an emission spectra?

36 **S:** hold on - THAT was an emission spectra! An absorption spectra would be the other way around, so it could absorb 1 to 2; 2 to 3; 3 to 4; or like 2 to 4

37 **I:** could it go from 1 to 4?

38 **S:** yeah

39 **I:** would they have the same peaks?

40 **S:** I would imagine so

41 **I:** 14:33 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

42 **S:** you would eject the electron and there would be a certain amount of KE which would be 200. The Ke would go into the electron and it would just like fly away fast

43 **I:** 14:55 What happens if you shine light on hydrogen with an energy of 500 kJ/mol?

44 **S:** nothing would happen, the light would just pass right through

45 **I:** why?

46 **S:** because it's not enough to ionize and it doesn't meet any of these energy differences

47 **I:** would it pass right through?

48 **S:** if it isn't the appropriate amount of energy, it can't excite any of these because none of the electron can go in this empty space, and you can't really split a photon, it's just like at one energy, so like it would just go right through the atom, and it wouldn't interact with any of the electron in the atom

49 **I:** 15:39 What happens if you shine light on hydrogen with an energy of 984 kJ/mol?

50 **S:** um, yeah then the photon would hit and be absorbed , and then the electron would be excited from the first energy level to the second

51 **I:** would it stay at the 2nd?

52 **S:** no, because after you excite it, nature or whatever favors lower energy states so eventually this excited electron is going to drop back down to one, and when it does so, it's just going to release a photon with this specific energy

Student No: 66

	Evidence	Code
Probabalist/ Determinist	I guess they are still away from the nucleus, but the distance is not so much fixed anymore, it's more like a greater probability that you will find it in a certain distance	3
Discrete/ Continuous	24:04 (928) the energy you put in is transmitted, I want to say its transmitted because it is neither enough energy to move it to a discrete orbital, a higher energy state orbital or correspond to that (984?) then I think you would observe that that energy of light would be observed	3
Interpreting Spectra Code	07:53 um, well I guess it will depend. If it is, if the energy of the light matches one of the energies enough to make an electron from a lower energy orbital reach a higher energy orbital then I would think you see an absorbance. Whereas it doesn't have that exact energy it will be reflected or transmitted (explain?) if it is a transmittance, energy or light is passed through the sample, but if it passed through like a metal, it would be reflected. when i think of it as transmitted i think it goes through the atom 19:57 from my understanding the absortion atoms and elements because it only absorbes the energy that the electron can be moved up to a higher energy orbital, so how you would calc that would be the different of the energies between the lowest orbital and the available higher energy state orbitals the electron can occupy. because there is so many different states higher states that they get progressively closer, so I guess what you see is many. i guess it moves.. the most, and I graphed it according to... 21:32 (different between 12 13 14) yes.	3
Energy/Force Code	09:45 um I guess the more general way to think of it before we learned about like the d orbs and all that, I guess what that does it would excite an electron from a lower energy orbital to a higher energy orbital then as that electron falls back, it falls back to a lower energy orbital because it wants to always be at a lower energy state, you will see that energy light emitted, and depending on that light energy you will see a specific frequency which will determine the color in the visible spectrum well it depends on the effective.. the charge of the nucleus of the atom which will describe how drawn in the electron are, and then it also depends on how many electron there are due to like which energy states they fill and also due to which orbitals are open for electron in the not in the highest orb to go up on 10:47 (why different colors) I think you have to go back to again like there are certain factors that depend or that determine what energy it takes to excite an electron so um like nuclear charge so the positive charge	4

Line No.		Transcript
1	**I:**	01:20 Describe how you visualize the atom
2	**S:**	oh boy, ok, well while last time I did think of it as a more cut and dry way I guess because I mean last timeI think I drew a nucleus with expanding outer shells to indicate the location of the electron was. But now that we've talked about various ways to interpret the probability of finding the electron like wave models and all that, I guess how I would imagine it is that still same nucleus except there are now places where the electron cannot be and then there is also.. because of the wave proeprties there is, if it appears in one place in the atom, it also appears in the opposing

3 **I:** 02:41 what are the electrons doing?

4 **S:** I guess they are still away from the nucleus, but the distance is not so much fixed anymore, it's more like a greater probability that you will find it in a certain distance

5 **I:** Do they stay within areas, or go in between 2s and 2p?

6 **S:** I think it would have to depend on the energy states actually, generally the rule is that it would want to occupy the lowet energy state

7 **I:** what are these energy states?

8 **S:** To me the energy states are sort of a relative way to determine the stability of either the molecule or in this case the position of the electron , um it's sort of arbitrary in my opinion because zero is set as the infinite distance between the proton and .. so the separation, and every other discrete point , or orbital where the electron can occupy, as it moves up, as it becomes more negative it indicates lower energy as opposed to a infinite separaton which would be characterized as zero

9 **I:** 04:41 in large atom with multiple energy states, can they go between those?

10 **S:** If they are filled in, I don't believe one an electron from a lower energy can reach a higher energy orb if that orb is at a higher energy are all filled

11 **I:** why these energy levels?

12 **S:** well it depends on the effective.. the charge of the nucleus of the atom which will describe how drawn in the electron are, and then it also depends on how many electron there are due to like which energy states they fill and also due to which orbitals are open for electron in the not in the highest orb to go up on

13 **I:** 06:15Describe how you visualize light

14 **S:** I guess last time whereas I believe I said I think of light as a wave but I did not consider it as light as a composition of different I guess different energies. It's composed of different energies of light, composed of light. I think the view of light as a wave model is more for me macroscopic properties because well it you have to take in consideration the ray model as well but those two combined helps me describe more macroscopic properties. whereas photons or light as particles, that helps me primarily when I apply light as a means of energy

15 **I:** 07:53 What happens when light hits a Hydrogen Atom with energy LESS than the Ionization energy?

16 **S:** um, well I guess it will depend. If it is, if the energy of the light matches one of the energies enough to make an electron from a lower energy orbital reach a higher energy orbital then I would think you see an absorbance. Whereas it doesn't have that exact energy it will be reflected or transmitted

17 **I:** can you explain more?

18 **S:** if it is a transmittance, energy or light is passed through the sample, but if it passed through like a metal, it would be reflected. when i think of it as transmitted i think it goes through the atom

19 **I:** 09:15 What happens when light hits a Hydrogen Atom with energy GREATER than the Ionization energy?

20 **S:** then it would be absorbed if you were able to measure it the proper apparatus, I think you would observe the electron being ejected

21 **I:** 09:45When you put an electric current through a tube filled with neon or helium gas, it glows with a certain color. What causes this color?

22 **S:** um I guess the more general way to think of it before we learned about like the d orbs and all that, I guess what that does it would excite an electron from a lower energy orbital to a higher energy orbital then as that electron falls back, it falls back to a lower energy orbital because it wants to always be at a lower energy state, you will see that energy light emitted, and depending on that light energy you will see a specific frequency which will determine the color in the visible spectrum

23 **I:** 10:47 Why are Ne and He tubes different colors?

24 **S:** I think you have to go back to again like there are certain factors that depend or that determine what energy it takes to excite an electron so um like nuclear charge so the positive charge as well as the what orbitals are empty so orbitals can be filled ad what orbitals can be filled

25 **I:** 11:25 Over time, would the tubes change color?

26 **S:** i don't believe it will from the ideal perspective because that sort of energy difference for a certain element is I want to say fixed

27 **I:** 13:42 Is there any amount of energy that wouldn't light the bulb?

28 **S:** um I think if you add energy that isn't even enough to make the electron reach the first available highest energy state then I would think it wouldn't be excited

29 **I:** 15:30 Can you draw an energy level diagram of Hydrogen? [hand piece of paper with table]

30 **S:** um I think first you have to understand that you have to assign a certain zero and that zero is infinite separation of the electron and the nucleus. From there I guess we can deduce our understanding of different orbitals and see which energy state which the electron can reside at lowest energy and so these are relative according to zero , the numerical expression indicates sort of the stability of the electron because the lower the energy is the more stable

31 **I:** how about in terms of the structure of the atom?

32 **S:** I guess these represent different shells

33 **I:** 17:00How much energy is needed to ionize Hydrogen?

34 **S:** since it's at its most stable state or lowest energy state available is -1312 kJ/mol, to make it reach what we call infinite separation or IE I guess would be the difference between zero and this number.

35 **I:** so, why is it from here?

36 **S:** because at its most stable state, this is where the electron will reside, because this is the lowest energy.

37 **I:** is this for every element?

38 **S:** no, this is only true for one electron for H or like H.

39 **I:** 19:57 Can you draw the absorption spectrum of Hydrogen?

40 **S:** from my understanding the absortion atoms and elements because it only absorbes the energy that the electron can be moved up to a higher energy orbital, so how you would calc that would be the different of the energies between the lowest orbital and the available higher energy state orbitals the electron can occupy. because there is so many different states higher states that they get progressively closer, so I guess what you see is many. i guess it moves.. the most, and I graphed it according to...

41 **I:** 21:32 the difference between 1,2 1,3 1,4

42 **S:** yes.

43 **I:** 21:51 How is this different from an emission spectra?

44 **S:** an emission spectrum is different in that it can fall from various ways from a higher energy orbital. Instead of having to always rise up from the lower energy state as an absorption, it can fall in various ways, so I guess you will see more emission lines because there is no discriminate way that it has to fall

45 **I:** does it have to fall to a line?

46 **S:** yes, because that's the discrete nature

47 **I:** 23:16 What happens if you shine light on hydrogen with an energy of 1512 kJ/mol?

48 **S:** oh ok, if you would hav an apparatus that would detect the emission of electron I think that you would get a reading, because I think that is enough energy for electron to be eject from these lower energies

49 **I:** What happens if you shine light of energy 982?

50 **S:** The energy you put in is transmitted, I want to say its transmitted because it is neither enough energy to move it to a discrete orbital, a higher energy state orbital or correspond to that [points to difference]

51 **I:** What happens at 984?

52 **S:** It's absorbed.

53 **I:** 985

54 **S:** Then I think you would observe that that energy of light, it would be observed, transmitted

Appendix D: Full Transcripts of Student 18 and 28 (for Chapter 5)

Student 18 ("I" = Interviewer, "S" = Student)

Line No.	Time		Transcript
1	4:25	I:	The first thing I want to show you… ok, so this is a visual.. And so what this is - these are all different gases. So, I'm going to pick hydrogen and put it in here.. That just connects it to the.. It makes it into a gas lamp
2		S:	ok
3		I:	ok, so just tell me a little bit about everything you see in this picture, this picture and this picture [points to spectra, energy level diagram and gas lamp]
4	4:57	S:	ok
5		I:	everything you see, and what you think it means
6		S:	so…um, ok, so I honestly don't know, but [laughs] I would say this is light and this is like the spectrum of light..so maybe this… but I can't really tell from the picture if this whole spectrum is coming in here or it's just certain light? But if I go with the fact that.. since it's just light, it will be in the spectrum, then all the colors are going in, and then this is like concentrating it or something, I guess it's just directing the light to this certain place - or maybe it's going the other way! I don't know...
7		I:	That's fine
8	6:00	S:	No! Ok, wait! Now I'm starting over! [laughs] Maybe this is the light bulb, and well obviously this is the light bulb..ok now I'm thinking this is the light bulb and it's shining light through the hydrogen gas and that is maybe absorbing.. Hydrogen molecules are absorbing certain wavelengths [inaudible] um.. and then what is not absorbed is passing through and then this.. the prism allows you to see the colors! ok! ok! whoa! and then.. so this is saying what is absorbed and what is not absorbed so that's saying what wavelengths the molecules absorb. ok. yeah.
9	6:54	S:	And then this is some sort of measurement of maybe what is the energy or something [looks at energy level diagram]
10	7:04	I:	And then one little thing - this is in electron volts, which.. In Chem 1A we always worked in kJ, so this is just energy
11		S:	ok
12		I:	so whenever you see this "electron volt" just think of it as energy
13		S:	ok
14	7:20	I:	[inaudible] and then this is wavelength, but for our discussion let's just ignore wavelength, we'll just work in terms of energy

15		**S:**	ok, so I guess it's measuring like how much energy the hydrogen has, like the energy the bond has or something, that's what's being absorbed.. Or maybe I just made that up…[laughs] I don't know..
16	**7:42**	**I:**	What do you think those black bars represent? [point to spectral lines]
17		**S:**	um…. Are these connected? Like is this line… oh, this is just going to this! [realizes the spectrum is coming from gas lamp] and this is like what you are referencing. Ok. So I guess this would be light that's absorbed, or different levels of energy that are absorbed.
18		**I:**	and how would you know that?
19	**8:03**	**S:**	oh, like a NMR type thing? No? is that different? Oh wait, that's different cause that's light, right right.. Yeah, so I guess this would different levels of energy that the hydrogen gas absorbed and that's why it's not transmitted
20	**8:28**	**I:**	Why do you think it's black? Why are those lines black?
21		**S:**	Because you can't see the light? Cause the light, like that particular energy level didn't go through maybe or something… And so you can't like.. The light isn't present cause that energy notch isn't present
22	**8:53**	**I:**	Ok, so what I'm going to do now is add energy level…ok, so I'm just going to put this at ten, so let's just say it's at negative 10
23		**S:**	ok
24		**I:**	energy units, we won't worry about what the actual energy is.. And I'll add one more.. And this is an absorption, so I'll add an arrow up here [added an arrow from lower level to higher level] ok.. So looking at this, what does that arrow mean to you? Or represent to you?
25	**9:29**	**S:**	Uh… so energy is increasing, right? Yes, that's.. Or like the "up" is more energy… so I guess to me that would be like.. If you like excite electrons up an orbital or something, so I guess it's pointing from lower energy to higher energy
26		**I:**	ok, so then what I want you to do is if you grab this bar on this side of the axis [energy level] and then you move it.. Move it up and down and see what happens. You can use 2 fingers if you want
27	**10:07**	**S:**	[moves energy level up and down]
28		**I:**	So what do you see happening? What do you think?
29		**S:**	So.. I mean I think like the lower you put it, the lower energy wavelength it goes to.. So I guess… I mean I would think that like maybe this [points to spectral line, gestures vertically] is just another way of expressing this [points to energy level diagram, gestures horizontally] yeah...
30		**I:**	ok, play around with it and try to get it to match up to one of the lines
31	**10:52**	**S:**	ok. So if you matched up to that… like that would mean that this is the amount of energy, like maybe that's a certain bond [points to black spectral line], and then that's the amount of energy the bond contains or something [points to energy level]
32		**I:**	If you look at the numbers, can you assign some numbers to that arrow?

33	**11:21**	**S:**	Wait, ok, like these numbers? [points to energy level diagram] So if you pretend that this is..um.. So I guess like this is the.. What is this again? Oh wait! These are the same.. That's eV and that's eV… so that's 1.9 [position of higher energy level], and this is 8 [spectral line]..um, what...[laughs, confusedly]
34		**I:**	move it around a little and see if those numbers will make sense
35		**S:**	so that's at 3 [higher energy level], and that's at 7 [spectral line]. Um, like I don't get why like if this at 1.9 [spectral line], why it's not at 1.9 here…[energy level]
36	**12:25**	**I:**	what happens if you put this at 1.9?
37		**S:**	[quiet for a while staring at screen] uh… then it [the spectral line] disappears. I don't know… what is happening. And it only appears around six and a half-ish, and I don't get what these numbers represent. [energy levels] and I don't get why they are all negative.. yeah... [laughs]
38		**I:**	why don't you line that up again to one of.. One of the black bars
39	**13:17**	**S:**	[silent] so, this is …I'm guessing that's a place where light doesn't go through because the wavelength was absorbed by the hydrogen gas…
40	**13:36**	**S:**	And this is… so this is… like .. If this is a wavelength, maybe that's like the amount of energy the wavelength has? And so this… *OH! Wait a Second!!! Maybe I get it! I get it! Ok! Wait, do I get it? Yeah! Cause this is the difference*.. Is this number... ok
41	**14:11**	**I:**	So, how did you know that? Or how did you get that?
42		**S:**	How did I just figure that out? I think cause, oh, cause in my head I was like ok like if these represent like 2 different energy levels, it has to go up that much, and then I saw that.. That this number, like this distance corresponded to that [points to spectra] yes.
43		**I:**	Let's do one more…
44		**S:**	ok
45		**I:**	this one .. Right there… go ahead and play with this one and get it to match up to another line so you have two bars matching
46		**S:**	ok [silently works on computer]
47	**14:50**	**I:**	So tell me what you see…
48		**S:**	ok, so this line.. Um.. This is a difference in energy that is represented by the 1.9 number and I don't really know if… this represents like different levels of energy that like electrons has to jump up to.. No, I don't think so, I think this is the number that the bonds.. like this is the energy wavelength .. I don't know if those two words [inaudible]... like this is what the bar represents.. like if this was like your zero, kinda.. this is how much energy the different bonds absorb in hydrogen.. which I don't really get because if its just hydrogen, why is there more than one [energy level]? I don't really get that. cause if it's just like..
49		**I:**	maybe we'll come back to that..
50	**16:37**	**S:**	ok

51 **I:** Looking at those 2 arrows, which one is higher energy/lower energy? Which one is more energy/less energy?

52 **S:** I think the top one is more energy

53 **I:** without moving them, if you had to match these two arrows to those 2 bars, what would you say?

54 **S:** yeah, so well I guess you'd say like this bottom one is the lower one, is lower down here [gestures to the left on spectra]. Yeah, because If this is the difference, then it's a smaller difference so this would definitely be smaller [points to left spectral line]

55 **I:** and then why don't you try moving it and see if your prediction is correct

56 **17:12** **S:** [moves it] So then, yeah, that makes sense

57 **I:** ok, so you were still wondering why there was so many levels

58 **S:** I guess,, well ok, because then in my head I was like wait, after I saw that, cause hydrogen is just an atom so why is.. So in my head before this was different bond energies, but that doesn't make sense because it's just one atom, so maybe that is electron orbitals then! ok, I don't know..

59 **I:** keep going

60 **S:** well, I don't know, wait, I haven't looked at the periodic table in a really long time, but hydrogen is the first one right? So there's just one electron, so maybe this is.. Oh! Cause if you.. Oh! If you put light on it it excites it up and there is lots of hydrogen atoms so they will all be at the exact same energy levels, so maybe that's why there are more than one line because it's measuring different hydrogen atoms at different energy levels.. and I just made that up [laughs] so I don't know..

61 **18:34** **I:** we'll come back to that.. Ok so another thing you can do with this is.. Ok… is instead of hydrogen you can put an unknown in there, ok and then.. What I did was I just took a screen shot of that and it's the same thing, you put some unknown in there, and get some spectra out [inaudible] so then can you construct for me.. tell me what the energy levels are?

62 **S:** ok

63 **I:** if I give you that n=1 is at -10 [draws it on paper] that's the first line down here [points to energy level diagram on computer]

64 **S:** ok, so if this one's 1.5 as one and this is like the difference I guess, oh, hmmm let us think about this.. Because uh.. [plays with computer simulation] So when it's at 1.5 there is 1.5 difference, ok .. So I don't get what n=1 means then..

65 **I:** don't worry about that, that's just the same as this [points to computer] lowest level

66 **S:** so the first bar is at 1.5 which means a difference of 1.5 between here and so that will be like right here.. Wait am I drawing the line?

67 **I:** mm-hmm

68 **20:42** **S:** so between those two, so that would be this one

69		**I:**	so how do you know it's that one?
70		**S:**	uh, because given that it's at number 1.5 and that's.. There's an energy difference.. Like these numbers [point to spectra] correspond to like this difference [points to energy level diagram] yeah, so and then so for 2.5.. Ten minus 2.5 is 7.5, yeah that would be right here, that's this one [points to 2.5 spectral line] and then 3 would be 7. yeah
71		**I:**	cool. Ok. So now I have kinda the opposite of what you just did. So this time, so ignore this, I couldn't get it to not print
72		**S:**	ok
73	**21:48**	**I:**	But now I'm gonna give you the levels and you fill in the bands up here
74		**S:**	ok, so this is the same thing, so there would be one right here I think. Cause that's like basically one..
75		**I:**	yeah, I actually wrote it down there
76		**S:**	oh! Kidding.. Yeah.. And so that.. So the next one would be at two.. Over here…
77		**I:**	go ahead and draw it in the bottom one [spectra]
78	**22:20**	**S:**	ok.. I like this pen.. It's a really good combination of a ball point and a gel
79		**I:**	I'm kinda a pen addict
80		**S:**	I understand, my mom works at REI and she like has special REI pens that I'm pretty sure are actually just like generic like Bic pens
81		**I:**	ok
82		**S:**	but they're so amazing.. I always make her like biring me some when she works
83	**22:50**	**S:**	ok, so this one would be 2.8 [draws in black bar in spectrum]
84		**I:**	can you draw in arrow too on this guy [points to energy level diagram] that kinda match [points to computer screen]
85		**S:**	oh, just like.. Ok so this one [points to spectra] matches this [points to energy level diagram] so it would be like shoo [makes rocket sound] so maybe that's going up and then that line is this one [points to spectra] and then that corresponds to this [correctly matches up arrows to spectral lines]
86	**23:28**	**I:**	So if you look at this line here, the 2.0, think about if we gave 2.1 eV, a little bit more energy
87		**S:**	ok
88		**I:**	what do you think would happen? Would hydrogen absorb that? Or would this unknown sample absorb that?
89		**S:**	um, oh, would this unknown sample absorb it?
90		**I:**	if it's an atom just like hydrogen
91		**S:**	oh, so if it's not corresponding to this [points to spectra]
92		**I:**	why don't we just stick with hydrogen, so here with hydrogen [looks at computer] so you have this one
93		**S:**	so if you put it at 2.1

94		**I:**	I guess what I'm asking is 2.6, a little bit more…
95	**24:22**	**S:**	ok, I don't think it would absorb it
96		**I:**	ok, why?
97		**S:**	because it's not.. Ok, assuming what I said before was correct which could be totally wrong [laughs] and um.. I mean like if the atom only absorbs certain wavelegnths of light it makes sense that it only absorbs certain wavelengths of light because..uh.. because of like each orbital I guess would be at a different level of energy , so if it's not that specific level it would just pass through
98	**24:59**	**I:**	So if it's in between.. [points to energy level diagram]
99		**S:**	So if it's in between there then it wouldn't absorb
100		**I:**	If it did absorb, what would your spectrum look like? Or what would..
101		**S:**	I mean it would be different because … because it would blocking the spectrum at a different place and so your line would be.. Somewhere else
102	**25:44**	**I:**	ok
103			[break]
104	**54:46**	**I:**	This is a short answer, this was on the final actually
105		**S:**	ok
106		**I:**	so go ahead and… you can just talk through you don't have to write it if you want
107		**S:**	ok, so an electron.. Would it absorb energy E2? Ok, I'm saying nobecause um, cause it doesn't correspond to a specific energy wavelegnth that hydrogen has and so the energy would just go through and um
108	**55:20**	**S:**	So, I don't think it can absorb the energy and it would just go around or just into the atmosphere [laughs] but yeah, because it's not enough where it would make the electron leave the atom, but it doesn't correspond to a specific level of energy that is around the hydrogen atom so.. or the hydrogen atom has I guess ...um.. I don't know if these.. if energy levels are.. I mean I guess they are associated specifically with the hydrogen atom but I don't really get.. I don't see where they are.. but I don't really get where they are, I mean.. like if they are surrounding the atom but like it's hard for me to conceive that it's not like something you can... not even something you can.. you can see.. but like just something that isn't really concrete, so that I have trouble with that
109	**56:27**	**I:**	actually, I think you did a good job with your pictures
110		**S:**	yeah, so it would not be able to .. So.. Yeah.. Is that enough? ok
111		**I:**	yeah, do I have any more questions...? No I think that's it
112	**56:43**	**S:**	ok

Student 28 ("I" = Interviewer, "S" = Student)

Line No.	Time		Transcript
1	**5:00**	**I:**	So what this is is a simulation of a lamp so these are all different gases in here
2		**S:**	mm-hmm
3		**I:**	So, I'm just going to pick Hydrogen and put it in there
4		**S:**	mm-hmm
5		**I:**	ok, so take a look at this , why don't you just describe to me what you see or what you think different parts of this mean to you
6	**5:20**	**S:**	well, it looks like it's glowing pink um and I guess that would have to do with the excitation of electrons from what I remember and um as the electrons fall they emit photons of a specific wavelength, and it's the pink wavelength that would be in it looks like this area [points to spectra] and um, the dark lines are the those photons that are emitted rather than absorbed.. and then the rest of the colors are absorbed, and that's why they don't show, visually
7		**I:**	yeah, so what do you think this strip represents? Or what.. Tell me a little bit more about these colors
8	**6:00**	**S:**	Um, the colors are the differenct wavelengths of light and that's the visual spectrum, that's the strip and ..
9		**I:**	what do you think those black bars mean
10		**S:**	I totally remember learning about this! Is the frustrating thing!
11		**I:**	it's ok
12		**S:**	the black bars are where the color, or are the colors that are emitted rather than absorbed
13		**I:**	and then one funny thing about this.. This is all units called "eV" electron volts but in Chem 1A we always talked about kilojoules so don't worry too much about the actual numbers just think of it as an energy scale
14		**S:**	mm-hmm
15		**I:**	in terms of electron volts, and this is also an energy in terms of these numbers
16		**S:**	mm-hmm
17		**I:**	now down here, it's wavelength, um, for our discussion, we're kinda just ignoring it, just ignore wavelength on that diagram
18		**S:**	mm-hmm
19	**6:54**	**I:**	oh, you mentioned emission and absorption, so what.. Tell me a little bit more about those 2 - what are they?

20		**S:**	um, trying to think.. So the colors are the.. As the electron.. So the electrons are spinning in orbitals around the nucleus of the atom and the're going in .. I totally remember learning about this, but I don't remember… but um some are, some of the, as the light comes into the atom some of those wavelengths...cause the light comes in with all different wavelengths, and some of those wavelengths are absorbed and then that sends the electron up in energy and then as the electron falls back down in energy, it emits photons and um those are the emission spectra I guess.. and absorption spectra
21	**7:58**	**I:**	let me show you one more thing.. So this is emission spectra, it's really similar.. So looking at these 2 things can you just tell me what you see, or how are they different?
22	**8:21**	**S:**	yeah, um, so this is what the "reader" I guess is picking up that are emitted.. Are these I guess energy levels, and then the other colors that aren't are the black lines, it means that these [points to emission spectra] are these black lines [points to absorption spectra] and then all the other colors are those that are absorbed, yeah.. and so these 2 charts complement each other
23		**I:**	ok, yeah, ok, so in… which one do you think you are more comfortable with? Or which one do you like more?
24		**S:**	I like this one. [points to emission]
25		**I:**	ok, let's stick with that one. Cause you're right they say the same things
26	**9:05**	**S:**	mm-hmm
27		**I:**	ok, so this is showing Hydrogen's emission spectra. So what I'm going to do is add an energy level [S adds] my computer is not that powerful.. Ok, good, so this is one energy level. I'm just going to put it at 10, again we are just going to pretend these are arbitrary units, for Hydrogen it actually should be around 13, for some reason their scale doesn't go down that far
28		**S:**	[laughs]
29		**I:**	ok, and this is emission so you were saying .. The electron - does it go up or does it go down when you have emission?
30		**S:**	emission is when it's falling, it's falling an energy level
31		**I:**	ok, so that means the electron is falling down
32	**10:15**	**S:**	ok, so what I want you to do - if you grab this level on this side of the axis, you can move it up and down.. So go ahead and play with that, move it up and down and see if you can.. Notice what happens up here when you do that
33	**10:30**	**S:**	ok
34		**S:**	it's not moving
35		**I:**	yeah, try it low
36	**10:45**	**S:**	oh, there we go.. I see it's [inaudible] color of the spectrum
37	**10:53**	**I:**	so why do you think it's doing that?
38		**S:**	umn, I believe that it's because it's at these specfic eV or the electron voltages, um, it's emitting photons of those wavelengths and that's why it's corresponding with the color of the spectrum, it's because those are the wavelengths that emits at these different energy levels

39		**I:**	go ahead and match it up to one of the lines, and see if you can.. It's a little buggy
40		**S:**	yeah
41		**I:**	so how much energy is involved in that transition?
42		**S:**	that would be like two and a half, I guess, two and a half ev's, um, so yeah, the higher energy would be in this direction [points right on spectra] or the higher energy voltages, or the greater distance between the electron levels, and the higher energy is shorter wavelength as well ..
43	**12:02**	**I:**	let's go ahead and do one more, so go ahead and move this one too and match it up to another
44		**S:**	[she moves it]
45		**I:**	ok, so looking at those 2 arrows, which one.. How do these 2 [points to energy level diagram] compare with these 2 [points to spectra]? Or relate to those 2?
46		**S:**	um, so this one is that this wavelength I guess and this one is higher energy than this one which is the same or essentially corresponds to shorter wavelength, in the pinker spectrum, longer wavelength in the bluer spectrum
47	**12:40**	**I:**	which one is lower energy? And higher energy?
48		**S:**	um, the pinker side is the higher energy and the bluer side is the lower energy
49	**12:52**	**I:**	ok, another thing you can do in here.. This is absorption, but just think of it emission wise, is you can put… anyway, you can put an unknown gas in here
50		**S:**	mm-hmm
51		**I:**	so let's go back to emission , let's say I take this off and put some unknown in there. What I did was I took a screen shot of something similar to that. This is absorption, but you can just flip it and think of it as emission
52		**S:**	mm-hmm
53	**13:38**	**I:**	so let's say I put some unknown, get some emission spectra like this
54		**S:**	mm-hmm
55		**I:**	can you draw me the energy levels that correspond to this? And I'll tell you that the lowest one is here at 10 volts. What would the other levels be? Kinda similar to the pictures you saw [points to computer] my computer's had a long day.. Anyway, we have these levels here..
56	**14:12**	**S:**	yeah, yeah
57		**I:**	can you draw similar levels, similar to that…
58	**14:27**	**S:**	[draws] So I'm going to say 1,2,3 [labels spectra] so this is one
59		**I:**	how did you know to put it there?
60		**S:**	um, maybe that it's because there are.. I guess this should be a little bit lower.. Maybe down here, um, because it's around 3 I guess electron voltages in energy, so that would be 3 emitted, 3 ev as it falls, and then this one would be 2.5, it would be lower energy, so that would be about here [draws] and then this one is only 1.5 and that's even lower energy so that's here.. so this one falls and [inaudible]
61	**15:22**	**I:**	ok, and another similar problem, This time I'm going to flip it, so I'm going to give you the energy levels, can you draw me the spectrum? And sorry, ignore these things, so just draw it on the bottom.

62	**15:36**	**S:**	ok, just draw the black lines?
63		**I:**	just draw the black lines
64		**S:**	I'm gonna say that this one is about 3 [draws on spectra] so over here. And this one is it looks like a little over 2.5, so about here, and then this one is over 1.5, so maybe like 1.8, so it would be over here, and this one is zero so
65		**I:**	cool, ok so if you look here or here, you have a certain number of lines [points to spectra] so in this case we have one at around 3
66		**S:**	mm-hmm
67		**I:**	why isn't there a line at like 2.75? Or somewhere in between here?
68		**S:**	mm-hmm
69		**I:**	why do you not see that do you think?
70		**S:**	um, my guess would just be that that portion is absorbed, as the electrons rise.. Or the.. It has to do with distance from the nucleus I believe, I think I remember, um or the electrons they essentially want to pull back to the positive charge in the center of the atom so as they are hit with the light energy they'll kinda float away and then they'll be drawn back and that's the energy that's emitted, as they're pulled back to the center of the atom.. and so this is just [points to 2.75] it never really goes into that energy range
71	**17:20**	**I:**	it's almost.. Like why do you think it doesn't go into that energy range
72		**S:**	because they have.. It depends on the size of the atom, I don't remember specifically exactly why.. I just remember that it doesn't [break]
73	**29:57**	**I:**	There's one more. Its a short answer question that was actually from the final
74		**S:**	ok [reads question aloud] yeah, I'm thinking that it can absorb this energy, but based off of that last question, I don't remember the specifics, but I feel like it does, it is transferred into kinetic energy, so I would say that um.. Should I be writing this down on here?
75		**I:**	no, it's ok
76	**30:28**	**S:**	ok, I would say it would absorb the energy up to n=2 or or E2 I guess, um and then the excess energy as it falls down to that level and then down to this level, the excess energy here would be kinetic energy and then as it falls more, that would be light energy between the 2 levels
77		**I:**	ok, so just one more question… so the reasoning that you just gave.. So if it absorbs here [points to E2], the excess would be kinetic, what would an absorption spectrum look like for that situation, or what energies of light would be absorbed? Just overall
78	**31:08**	**S:**	I would say that it would still, it would just show up here [circles n1 to n2], as the energy that's absorbed
79		**I:**	ok
80		**S:**	um, just because, um, I don't.. This, this wavelength up here [excess over n=2] as it falls would not be emitted, it would, because it would fall here [to n=2] and then this wavelength [n2 to n1] would be emitted so I'm thinking that it would still show up just as that - this line of energy [n2 to n1] on the spectrum

81	**31:34**	**I:**	so what goes on, like right there [over n2] when it falls? That little bit?
82		**S:**	um, I wanna say that they they would turn into heat of some kind? Because it wouldn't be a wavelength equal to that of light energy so I want to say kinetic energy would be heat or temperature
83		**I:**	so if you were to draw a spectrum like the ones we did here
84		**S:**	mm-hmm
85		**I:**	what would it look like?
86	**32:06**	**S:**	So, say this is the wavelength for n=2 or the energy required for n2. um, there would be, there would be a line here
87		**I:**	or E1, whatever energy that is, got it
88		**S:**	yeah, ok, oh yeah, yeah, so this would be E1, I guess would be [inaudible] but yeah so that would be the E1 energy
89		**I:**	ok
90	**32:33**	**S:**	and then E2 wouldn't show, just because the excess little portion would be heat
91		**I:**	ok, and then what would be your next one? It's not on that diagram, but if you were to draw another arrow here
92		**S:**	mm-hmm
93		**I:**	for your next line in your spectrum
94		**S:**	and then next one would come up to n= or n3, so it would be.. This would be higher in energy, so it would be further down this direction, and then that would be the.. Let's say this is E two and a half
95		**I:**	ok
96	**33:08**	**S:**	This would be E two and a half or I guess n3
97		**I:**	ok, I think that's it..