

ATOMIC STRUCTURE ACTIVITIES FOR SECONDARY SCIENCE

by

David W. Miller

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Abstract

Section One - The Development of a New Atomic Model and the Rutherford Gold Foil Activity

Students who performed the Rutherford gold foil activity simulated Ernest Rutherford's famous gold foil experiment. In this activity students determined the shape of two different irregularly shaped objects utilizing a ball bearing rolling down a ruler. By rolling a ball bearing down a ruler students found that the vast majority of times the ball bearing passed straight past an object hidden under a platform. This activity helped to confirm that most of the atom is made up of empty space with a small portion of the atom being that of a small positively charged nucleus.

Section Two - Quantum Model of the Atom and Schrödinger's Electron Probability Activity

During the Schrödinger's Electron Probability activity students used marbles and a target to investigate the three-dimensional distribution of the electron in the ground state orbital of hydrogen. This two-dimensional model that students created helped them to better understand the three-dimensional distribution of an electron in the ground state orbital of hydrogen.

Section Three - Electron Configurations and the Electron Battleship Activity

This lab activity gave students the opportunity to learn the noble gas and standard electron configuration notations of atoms in their ground state. Students worked in pairs of two and played a game called Electron Battleship. The goal of the game was to place all five ships on the periodic table hidden from their opponent's view keeping them from being destroyed. Each player kept track of their own ships and their opponent's ships by using different laminated periodic tables. The first player flipped a penny; if the penny was tails then the first player gave the electron configuration using the noble gas notation. If the penny was heads then the first player gave the electron configuration using standard notation. This allowed practice for both methods of naming the electron configuration of an atom.

This paper is dedicated to the memory of Andy Edington, my friend and mentor who was always available to help me with many of the questions that I had in the areas of chemistry and physics.

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Description of Activities

Overview

Section One - The Development of a New Atomic Model and the Rutherford Gold Foil Activity

Discuss the properties of the atomic nucleus; identify mass number, atomic number and neutron number; explain why some nuclei are unstable; and show how to calculate binding energy.

Section Two - Quantum Model of the Atom and Schrödinger's Electron Probability Activity

Describe the location of electrons around the nucleus from a wave mechanical, or quantum perspective using quantum numbers.

Section Three - Electron Configurations and the Electron Battleship Activity

Discuss the rules used to determine the electron configurations of the elements and introduce electron configuration notations.

Prerequisites

Students may need to review the following:

- 1.) The fundamental particles of matter: protons, neutrons and electrons.
- 2.) The mass of electrons, protons and neutrons.
- 3.) The structure of the atom which consists of a positive nucleus surrounded by negatively charged electrons.
- 4.) The periodic table.
- 5.) The atomic numbers of certain elements.
- 6.) The force between two charges proportional to the magnitudes of the charges and inversely proportional to the distance between them squared.

Learner Objectives

Section One - Development of a New Atomic Model and the Rutherford Gold Foil Activity

- 1.) Explain how Rutherford's experiment worked.
- 2.) Describe the significance of Rutherford's experiment on the scattering of alpha particles in the experimental determination for the nuclear nature of the atom.
- 3.) Describe the experimental setup used by Rutherford to probe the structure of the atom.
- 4.) Explain how the results of Rutherford's experiment challenged the Thomson model of the atom.
- 5.) Explain how Rutherford's model of the atom fits the data of Rutherford's experiment.
- 6.) Explain how the results of this experiment provided evidence for the nuclear model of an atom.
- 7.) Explain how an estimate for the nuclear radius can be obtained from Rutherford's Experiment.

Section Two - Quantum Model of the Atom and Schrödinger's Electron Probability Activity

- 1.) Discuss Louis de Broglie's role in the development of the quantum model of the atom.
- 2.) Explain the similarities and differences of the Bohr and quantum models of the atom.
- 3.) Explain how the Heisenberg uncertainty principle and the Schrodinger wave equation led to the idea of atomic orbitals.
- 4.) Explain the four quantum numbers and describe their significance.
- 5.) Explain the number of sublevels corresponding to an atom's main energy levels, the number of orbitals per sublevel, and the number of orbitals per main energy level.

Section Three - Electron Configurations and the Electron Battleship Activity

- 1.) Describe the total number of electrons needed to fully occupy each main energy level.
- 2.) Describe the Aufbau principle, the Pauli Exclusion Principle, and Hund's Rule.
- 3.) Describe the electron configurations for the atoms of an element using orbital notation, electron configuration notation, and, when appropriate, noble gas notation.

Science Content Standards

Alignment with Minnesota State Science Content Standards

MN State Science Content Standard	Fulfillment of Science Content Standard
Pure substances can be identified by properties which are independent of the sample of the substance and the properties can be explained by a model of matter that is composed of small particles.	1. Explain how the Schrodinger wave equation led to the idea of atomic orbitals.
Describe properties of waves, including speed, wavelength, frequency and amplitude.	1. Explain how the Schrodinger wave equation led to the idea of atomic orbitals. 2. Explain the mathematical relationship among speed, wavelength, and frequency of electromagnetic radiation.
The structure of the atom determines chemical properties of elements. Describe the relative charges, masses, and locations of the protons, neutrons, and electrons in an atom of an element.	1. List the total number of electrons needed to fully occupy each main energy level. 2. Describe the electron configurations for the atoms of any element using orbital notation, electron configuration notation, and, when appropriate, noble gas notation.
The periodic table illustrates how patterns in the physical and chemical properties of elements are related to atomic structure. Explain the relationship of an element's position on the periodic table to its atomic number and electron configuration.	1. List the total number of electrons needed to fully occupy each main energy level. 2. Describe the electron configurations for the atoms of any element using orbital notation, electron configuration notation, and, when appropriate, noble gas notation.

Section One - The Development of a New Atomic Model and the Rutherford Gold Foil Activity

Description of the Rutherford Gold Foil Activity

Lecture and Lecture Strategy on Quantum Mechanics

Visualizing Rutherford's Model – Explain to students that the size of the nucleus and the number of deflected alpha particles has been exaggerated for emphasis. In reality, the nucleus occupies much less space in an atom than indicated in my notes. In Rutherford's experiment, almost all of the alpha particles passed undisturbed through the atoms composing the foil. If an atom were the size of a large football stadium, the nucleus would be about the size of a marble. This model suggests that the atom is mostly empty space.¹

Lecture – Show students two different shapes made from identical pieces of a toy construction set. Demonstrate how even though the two shapes look different, the characteristics of the various parts that compose them are the same. The same is true with the atom. Though atoms of different elements display different properties, isolated subatomic particles have the same properties, regardless of their source. As technology improved, scientists learned to isolate the parts of the atoms that display similar properties. For example, the cathode-ray tube led to the isolation of subatomic particles, electrons.

Description of Student Activities

Purpose – In this lab activity students will attempt to simulate Ernest Rutherford's famous gold foil experiment where he discovered that the atom is composed of a small positively charged nucleus surrounded by empty space. Students will determine the shape of polygonal objects (see Figure 1) utilizing a ball bearing rolling down a ruler. By rolling a ball bearing down a ruler a student will find that the vast majority of times the ball bearing will pass straight past the object hidden under the platform.

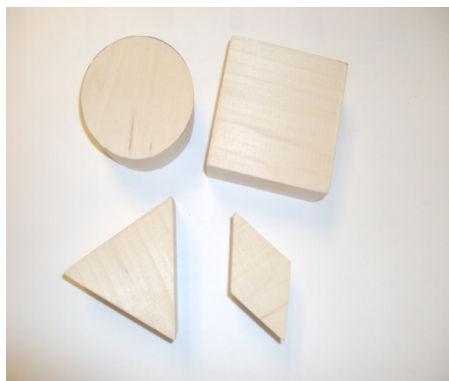


Figure 1 - Polygonal Shaped Objects
Polygonal shaped objects which simulate the nucleus of the atom.

¹ Brown, Theodore, Chemistry the Central Science pp. 41-42.

Background – In 1911, Ernest Rutherford performed an experiment to test J. J. Thomson’s plum pudding atomic model. J. J. Thomson considered that the structure of an atom is something like plum pudding. He postulated that the basic body of the atom is a spherical object containing electrons confined in homogeneous jellylike material which is positively charged with the two charges canceling each other out.

He fired energetic alpha particles at a foil a few atoms thick, and measured the deflection of the particles as they came out the other side. From this he could deduce information about the structure of the foil.² To understand how this works, imagine shooting a rifle at a mound of loose snow: one expects some bullets to emerge from the opposite side with a slight deflection and a bit of energy loss depending on how regularly the pile is packed. One can deduce something about the internal structure of the mound if we know the difference between the initial (before it hits the pile) and final (after it emerges from the pile) trajectories of the bullet. If the mound were made of loose, powdery snow, the bullets would be deflected very little; if the bullets were deflected wildly, we might guess that there was a brick of hard material inside.

Rutherford expected all of the particles to be deflected just a bit as they passed through the plum pudding. He found that most of the alpha particles he shot at the foil were not deflected at all. They passed through the foil and emerged undisturbed. Occasionally, however, particles were scattered at huge angles (Figure 2). While most of the alpha particles were undisturbed, a few of them bounced back directly.³ Imagine if something like this happened at our mound of snow. We shoot bullets at the pile for days, and every round passes straight through unperturbed, then a bullet hits the snow, reflects back, and splinters the gun’s stock! Rutherford’s results led him to believe that most of the foil was made of empty space, but had extremely small, dense lumps of matter inside. No other model accounted for the occasional wide angle scattering of the alpha particles. With this experiment, Rutherford discovered the atomic nucleus.

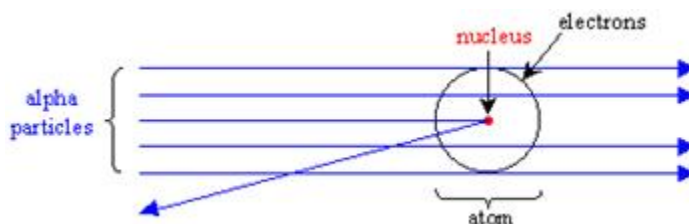


Figure 2 - Alpha Particle Deflected;

Most of the alpha particles pass through the gold foil undisturbed, a few bounce back directly.

Materials –

Channeled plastic ruler, ball bearing, various shaped objects

² Laird, Brian B. University Chemistry, pp. 14-15.

³ Davis.

Instructions –

1. Set up your channeled ruler as shown in Figure 3.

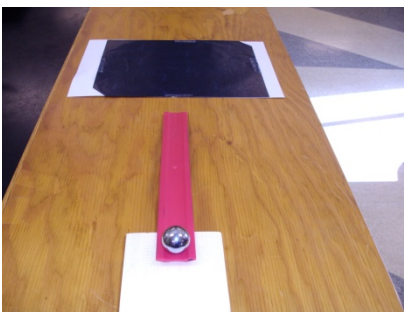


Figure 3

Ball Bearing and Channeled Ruler.

The ball bearing represents an alpha particle while the carbon paper traces the trajectory.

2. This will serve as a ramp for your ball bearing to travel down.
3. Tape a plain piece of white paper to the platform on top of which you will tape a sheet of carbon paper as shown in Figure 3.
4. Pick one the irregular shaped object which is fastened to a board and place it on top of the carbon paper as pictured in Figure 4. Remember not to look at the irregularly shaped object.

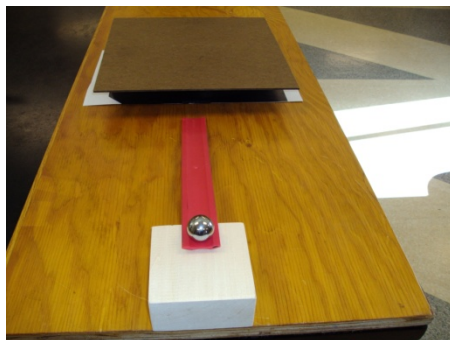


Figure 4

Ball Bearing, Channeled Ruler and Hidden Irregular Shaped Object.

An irregularly shaped object is fastened under the board placed on top of a piece of carbon paper.

5. The carbon paper will pick up the path of the ball bearing as it travels towards the irregularly shaped object and imprint the path of the ball bearing upon the plain white paper. This will allow you to view the trajectory of the ball bearing as it travels down the ramp towards the irregularly shaped object.
6. By having an imprint of the trajectory of the ball bearing, you will then be able to hypothesize what the shape of the irregularly shaped object is that is hidden under the board.
7. The carbon imprint is somewhat similar to the deflection of the alpha particles which Rutherford observed.

8. Try pointing the ruler towards the middle of where the unknown object is located and roll the ball bearing three times perpendicular to the board with the irregular shaped object hidden beneath. .
9. Once you have rolled the ball bearing three times towards the irregularly shaped object you are then to move the ruler to the right one centimeter and repeat the process of rolling the ball bearing perpendicular to the board.
10. This process should continue until you have moved the ruler ten centimeters to the right.
11. Once you have moved the ruler ten centimeters to the right then move the ruler back to the center position completing the same process over only moving the ruler one centimeter at a time to the left until you have reached the ten centimeter mark to the left of the irregularly shaped object.
12. Once you have completed your trials with the first object try steps three through eleven for the second object.
13. Do not look at the object under the board until after you have finished sketching your irregularly shaped object.
14. Once you are finished sketching both irregularly shaped objects you may then make comparisons of your initial drawings to the actual shape of the object.

Observations -

<u>Irregularly Shaped Object Sketch</u>	<u>Actual Object</u>

Questions –

How well does this lab relate to Rutherford's discovery of the nucleus?

How close were you to determining the shape?

Explain how Rutherford's experiment worked.

How did the results of Rutherford's experiment challenge the Thomson model of the atom?

Section Two - Quantum Model of the Atom and Schrödinger's Electron Probability

Quantum Mechanics is the application of quantum mechanical principles and equations to the study of molecules. In order to understand matter at its most fundamental level, we must use quantum mechanical models and methods. There are two aspects of quantum mechanics that make it different from previous models of matter. The first is the concept of wave-particle duality, that is, the notion that we need to think of very small objects (such as electrons) as having characteristics of both particles and waves. Second, quantum mechanical models correctly predict that the energy of atoms and molecules is always quantized, meaning that they may have only specific amounts of energy. Quantum chemical theories allow us to explain the structure of the periodic table, and quantum chemical calculations allow us to accurately predict the structures of molecules and the spectroscopic behavior of atoms and molecules.⁴

Lecture and Lecture Strategy on Quantum Mechanics

Write down some fake student addresses. Use the format of street name, house/apartment number, and Zip Code. These items describe the location of their residence. How many students live on the same street? How many have the same house number? Create a unique address for each student. In the same way that no two houses have the same address, no two electrons in an atom have the same set of four quantum numbers. In this section, students will learn how to use the quantum-number code to describe the properties of electrons in atoms.

Emphasize that the values of l and the letters s, p, d, and f are synonymous for the names of differently shaped orbitals. Be sure students are aware of the general orbital shapes.

An orbital is a single allowed location for atomic electrons. It is described by specific values of n , m , and l , and it is capable of holding, at most, two electrons of opposite spin states, according to the Pauli Exclusion Principle. A sublevel includes all the similarly shaped orbitals in a particular main energy level. For a given value of n , a sublevel consists of all orbitals with the same value of l .

The number of different possible values for the magnetic quantum number, m determines the number of orbitals in a particular sublevel. For example, when $l = 1$, m can equal -1, 0, +1. These three possible values for m indicate that there are three different orbitals (each oriented differently around the nucleus) in the sublevel corresponding to $l = 1$. These three orbitals are known as p orbitals. More specifically they are p_x , p_y , p_z orbitals.

⁴ “What is Quantum Physics?” <http://library.thinkquest.org/3487/qp.html> .

Schrödinger's Electron Probability Activity

Description of Student Activities

Purpose – In this lab activity, you will use marbles, carbon paper and a target to investigate the three-dimensional distribution of the electron in the ground state orbital of hydrogen. This two-dimensional model will help you better understand the three-dimensional distribution of the electron in the ground state orbital of hydrogen. As students you will enter your data for this lab activity into your lab notebook using the lab notebook guidelines covered in class.

Background – In 1926, Austrian physicist Erwin Schrödinger developed an equation that treated electrons in atoms as waves. The Schrödinger wave equation laid the foundation for modern quantum theory. Quantum theory describes mathematically the wave properties of electrons and other very small particles. Electrons do not travel around the nucleus in neat orbits, as Bohr had postulated. They exist in regions called orbitals. An orbital is a three-dimensional region around the nucleus that indicates the probable location of an electron. In Figure 5, you can see a nice graph which depicts the electron probability verses the distance an electron might be found in relevance to the nucleus of an atom. An orbital (“electron cloud”) is a region in space where there is 90% probability of finding an electron. One can see in Figure 6, what this 90% probability would look like. Erwin Schrodinger described electrons as a probability cloud. The Schrodinger wave equation laid the foundation for modern quantum theory.⁵

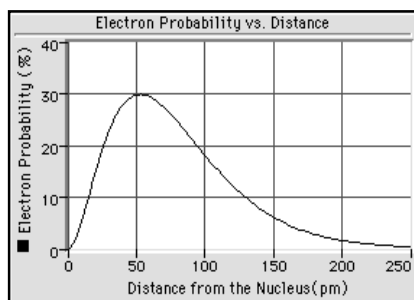


Figure 5
Electron Probability vs. Distance
Depiction of the probability of finding an S-orbital electron.

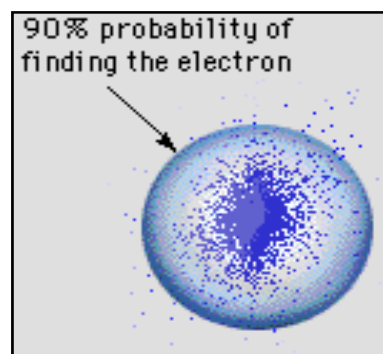


Figure 6
Electron Probability Diagram
Diagram depicting S-orbital electron density

⁵ Laird, Brian B. University Chemistry, pp. 98-106.

Materials – 5 marbles, carbon sheet, graduated cylinder, funnel and target.

Procedure

1. Place your target on the floor with a sheet of carbon paper taped to the top of the target making sure the carbon paper is facing towards the target. Make sure that the target is flat and the carbon paper is smoothly placed over the top of the target.
2. Drop your marbles from a height of approximately 100 cm above the carbon paper so that the marble imprints a mark from the carbon onto the target. Make sure that you aim for the center of the target repeating this one hundred times. Make sure that you do not throw the marbles but let them fall freely from your hand aiming for the center of the target.
3. Next to the target have a second student catch the marble after it hits the target so that the marble does not strike the target a second time.
4. Once you are throughd, count the number of marks in each of the numbered regions of the target and record these numbers in the data table. It is best to circle the marks with a pencil so as to avoid counting a mark twice.
5. If a carbon mark from a marble is completely within an area, it belongs to that area.
6. If the carbon mark is on a line, it belongs to the area that the greater portion of its mark occupies.
7. If the mark is on a line, and seems to be equally in two areas, it belongs to the area nearest the center.
8. Any part of a carbon mark counts as a complete mark.

Data –

<u>Region</u>	<u>Number of Marks</u>
1	
2	
3	
4	
5	
6	

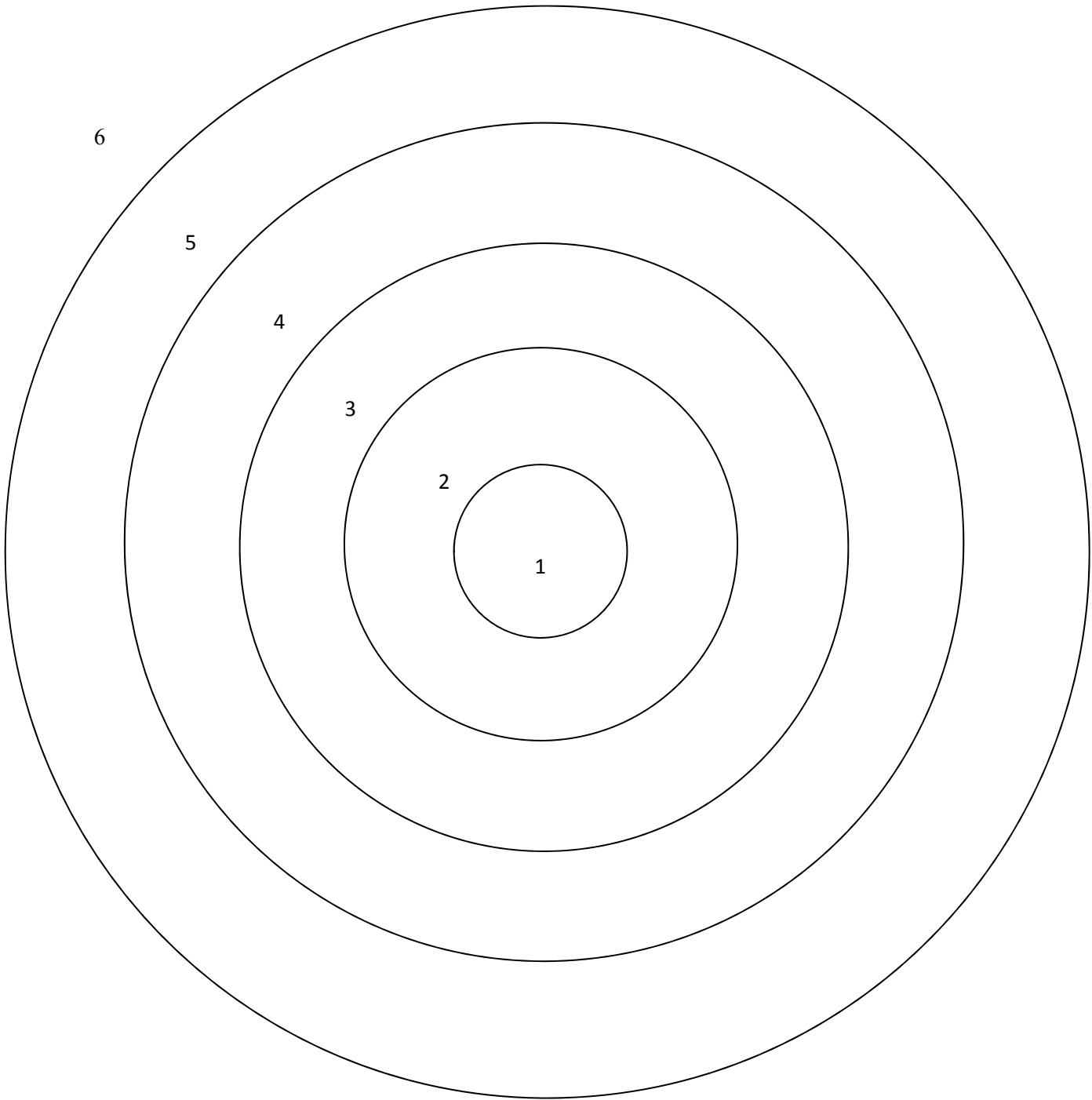
Analysis –

Graph the number of markings on the y-axis and the region each of the marks were located on the x-axis.

Once you have finished the graph draw a curve which shows your data points. Place this graph in the analysis section of your lab report.

Laboratory questions –

1. Explain the difference between Schrödinger's orbitals and Bohr's electron orbits.
2. Draw the shapes of the s and p orbitals:
3. Does the probability of finding an electron change as you move away from the nucleus of the atom?
4. How does the distribution of dots compare from region to region?
5. How does your target area compare to the electron cloud of a 1s orbital which was shown on your handout during our lecture session?
6. Do 90% of the marks fall close to the nucleus of the atom and how does this compare to Schrödinger's results?



Section Three - Electron Configurations and the Electron Battleship Activity

Lecture and Lecture Strategy on Quantum Mechanics

Introduction to Lesson – Write an electron configuration such as that of carbon, $1s^22s^22p^2$ – on the board. Explain that an electron configuration describes the arrangement of an atom. For example, in carbon's electron configuration, the integers indicate the main energy level (or principal quantum number, n) of each orbital occupied by electrons. The letters indicate the shape (or angular momentum quantum number, l) of the occupied orbitals. The superscripts identify the number of electrons in each sublevel.

When Erwin Schrodinger used quantum numbers to describe the location of electrons, he allowed scientists to accept the uncertainty of the exact location of electrons. Electron configurations summarize the locations of electrons in clouds, or orbitals, around the nuclei of the atom.⁶

Description of Student Activities

Chemistry Concepts

Electron configuration – both standard and noble gas configurations

Materials

Two laminated periodic tables per player

One coin

Red marker

Blue marker

Game board divider

Purpose

The electron configuration of an atom is the representation of the arrangement of electrons that are distributed among the orbital shells and sub shells. Commonly, the electron configuration is used to describe the orbitals of an atom in its ground state, but it can also be used to represent an atom that has ionized into a cation or anion by compensating with the loss of or gain of electrons in their subsequent orbitals.⁷ This lab activity will allow a student to learn different electron configurations of atoms in their ground state using the noble gas and standard electron configuration notations.

⁶ Davis, Raymond E. Modern Chemistry. p. 111-113.

⁷ Davis, Raymond E. Modern Chemistry. p. 111-113.

Rules

1. You along with another student will be playing the game Electron Battleship. The goal of the game is to place your ships on the periodic table hidden from your opponent's view keeping them from being destroyed.
2. Each player has two laminated periodic tables, one is for keeping track of your ships and the other is for tracking your opponent's ships.
3. You will need to "hide" your four ships on the periodic table by highlighting them with a marker. The ship sizes are:

One ship is two spaces - Cruiser
One ship is three spaces - Destroyer
One ship is four spaces - Battleship
One ship is five spaces – Aircraft carrier

4. The ships may be placed on the periodic table horizontally (along a period) or vertically (along a family) and should occupy the specified number of boxes therefore negating the use of partial boxes. Furthermore, you may not place your ship diagonally
5. Make sure you use a barrier to keep your periodic table hidden from your opponent.
6. The first player flips a penny; if the penny is tails then the first player gives the electron configuration in noble gas notation. If the penny is heads then the first player gives the electron configuration in standard notation. This allows practice for both methods of naming the electron configuration of an atom.
7. Once the type of electron configuration is determined by the coin flip, the first player then "fires" at their opponent's ships by naming the respective electron configuration.
8. Player two then confirms whether the shot was a "hit" or a "miss" by confirming the element.
9. Both students need to make sure they are in agreement, with the second player confirming the targeted element by stating its name.
10. If both players are in agreement, the electron configuration is most likely correct.
11. Each shot is recorded on both individual players' periodic tables with a blue marker for a miss and a red marker for a hit.
12. The second player then trades roles and fires at their opponent's ships.
13. A ship is declared to be "sunk" when each of the spots on the ship have been hit.
14. The player who sinks all of his opponent's ships first is declared to be the winner.

Positive and Negative Outcomes

Rutherford Gold Foil Experiment

There were nineteen students who completed the Rutherford Gold Foil Experiment with the possibility of earning up to twenty five points once they completed the lab write-up according to the directions which are outlined in this paper. Students who completed the Rutherford Gold Foil Experiment are enrolled in advanced college chemistry which is a part of the college in the schools program through the Minnesota State college system at KMS HS.

The positive result from this activity was that many of my students could better visualize Rutherford's Model of the atom as a result of performing this lab activity. Students came to the understanding by performing this lab that the size of the nucleus in relation to the rest of the atom is much smaller by comparison. This was demonstrated when students found that most of the ball bearings passed undisturbed past the unknown object just like the alpha particles of Rutherford's experiment passed through the gold foil of the atom undetected. Some of the ball bearings were deflected by the unknown object just as some of the alpha particles in Rutherford's gold foil experiment were deflected by the positively charged nucleus of the atom. As the ball bearings were deflected students were able to determine the shape of the unidentified object. This was very similar to Rutherford's discovery of the nucleus of the atom. My students then concluded in their laboratory reports that a small portion of the atom must be composed of a small positively charged nucleus.

Students were helped in their understanding of the composition of the atom by a detailed analogy in their laboratory notes which stated that if an atom were the size of a large football stadium, the nucleus would be about the size of a marble. This model further instilled in my students' minds Rutherford's concept of the atom. Once the lab activity was completed, all of my students scored a ninety percent or higher with respect to their lab write up based upon the scoring rubric in this paper. Their scores on the Atomic Model quiz (see Appendix A) were an average of ninety one percent.

The quiz covered concepts in the lecture portion of the course which students earlier applied in the Rutherford Gold Foil Experiment. For example, the quiz question "In Rutherford's experiments, alpha particles were used to bombard thin metal foil" was covered in the lecture portion of the course and later applied in the experiment. Application was made by students rolling a ball bearing down a ramp and then striking the unknown object. The ball bearing represented the alpha particles while the unknown object represented the atomic nucleus of a gold atom within the metal foil. Another example of a quiz question which was covered in the lecture and later applied in the experiment was the question "Because most particles fired at metal foil passed straight through, Rutherford concluded that atoms were mostly empty space." The conceptual aspect of this quiz question was covered in the lecture portion of the course while the practical application was made by rolling the ball bearing down a ramp towards an unknown object. Many of the attempts at rolling the ball bearing towards the unknown object resulted in the ball bearing missing the unknown object entirely. As a result, students visually experienced Rutherford's Gold Foil Experiment.

A negative result from this lab activity was that some students had difficulty with being accurate in their tracings of how the ball bearing rolled towards the hidden object. In the future I would have students use a heavier sheet of carbon paper which would be taped to a piece of plain white paper. As the ball bearing would roll over the heavier sheet of carbon paper it would then imprint a better tracing of the trajectory of the ball bearing as it traveled towards the irregularly shaped object. This would then eliminate the possible errors which would most certainly occur if one were to try to obtain a similar tracing with a lighter sheet of carbon paper. By having a darker carbon imprint one could better hypothesize what the shape of the irregularly shaped object is.

Schrödinger's Electron Probability Lab

Just like the Rutherford Gold Foil Experiment there were nineteen students who completed the Schrödinger's Electron Probability Lab. Students could earn up to twenty five points once they completed the lab write up according to the directions which are outlined in this paper.

The positive result from this activity was that many of my students could better visualize quantum mechanics principles as a result of performing this lab activity. At the start of this unit I wrote down some fake student addresses using the format of street name, house/apartment number, and Zip Code. These items were used to describe the location of their residence. Just as no two houses have the same address so no two electrons in an atom have the same set of four quantum numbers. Students were able to take this information and apply it to their understanding of how to use the quantum-number code to describe the properties of electrons in atoms.

Students used marbles and a target to investigate the probability distribution of carbon markings about a central point. By doing this students created a two-dimensional model which helped them to better understand the three-dimensional distribution of an electron in the ground state s-orbital of the hydrogen atom. The carbon marks helped the students visualize the probable location of an electron otherwise known as an Orbital which Schrödinger hypothesized as a region in space where there is 90% probability of finding an electron.

Once students collected their data they were able to take their data and graph the number of markings on the y-axis and the region where each of the marks were located on the x-axis. Once they finished the graph they then drew a curve which showed their data points. The graph represented an s-orbital in a two dimensional region around the nucleus of an atom and indicated the probable location of an s-orbital electron. It was nice to see that students' graphs represented the shape of an s-orbital of an atom. This graph was then placed in the analysis section of each student's lab report and later graded according to their ability to follow the scientific method.

All of the students who participated in the lab activity scored a ninety four percent or higher on their lab report (see Table 2-1). The score on the quiz for this activity was an eighty nine percent average with the quiz showing student mastery with respect to the four principal quantum numbers. The Quantum Mechanics quiz (see Appendix B) covered concepts in the lecture portion of the course which students later applied in the Schrödinger's Electron Probability Lab.

For example, the quiz question “If $n=3$, $l=2$, $m_l=0$ and $m_s=+1/2$, what element is being referred to” was a concept which was discussed during the course lecture. Students were able to apply this concept to the experimental aspect of the course. Students made application by using the four principal quantum numbers to identify the location of an unknown ship on the periodic table of elements. A second example of a quiz question which was covered in the lecture and later applied in the experiment was “For the f sublevel, the number of orbitals is?” I covered the conceptual aspect of this quiz question during the lecture portion of the course. Students later took this new found knowledge and made practical application by trying to determine the arrangement of electrons that are distributed among the orbital shells and sub shells. They then used this knowledge to locate an unknown ship which was placed on the periodic table of elements. All four of the principal quantum numbers which were discussed-in the classroom lecture were later tested in this lab activity. Many students commented that they had a greater understanding of these concepts over and above that from the lecture component.

A negative outcome from this lab activity was the target did not have a zero mark on the target sheet. By having the zero mark the target would better simulate the nucleus of the atom therefore giving the students a more complete picture that the nucleus of the atom does not contain electrons. The graphs of my students would look even better with this zero mark added as it would more completely reflect the s-orbital of an atom. A zero mark could be added by simply having the students cut out a two millimeter hole in the carbon paper that they would overlay on the target. By cutting out the carbon paper just above the center of the target no carbon marks would be created over the central region of the target. This would then simulate the nucleus of the atom showing that there are no electrons in the nuclear area of the atom.

Another negative aspect of this lab activity is that it fails to instill the concept of wave-particle duality, which is the notion that we need to think of electrons as having characteristics of both particles and waves. This concept could be further emphasized in the lecture component of the course and how it relates to the Schrödinger’s Electron Probability Lab activity.

Electron Battleship

For the Electron Battleship lab there were nineteen participants who completed this lab activity. Students had the opportunity to earn up to twenty points towards their grade once they completed this lab activity.

The positive result from this activity was that many of my students had a better understanding of how to write out an electron configuration. They also learned that electron configurations summarize the locations of electrons in clouds, or orbitals, around the nuclei of the atom. As they performed the lab activity students were able to practice different electron configurations of atoms in their ground state using the noble gas and standard electron configuration notations. Students also became more familiar as to where the s, p, d, and f energy levels are located on the periodic table as they placed their ships on the periodic table and tried to locate their opponents’ ships. By keeping track of their ships and their opponents on the periodic table they learned the names as well as the locations of different elements of the periodic tables.

In an effort to determine what type of electron configuration they would use students flipped coins. By giving out either standard or noble gas electron configuration notations student understanding was

increased. When player number one gave out the standard or noble gas electron configuration player two then confirmed whether the shot was a “hit” or a “miss” by confirming the element. This method allowed for both players to practice both methods of naming the electron configuration of an atom. In an effort to confirm as to whether or not the electron configuration was correct both players had to be in agreement that the electron configuration that was called out by player one was correct.

All of the students who participated in this activity passed the assignment with a score of ninety percent or better on the lab report. The quiz scores were even higher with all of the students scoring a ninety two percent or higher on the Quantum Mechanics quiz. Recently, I received a note from a former student who shared that this lab activity helped her during her freshman chemistry course at North Dakota State University.

One of the negative aspects of this lab activity was it took a couple of days to complete the lab activity. This could be circumvented by giving students more practice time in class with noble gas and standard electron configurations. Practice time could include things such as more homework problems covering this topic as well as additional review time in class with students covering these concepts. With additional practice time students would be able to complete this lab activity in one day rather than two.

MSE Coursework

The following coursework was instrumental in developing the three unique activities:

PHYS – 704 Modern Physics

TED – 750 Advanced Educational Psychology for Teachers and Administrators

TED – 760 Methods of Research

CHEM – 9000 (transfer credit from Hamline University)

PHYS – 704 Modern Physics

The course I completed in Modern Physics with Professor Curt Larson helped me in my understanding of the properties of the development of the atomic model of the atom. As this course progressed I came to learn the significance of Rutherford’s experiment on the scattering of alpha particles in the experimental determination for the nuclear nature of the atom. This then led me to be able to explain how the results of Rutherford's experiment challenge the Thomson model of the atom and how these experimental results provided evidence for the nuclear model of an atom.¹⁰ As a result of this information I was able to formulate the Rutherford Gold Foil experiment where students attempted to determine the shape of unidentified objects by using a ball bearing which rolled down a ruler. In this lab activity the ball bearing took the place of the alpha particles in Rutherford’s experiment. The object which was hidden under the platform took the place of the nucleus of the atom.

The concepts I learned in Modern Physics helped me to understand that the nucleus of the atom is very dense with positively charged particle(s) which deflected the alpha particles Rutherford shot towards the nucleus. Just as the alpha particles passed through the gold foil so did the ball bearing pass by the hidden object under the platform.

In addition to learning about Rutherford's experiment, I also learned about the quantum model of the atom. During this unit Prof. Larson spent time describing the location of electrons around the nucleus from a wave mechanical, or quantum perspective using quantum numbers. He listed as well as explained the four quantum numbers and described their significance. He then went on to explain the various sublevels, the atom's main energy levels, the number of orbitals per sublevel, and the number of orbitals per main energy level. He even went so far as to derive in class the highly complicated Schrödinger Wave equation which laid the foundation for modern quantum theory.

I was able to use this information on the quantum model of the atom to put together the Quantum Model activity. I then used this information to explain to my students what Quantum theory is and how electrons exist in regions called orbitals. I then showed them through various Power Point slides how electron orbitals are three-dimensional regions around the nucleus which indicate the probable location of finding an electron. I shared with them that an orbital ("electron cloud") is a region in space where there is 90% probability of finding an electron. With this being explained to them during the lecture component of my college chemistry course, my students then took this new found information and applied it to the Quantum Model activity.

TED – 750 Advanced Educational Psychology for Teachers and Administrators

There are two theoretical foundations of learning which I explored in Advanced Educational Psychology for Teachers and Administrators which I have tried to emphasize in the three learning activities which I developed for this paper; they are inquiry learning and constructivist learning. Constructivist theory of learning is the learning process which is an active process in which learners construct new ideas or concepts based upon their current and past knowledge. I implemented this type of learning in the Rutherford Gold Foil Experiment by having my science students transform information, construct hypotheses, and make decisions which relies on a cognitive structure. The Rutherford Gold Foil Experiment allowed for cognitive structure which helped to provide meaning and organization to their lab experience and allowed the student to go above and beyond the information which they were given in the lab activity.

For example, in their attempt to simulate Ernest Rutherford's famous gold foil experiment students tried to determine the shape of an unknown object using a ball bearing which rolled down a ruler. In rolling the ball bearing down the ruler students were able to take the information they learned in the lecture portion of the course and make a hypothesis about the shape of the unknown object. Students found out through the experimental process that the vast majority of times the ball bearing passed right on by the hidden object which lied under the platform. By going through the process of trial and error students were able to utilize a constructivist approach to learning where they constructed new ideas about their understanding in of the atom based upon their current and past knowledge. Prior to the start of the lab activity students constructed a hypothesis about what they thought the unknown object would look like. They then went through the process of the scientific method to collect data and transformed this information into a conclusion about what the shape of the object was and how it related to Rutherford's Gold Foil Experiment. The Rutherford Gold Foil Experiment allowed students to go through the experimental process which went beyond the information they were given in the lab activity. As a result, students obtained a greater understanding of Rutherford's Gold Foil Experiment and his conclusions about the structure of the atom.

The second type of theoretical foundation of learning that I implemented in my three learning activities is that of Inquiry Based Learning.⁸ Inquiry Based Learning helped me to model new sets of concepts which allowed me to engage my students by asking and answering questions on the basis of the information that they collected.

Once my students collected their data they then had some new ideas and concepts about quantum theory and how it describes mathematically the wave properties of electrons. They were able to conclude through the process of inquiry learning that electrons do not travel around the nucleus in neat orbits, as Bohr had postulated. As they questioned their results they came to learn that electrons exist in regions called orbitals. Their data reflected an s-orbital which is a region around the nucleus which indicates the probable location of an electron. As they performed their lab, they found that 90% of their carbon markings landed close to the nucleus of the atom. Students then entered their data for this lab activity into their lab notebook using the lab notebook guidelines covered in class (see Appendix C). This was done in a cooperative group setting⁹ where the students discussed their new found ideas with each other, and ask others about their own experiences and investigations.

During the Schrödinger's Electron Probability Lab students collected information where they used marbles, carbon paper and a target to investigate the three-dimensional distribution of the electron in the ground state orbital of hydrogen. This lab activity fostered cooperative learning where the student discussed their ideas, experiences and investigations with each other in their own lab groups as well as other lab groups throughout the classroom.

TED 760 Methods of Research

While participating in Physics 760, I have had time to reflect upon how the content of Methods of Research has helped me to prepare these three lab activities. Firstly, I was able to enhance my understanding of the concept of research variables and their relationship to educational research. There were two types of variables that I studied in my Methods of Research course; they were the independent and dependent variables. An independent variable is the characteristic of an experiment that is manipulated or changed while the dependent variable is the variable that is being measured in an experiment. For example, in the Schrödinger's Electron Probability Lab activity, the height at which the marbles were dropped was the independent variable while the number of carbon markings on the target is the dependent variable.

⁸Baxter, Juliet. Inquiry Takes Time. Science & Children; Sep2012, Vol. 50 Issue 1, p42-47, 6p. By knowing what independent and dependent variables are students were able to understand more how the region in which an electron exists is dependent upon its relation to how close it is to the nucleus of the atom. Schrödinger hypothesized that electrons do not travel around the nucleus in neat orbits, as Bohr had postulated.⁹ They exist in three-dimensional regions called orbitals which are sometimes called probability clouds. An orbital is a region in space where there is 90% probability of finding an electron.¹⁰

Studying Analysis of Research has helped me to better understand the different types of experimental design. During the Rutherford Gold foil Experiment the experimental design method that I utilized from my studies in Analysis of Research was that of the scientific experimental method.¹¹ The scientific method is a combination of inductive and deductive reasoning, where Induction is taking information from our senses and producing general statements about our world. For example, in the Schrödinger Electron Probability Experiment students were able to use inductive methods in their observation that the marbles consistently landed towards the center of the target area. Deductive reasoning is taking a general principle about the world and deducing what will or should happen in particular instances. Thus students worked from the principle that electrons go to the lowest energy level, they then deduced that most of the carbon markings which reflected the probability of finding one electron in the s-orbital would be found close to the nucleus of the hydrogen atom.

In utilizing an inquiry approach to learning I found that students were highly motivated in taking control of their own learning. One of the most important things for educators to do in order to get their students self motivated about their own learning is that there has to be an interest for the students in regards to the subject matter. If the students are not interested in what they are learning in the classroom they will have very little interest in learning the material on their own. In order for a teacher to get the students motivated there has to be an environment where the students can take charge of their own learning, something which is done by engaging the students in inquiry and constructivist-based learning.

1. Observation:

Students observed during the Rutherford Gold Foil Experiment that the ball bearings were deflected by some unknown object which was hidden under a platform.

2. Repetition:

Students found during the Rutherford Gold Foil Experiment that a single observation had very little value, so more observations were necessary. As a result they rolled the ball bearing multiple times towards the hidden object in an effort to confirm or refute the initial observation in #1.

3. Induction:

After arranging and considering their observations during the Rutherford Gold Foil Experiment, they created a general principle to describe what happened and, more importantly, explained why it happened. This principle, they learned is a hypothesis, which they framed as broadly as possible.

4. Deduction:

In an effort to prove whether their hypothesis was correct or not, they created deductions phrased as predications in the form of an "if principle ____ is true, then ____ should happen. "

⁹ Davis, Raymond E. Modern Chemistry. p. 104-106.

¹⁰ O. Patrick, Ajaja Electronic Journal of Science Education pp.2-4.

¹¹ Prado, Richard The Inquiry Flame. Science Teacher. Pp.1-3

5. Testing:

Once students made their predictions about the shape of the object in the Rutherford Gold Foil Experiment, they then collected more observations by testing them. They tried to determine if the shape of the object was according to their prediction.

6. Induction:

After students produced more observations, they then determined whether or not their hypothesis was correct. If their prediction was incorrect they then provided reasons as to why this was so.

In summary, after completing the Analysis of Research course I can now reflect upon how the content of this course helped me in my design of the three lab activities. During the course of this study I have had the opportunity to learn how to more objectively design lab activities. I was also able to enhance my understanding of the many different types of research variables and their relationship to formulating lab activities. Lastly, studying Analysis of Research has helped me to better understand the many different types of experimental design which are a part of teaching science.

Chemistry 9000

Participating in chemistry 9000 at Hamline University helped me in my understanding of electron configurations, orbital notation, and noble gas notation. Electron configurations summarize the locations of electrons in clouds, or orbitals, around the nuclei of the atom. For example, in Boron's electron configuration, the integers indicate the main energy level (or principal quantum number, n) of each orbital occupied by electrons. The letters indicate the shape (or angular momentum quantum number, l) of the occupied orbitals. The superscripts identify the number of electrons in each sublevel.

Learning about electron configurations, orbital notation, and noble gas notation helped me in my design of the Electron Battleship lab activity. While participating in this course I came to a more complete understanding of how to write out an electron configuration as well as the rationale behind this concept. This in turn helped me to more intelligently explain these concepts to my college chemistry students through the design as well as implementation of the Electron Battleship lab activity.

Additionally, I learned that Schrödinger's probability calculation is used in calculating the probability of finding the electron in a specific place around the nucleus. I was able to take the knowledge which I learned about Schrödinger's probability calculation of finding an electron and use this information in the implementation of the Schrodinger Electron Probability Lab. Students were able to duplicate the shape of the electron cloud of the hydrogen atom in a similar fashion to Schrödinger's calculations.

Lastly, I gleaned additional information about Rutherford's Gold Foil Experiment. One of the most interesting things that I learned about this experiment was that 1 in 20,000 of the alpha particles were deflected approximately 90 degrees or more from the parent beam. Sometimes an occasional particle even fired right back at the experimenter. Rutherford described the awe inspiring nature of the discovery best when he said: "It was as if you fired a 15-inch shell at a sheet of tissue paper and it came back to hit you." With the information that I learned about Rutherford's Gold Foil experiment, I was able to design a lab activity which allowed my students to simulate Rutherford's experiment.

Future Changes

Rutherford Gold Foil Experiment

In the future I could do a better job in explaining to my students that the size of the nucleus and the number of deflected alpha particles has been exaggerated in order to simulate the lab activity. There is a much higher percentage of the number of times a marble hits the simulated nucleus in comparison to the number of alpha particles that were deflected in Rutherford's lab by the nucleus.

Another possible change in this lab activity would be to use a heavier carbon paper. The carbon paper did a fairly good job imprinting a tracing of the trajectory of the ball bearing as it traveled towards the irregularly shaped object. But a heavier piece of carbon paper would help to eliminate any possible errors which might occur with the lighter carbon paper. If students had a more clear carbon imprint of the trajectory of the ball bearing they could better determine the shape of the irregularly shaped object. As a result, this would help students to better visualize how the deflection of the ball bearing is similar to the deflection of the alpha particles which Rutherford observed.

The directions call for students to move the ramp to the right as well as the left ten centimeters from center. In the future I would have my students move the ramp around the irregularly shaped object in a clockwise manner so as to get a more complete trajectory of the ball bearing as its carbon imprint is placed upon the plain white paper. As a result, students would have a better picture of what the irregular shaped object looks like.

Schrödinger's Electron Probability Lab

In the future I might have my students try using a dry erasable marker rather than marbles as using the marker would require less set up time than having to tape carbon paper to the target. Using a dry eraser marker might give a better imprint on the target whereas the carbon marks left by marbles can sometimes be hard to see as well as differentiate from one another. Also, students often found that after the marble dropped onto the target the marbles would bounce to different parts of the room therefore causing students to spend extra time chasing after marbles. Perhaps this hindrance would be less exacerbated by the use of dry erase markers.

Another change would be to have students drop the marbles or dry eraser marker from a height of 50 cm rather than 100 cm above the target. By having students drop the object from lesser height students would be more apt to make markings closer to the center of the target rather than having the markings more widespread. By having the markings closer to the center of the target students might create an electron cloud which would be more like the s-orbital Schrödinger calculated.

Electron Battleship

For the Electron Battleship lab activity one thing that I would change would be to have my students guess the location of an opponent's ship by using the four principal quantum numbers. Rather than having my students flip a coin they would roll a die. When students roll a one or two they would give the electron configuration in noble gas notation. When students roll a three or four they would give the electron configuration in standard notation and when students would roll a five or six they would name the element using the four principal quantum numbers. Once the type of electron configuration or principle quantum numbers are determined by the dice roll, the first player then "fires" at their opponent's ships by naming the respective electron configuration. Play then continues as outlined in the Electron Battleship directions.

By having students add the four principle quantum numbers to this lab activity, students will be able to better understand the structure of the periodic table. Just like no two houses have the same address, no two electrons in an atom have the same set of four quantum numbers. Students will also have a more complete understanding of how to use the quantum-number code to describe the properties of electrons in atoms.

Educational Models

Madeline Hunter and Schrödinger's Electron Probability Lab

In the Schrödinger's Electron Probability Lab I started the activity with an anticipatory set which is Hunter's term for the "hook" to grab the students' attention and put students in a receptive frame of mind at the beginning of the lesson.¹² This was accomplished by writing down a fake student address on the white board. I used the format of street name, house number, and Zip Code. These items described the location of a fictitious residence. I then created a unique address for each student. In the same way that no two houses have the same address, no two electrons in an atom have the same set of four quantum numbers. During this section, students learned how to use the quantum-number code to describe the properties of electrons in atoms.

There are three main components one uses when instructing ones classroom using Madeline Hunter techniques. The first includes input which includes the teacher providing the information or content needed to the whole class. My input strategy included the use of whole group instruction with classroom lecture where I showed the students how to process and understand the information/content. This included a Power Point presentation which demonstrated the four principal quantum numbers along with electron configurations. Collaborative pairs of students then took this information and applied by performing the lab activity.¹³

¹² Hunter, Madeline Hunter Lesson Design Helps Achieve the Goals of Science Instruction p. 79.

¹³ Hunter, Madeline Hunter Lesson Design Helps Achieve the Goals of Science Instruction p. 80-81.

Secondly, there is checking for understanding which means determining whether students had "gotten it" before proceeding in the lesson and lastly, the use of questioning strategies which goes beyond mere recall. As the activity was performed I would check for student understanding by stopping individual groups of students during the lesson to answer questions and discuss their learning (distributed summarizing and practice).¹⁴

In using questioning, which is sometimes called sampling, I would allow students time to think, and then call on class members representative of the ability strata of the group.¹⁵ This process helped to focus everyone on the generation of an answer and developed student readiness to hear an affirmation or challenge of his/her answer. At the beginning of learning, correct answers are most enabling. An example of such a questioning process was accomplished by mine giving the direction for the lab activity, then giving students thinking time before naming a student to respond.

In using Hunter's questioning techniques; I asked students several sampling questions. For example, in the Rutherford Gold Foil Activity I asked students how they thought the ball bearings rolling down the ramp related to Rutherford's discovery of the nucleus. During the Schrödinger's Electron Probability Activity I asked students how their graphs correlated to the shape of an s orbital and how the distribution of dots related to the shape of an s orbital. For the Electron Battleship Activity I asked students how the electron configuration for the noble gas notation is different from the standard electron configuration notation.

In using Hunter's Guided Practice during the lab activity I gave each student an opportunity to demonstrate their understanding of the lab concepts while under direct supervision. As the students mastered their understanding of the lab activity I backed off from using Hunter's Guided Practice.¹⁶ A lesson which uses Hunter's techniques ends with Closure, where actions or statements are designed to bring the lesson to an appropriate conclusion and to help students bring things together in their own minds. This strategy involves having the students summarize and pull together important facts through by a lab report using the scientific method. The grading rubric and guidelines for writing up this lab report are included in this paper. Finally, I used Hunter's Independent Practice for reinforcement by having the students culminate their learning through a worksheet which covers the concepts they learned.¹⁷

¹⁴ Riedl, Cindy, How to Get the Most from Summarizing Strategies? Pp.1-3.

¹⁵ Harris, Robin Lee Batting 1,000: questioning techniques in student-centered classrooms. Pp.1-2.

¹⁶ Hunter, Madeline. Hunter Lesson Design Helps Achieve the Goals of Science Instruction. Pp. 79-81.

¹⁷ Stallings, Jane, A Study of Implementation of Madeline Hunter's Model and Its Effects on Students. Pp 325-327.

Assessment and Hunter's Lesson during the Electron Battleship Lab

In an effort to determine whether my students have "got it" before proceeding to the Electron Battleship lab activity, it is essential that students practice writing out electron configurations so that they know what they are doing before proceeding to the lab activity. If the class does not understand how to write electron configurations, the concept should be re-taught before the lab activity begins.

Prior to the start of the Electron Battleship lab, I had students working on problems using group work. While they worked on the problems I used questioning strategies where I asked questions that go beyond mere recall to probe for the higher levels of understanding as to ensure memory network binding and transfer. Bloom's Taxonomy of Educational Objectives provides a structure for questioning that is hierarchical and cumulative. It helps guide me as a teacher as to how to structure questions at a level of proximal development. The questions I asked my students progressed from the lowest to the highest of the six levels of the cognitive domain of Bloom's Taxonomy of Educational Objectives: knowledge, comprehension, application, analysis, synthesis, and evaluation.¹⁸

As students do not learn in the same way, they cannot be assessed in a uniform fashion. Knowing how each student learns will allow me as a teacher to properly assess my students' progress. This individualized evaluation practice will allow me to make more informed decisions on what to teach and how to present information. The most preferred assessment method for this lab activity is having my students complete a lab write-up which uses the scientific method which I have outlined in this paper (see Appendix C). Along with the outline I have included in Appendix D a grading rubric by which my students are assessed.

Cooperative Learning and the Schrödinger and Rutherford Labs

During the Schrödinger Lab and Rutherford Lab activities I utilized Cooperative Learning techniques where my students worked together in cooperative interdependence with one another. During these lab activities I used five key elements which are often associated with cooperative grouping activities. Firstly, students displayed a positive interdependence with one another when they had a mutual goal in completing the lab activities by dividing their responsibilities for completing the lab activities among themselves.¹⁹ For example, during the Schrödinger Lab activity one student performed the drop of the marble, while another caught the marble and a third recorded the data into their lab notebook. In taking on different roles each student took on a different part so as to make their grade interdependent on the performance of the rest of the group.

Secondly, students displayed individual accountability in cooperative learning by learning together, and also by performing alone. This helped to ensure that no one person is able to "hitch-hike" on the work of others. While students were interdependent upon one another in order to complete both lab activities in their collection of laboratory data, they were individually accountable in what they entered into their lab notebooks and the laboratory grade they received for their lab notebook.

¹⁸ Lord, Thomas Moving Students From Information Recitation to Information Understanding: Exploiting Bloom's Taxonomy in Creating Science Questions. Pp. 41-44.

Thirdly, students had face-to-face interaction with one another in performing these lab activities. This occurred when students promoted each other's learning in performing these cognitive activities. Students also interacted with one another by orally explaining to one another how to solve the various problems which went along with the labs which included the summary questions. Students also discussed in depth the nature of the concepts being learned and connected the present learning with previously learned knowledge.

Fourthly, students displayed interpersonal and small group social skills. In cooperative learning groups, students learned the academic subject matter presented within the lab activities and also interpersonal and small group skills. Thus, as a group they learned how to provide effective leadership, decision-making, trust-building, communication, and conflict management skills as they performed both lab activities.

Fifthly, students were able to process their data by group processing. After they completed their task of collecting data, students were given time to process their data by using the scientific method. They entered their data into their laboratory notebooks which were later graded according to the grading rubric which is included in this paper (see Appendix D).

Lastly, assessment activities in cooperative learning can be categorized as either formative or summative, both of which are appropriate for cooperative learning exercises as they provide opportunities to enhance key components of cooperative learning exercises such as positive interdependence and individual accountability which is one of the five key elements of cooperative learning. I utilized formative assessment activities where I provided feedback to my students as well as evaluated their learning progress so as to motivate my students to higher levels of learning. This was primarily accomplished by the lab notebook entries which they completed as a part of their formative assessment.²⁰

As for summative assessment, I had my students complete a summative test which covered the key concepts which are related to these two lab activities. This test helped me to judge them in their competency as well as their demonstrated improvement. One means of improving my lab write ups would be to have my students go through a revise and resubmission process which provides my students with feedback on which aspect of their lab work is in need of improvement prior to their final assessment.²¹ When students performed the three unique lab activities they were able to apply both Bruner's and Piaget's educational philosophies in learning physics by doing physics.²²

¹⁹Köse, S., Şahin, A., Ergü, A., Gezer, K., The Effects of Cooperative Learning Experience on Eighth Grade Students' Achievement and Attitude Toward Science. Pp. 169-170.

²⁰ Cornelius, Kyena E, Formative Assessment Made Easy. Pp.14, 15, 21.

²¹ Cavicchi, Elizabeth. Faraday and Piaget: Experimenting in Relation with the World. P. 68.

²² Hall, Jody S. Psychology and schooling: the impact of Susan Isaacs and Jean Piaget on 1960s science Education reform. Pp.158-161.

In Piaget's view, a schema includes both a category of knowledge and the process of obtaining that knowledge. As experiences happen, this new information is used to modify, add to, or change previously existing schemas. For example, a student might have a schema about how the electron circles the nucleus of the atom like planets circling the sun. If the student's sole experience has been an experience where the student was taught that electron circles the nucleus of the atom like planets circle the sun, that student might believe that all electrons travel around the nucleus of the atom in concentric circles. Suppose then that the student performs a lab activity such as the Schrödinger Electron Probability Lab. The student would then take in this newfound information, modifying the previously existing schema to include this new information.

As a student takes in new information into their previously existing schemas Piaget called this assimilation. Once a student assimilates new information they start to accommodate their existing schema in the light of new information. Piaget believed that students will try to strike a balance between assimilation and accommodation, which is achieved through a mechanism Piaget called equilibration. Students should try to maintain a balance between applying previous knowledge (assimilation) and changing behavior to account for new knowledge (accommodation). Equilibration helps explain how students are able to move from one stage of thought into the next.

With respect to Bruner, he viewed the purpose of education as not to impart knowledge, but to facilitate a student's critical thinking skills. Bruner implemented this idea by implementing a concept called the spiral curriculum where information is structured in such a way so as to allow more complex ideas to be instructed first at a more rudimentary level, after which these ideas are later re-taught at a more complex level.

During the quantum Mechanics unit which dealt with the Electron Battleship activity I was able to introduce the concepts of the four principal quantum numbers, standard electron configuration as well as noble gas notation using Bruner's Spiral Concepts. Each of these topics were introduced during a topical lecture after which students applied what they learned by completing problems sets with the culmination of their learning occurring with the Electron Battleship activity.

Bruner believed that the role of the teacher is not to teach information by rote learning, but instead to facilitate the learning process. During the Electron Battleship activity student learning was facilitated by the teacher as students learned about the four principal quantum numbers, standard electron configuration as well as noble gas notation. Students were able to discover the relationship between bits of information which they learned from previous experiences and organize them into concrete concepts. By using the spiral curriculum for the quantum mechanics unit students were engaged in what Bruner called discovery learning.

How has your professional development benefited from designing these activities?

My professional development has benefited from designing these three unique lab activities by helping me to implement labs which will allow my students to learn atomic physics by practicing (simulations of atomic physics) Piaget's research clearly mandates that the learning environment should be rich in physical experiences which help to stimulate intellectual development. Bruner also stressed learning by

doing. "The school boy learning physics is a physicist, and it is easier for him to learn physics behaving like a physicist than doing something else."²³

My professional development coursework in the areas of chemistry as well as modern physics have helped me in my understanding of the three-dimensional distribution of the electron in the ground state orbital of hydrogen. This in turn helped me in designing the Schrödinger's Electron Probability Lab, a two dimensional model which helped my students to better understand electron probability of the hydrogen atom. Participating in the modern physics course as well as chemistry helped me to further understand the different electron configurations of atoms in their ground state using the noble gas and standard electron configuration notations. Having a more complete knowledge of these concepts allowed me to design the Electron Battleship lab activity.

My professional development has benefitted greatly from these learning activities as I have taken on more of a constructivism approach to instruction. I have come to learn through developing these lab activities as well as the coursework which I have completed at UWRF that having students experience science is the best possible way to engage them in learning. Students in my classes now have more time to think about what they are doing as well as understand what they are learning. The three laboratory activities that I have put together in this paper appeal as a way of allowing students to learn with understanding and, at the same time, engage in a process of constructing knowledge by doing science.

Results

Section One - The Development of a New Atomic Model and the Rutherford Gold Foil Activity

Lab scores for the Rutherford Gold Foil Activity

Points	Frequency
25	3
24	5
23	4
22	4
21	3
20	0
19	0
18	0
17	0

Table 1-1

Students who completed the Rutherford gold foil activity could earn up to twenty five points once they completed the lab write up according to grading rubric which is found in the appendices section. All of the students who participated in this activity scored an eighty eight percent or higher on the lab write up. Please see table 1-1 for a list of the scores that students earned on this activity.

²³ CUREE. P. 3. <http://www.curee-paccts.com/files/publication/1224601725/Bruner.pdf>

The Rutherford gold foil activity allowed for cognitive structure which helped to provide meaning and organization to their lab experience and allowed the students to go above and beyond the information which they were given in the lab activity. In performing the lab activity students went through the process of trial and error and were able to utilize a constructivism approach to learning where they constructed new ideas about their understanding in of the atom based upon their current and past knowledge.

Prior to the start of the lab activity students constructed a hypothesis about what they thought the unknown object would look like. They then went through the process of the scientific method to collect data and transformed this information into a conclusion about what the shape of the object was and how it related to Rutherford's gold foil activity. The Rutherford gold foil activity allowed students to go through the experimental process which went beyond the information they were given in the lab activity. As a result, they obtained a greater meaning as well as understanding of the structure of the atom.

Students who picked one of the four irregularly shaped objects described in detail how the shape of the irregularly shaped object was observed by the pathway of the ball bearing as it traveled toward the irregularly shaped object. One student noted concerning the circular shaped object that while they were only able to look at the shape of the object from one direction that the actual shape of the object must be similar on all sides. Another student noted in their lab notebook that they were able to trace the outline of the irregularly shaped object as the trajectory of the ball bearing was imprinted upon the plain white paper. They went on to state that as the ball bearing reflected off of the object it was similar to what occurred when the alpha particles bounced off the nucleus of the atom during Rutherford's experiment.

Once students completed their two trials they were then able to take the plain sheets of white paper and draw the shape of the irregularly shaped object. Student drawings were surprisingly close to the actual shapes of the four objects. The lab reports which students completed often showed a detailed outline of what the one side of the object looked like. Students then took this outline and hypothesized what the other side of the object looked like. Many of their drawing reflected a solid line on one side while the other side showed forth a dotted line tracing which was the students guess at what the other side of the object looked like. Students then took this drawing/tracing and compared it to the actual shape of the object.

Many of the students compared and contrasted how the actual shape of the objects compared to their hypothesized tracings. Most noted in striking detail how the one side of the carbon tracings matched exactly that of the objects. Students did quite well in giving explanations as to why their hypothesized drawing did not exactly match that of the actual drawing. For example, one student noted that their hypothesized drawing could have been better if they were able to roll the ball bearing from many different directions.

Section Two - Quantum Model of the Atom and Schrödinger's Electron Probability Activity

Lab scores for Schrödinger's Electron Probability Activity

Points	Frequency
25	2
24	4
23	6
22	4
21	3
20	0
19	0
18	0
17	0

Table 2-1

Students who completed the Schrödinger's Electron Probability Activity earned twenty five points towards their first quarter grade. Lab write ups were graded according to grading rubric which may be found in the appendices section (see Appendix D). Students who participated in this activity scored an eighty four percent or higher on the lab write up. Please see table 2-1 for a list of scores that students earned on this activity.

As you can see from the lab grading scores all students demonstrated a mastery of the topic with two of the nineteen students earning a perfect score on the lab write-up. For the lab write up students had to have a complete data table which showed the different regions along with the carbon marks. In the analysis section students were required to graph the number of markings on the y-axis and the region each of the marks were located on the x-axis. When the graph was completed students drew a curve which showed their data points. In reviewing all of the student notebooks I observed that these data points reflected an s-orbital just like the one that Schrödinger found during his electron probability experiments.

In the laboratory question and answer section students explained what the difference was between Schrödinger's orbitals and Bohr's electron orbits. Ten of the nineteen students were able to come to a correct conclusion when they stated that Bohr's model incorrectly concluded that electrons orbit the nucleus in circular paths. While Schrodinger's model involves the idea that electrons are not actual particles with defined points when in an atom, but actually have regions of where they are most likely to be.

When it came to correctly drawing the shapes of the s and p orbitals, all students correctly drew the s-orbital as a sphere and the p-orbital in the shape of a dumbbell. All nineteen students concluded correctly that the probability of finding an electron decreases the further you move away from the nucleus of the atom. They demonstrated this understanding by correctly showing in their drawings the distribution of the carbon dots with the greatest concentration being found near the nucleus of the atom while the least amount being distributed as you go further away from the nucleus of the atom. In all of the student analysis sections I found that their target area of the electron cloud was quite similar to that of a 1s orbital which was is depicted on the lab sheet as well as in their lecture notes. As a result of their target areas

being similar to that of a 1s orbital they were then able to conclude that ninety percent of the carbon markings fell very close to the nucleus of the atom. Students then came to the conclusion that their experimental results compared quite closely to Schrödinger's results. When students completed their lab notebooks I provided for them a formative assessment where they received feedback as well as an evaluation of their learning progress.

Section Three - Electron Configurations and the Electron Battleship Activity

Students who completed the Electron Battleship Activity earned up to ten points on the Electron Configurations Worksheet (see Appendix E) with the points being allocated towards their first quarter grade. Students also completed a forty point quiz as well as a laboratory report which assessed their understanding of electron configurations. Please see table 3-1 for a list of scores that students earned on the Electron Configurations Worksheet as well as table 3-2 for student scoring on the electron configuration quiz.

This lab activity allowed students the opportunity to practice writing out electron configurations. In an effort to assess student mastery of the concept of their learning of electron configuration they worked in collaborative groups on a worksheet called electron configurations. As they worked on the problem sets I used questioning strategies in order to ensure that they had an understanding of the concepts being covered. In table 3-1 I have listed the scores of students who completed this worksheet with an average score well above ninety percent.

Scores for Electron Configuration Worksheet

Points	Frequency
20	3
19	4
18	4
17	3
16	2
15	1
14	1
13	1

Table 3-1

Scores for Electron Configuration Quiz

Points	Frequency
20	3
19	4
18	4
17	3
16	2
15	1
14	1
13	1

Table 3-2

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Appendices

Appendix A

Atomic Model Quiz

Name _____ Hour ____ Score ____/40

Atomic Model Quiz

- 1.) Whose series of experiments identified the nucleus of the atom?
a. **Rutherford** c. Chadwick
b. Dalton d. Bohr
- 2.) In Rutherford's experiments, alpha particles
a. passed through a tube containing gas. c. collided with electrons.
b. were used to bombard a cathode plate. d. **were used to bombard thin metal foil.**
- 3.) Because most particles fired at metal foil passed straight through, Rutherford concluded that
a. **atoms were mostly empty space.** c. electrons formed the nucleus.
b. atoms contained no charged particles. d. atoms were indivisible.
- 4.) Which part of an atom has a mass approximately equal to 1/2000 of the mass of a common hydrogen atom?
a. nucleus c. proton
b. **electron** d. neutron
- 5.) Experiments with cathode rays led to the discovery of the
a. proton. c. neutron.
b. nucleus. d. **electron.**
- 6.) The nucleus of an atom has all of the following characteristics *except* that it
a. is positively charged. b. is very dense.
c. contains nearly all of the atom's mass. d. **contains nearly all of the atom's volume.**
- 7.) Most of the volume of an atom is occupied by the
a. nucleus. c. **electrons.**
b. nuclides. d. protons.
- 8.) A quantum of electromagnetic energy is called a(n)
a. **photon.** c. excited atom.
b. electron. d. orbital.
- 9.) Max Planck proposed that a hot object radiated energy in small, specific amounts called
a. **quanta.** c. hertz.
b. waves. d. electrons.
- 10.) Bohr's theory helped explain why
a. electrons have negative charge. b. most of the mass of the atom is in the nucleus.
c. **excited hydrogen gas gives off certain colors of light.** d. atoms form molecules.

Appendix B

Quantum Mechanics Quiz

Name _____ Hour ____ Score ____/40

Quantum Mechanics Quiz

- 1.) What values can the angular momentum quantum number have when $n = 2$?

$l = 0$ and 1

- 2.) The number of possible different orbital shapes for the third energy level is?

s, p and d

- 3.) For the f sublevel, the number of orbitals is?

7

- 4.) How many electrons are needed to completely fill the fourth energy level?

64

- 5.) How many more electrons are needed to completely fill the third main energy level if it already contains 8 electrons?

10

- 6.) At $n = 1$, the total number of electrons that could be found is?

2

- 7.) If $n=3$, $l=2$, $m_l=0$ and $m_s=+1/2$, what element is being referred to?

Ni

- 8.) The number of possible different orbital shapes for the third energy level is?

Three

The Lab Notebook

Science

Mr. Miller

Laboratory notebooks are an integral part of scientific research. They serve as permanent records of actual experimental work. Thus, it is critical that they are both accurate and truthful. In this course, you will implement some of the procedures used by chemists to safeguard against false or inaccurate records.

- ◆ Your lab notebook should be a composition book used only for lab experiments. Write your student ID# and class period neatly on the front cover, save the first two pages for a Table of Contents, and number one side of the remaining pages in the lower middle of the page.

- ◆ In your lab notebook, write neatly using only **black** ink. If you make an error, draw a single line through the mistake. **DO NOT SCRIBBLE OUT ERRORS OR USE WHITE OUT.**

- ◆ Start each lab on a new page and record the title and starting and ending page numbers in the Table of Contents.

- ◆ All notes made during a lab should go **directly** in your lab notebook, **NOT** on a separate piece of paper.

- ◆ When turning in your lab notebook for grading, mark the first page of the current lab with a Post-It. Then, have your team manager collect your group's books and turn them in together.

- ◆ Use the following format for each lab unless instructed otherwise. Include headings for each section. You should have the Title and Purpose written before you come to class. If the lab requires a Data Table, you should also prepare that in advance in order to save time during class.

Title of Experiment:

1. A relevant title should be clearly and neatly written at the top center of the first page of the lab.

Date:

1. The start and end dates for the lab should be written in the table of contents as well as the upper right hand corner of the first page of the lab.

Purpose:

- 1.) This is where you tell the reader your reason for doing the lab.
 - a. For example, many researchers for drug companies have as their purpose that they want to cure cancer or some other disease.
- 2.) The purpose should be two or three sentences long.
 - a. If it's too short, it won't be clear why you're doing the lab.
 - b. If it's too long, you're doing too much work and the reader will probably just skip over it.

Hypothesis:

- 1.) If _____, then _____.
 - a. The hypothesis is a one-line sentence where you discuss how you'll solve the problem at hand.
 - b. The statement after "if" is the independent variable. The independent variable is whatever you'll do to solve the problem.
 - c. The statement after "then" is the dependent variable, because what happens will depend on what you did in the first place.
 - d. Generally, the dependent variable will be that the problem you mentioned in the purpose will be solved.

Materials:

- 1.) Your materials list must be VERY complete.
 - a. Indicate how much of each material will be used in the experiment so you know what you'll need.
- 2.) If you plan on arranging some of the equipment into a more complex set up (for example, if you're going to heat something over a Bunsen burner, you'd need a ring stand, wire gauze, etc.), **draw and label** it as well as mentioning the equipment used.
- 3.) It's never a bad idea to leave a couple of extra lines at the end of this section so you can add more things that you've forgotten when you started your lab.

Procedure:

- 1.) A very clear step-by-step list of things you plan on doing during the experiment.
- 2.) Each step should be short (one phrase or sentence).
- 3.) Leave a few blank lines at the end of this section to add things that you may have forgotten.

Results:

- 1.) This is where you write down all of your raw data.
- 2.) Quantitative (numerical) data. Ex. time, temperature, mass, volume, density
 - a. Arranged in a meaningful data table:
 - Title
 - Column headings
 - Units
- 3.) Qualitative (non-numerical) data.
 - a. May also be arranged in a meaningful data table.
 - This would include things that you observed happen. Ex. Physical or chemical changes.
 - b. Experimental notes and observations of what you saw would be written here.
- 4.) The results section will most likely be long, so make sure you leave plenty of room. A good rule of thumb when writing the results section is that if you're not sure if what you've seen is a result, write it down. Your results section can never be too long.

Analysis:

- 1.) Graphs using the data you entered in the results section would be placed here.
- 2.) Graphs should have:
 - a. Solid data points.
 - b. Axes labeled with units.
 - c. Title - Listing the independent variable versus the dependent variable.
 - d. Scale graph axes starting at zero.
 - e. Graphs should conform to the *Graphing Guidelines*.
- 3.) Any calculations entered here.
 - a. If repetitive calculations are necessary, show one sample calculation of each type.
 - b. Calculations should be organized and show all work.

For example:

$$\text{Density of metal A: } D = \frac{M}{V} = \frac{56.03 \text{ g}}{8.0 \text{ mL}} = 7.0 \text{ g/mL}$$

- 4.) Data that you collected which requires mathematical calculations should be accompanied with an organized table including labels and units for each value.

For example:

Density of metal A	7.0 g/mL
Density of metal B	0.79 g/mL

Questions:

- 1.) Lab questions
 - a. Rewrite the complete question.
 - b. Answer in complete sentences.
 - c. Be sure to include the question number.

Conclusion:

- 1.) Restate your hypothesis and tell if it was supported or not.
 - a. For example, if you proved the hypothesis that “If I poke myself in the eye, then my eye will hurt.” This first sentence would be “When I poked myself in the eye, it hurt.”
- 2.) If the hypothesis didn’t work, an explanation of what you think went wrong.
 - a. These should be very specific suggestions (I should have heated the mixture to 55 °C), not general suggestions (I should have heated it more).
- 3.) If the hypothesis did work, an explanation of what you think went well.
 - a. These should be very specific observations of what went right (I massed the NaCl to 3.50 grams) not a general observation (I massed the NaCl).
- 4.) A brief error analysis section.
 - a. List at least two things that could have caused errors in the lab.
 - b. List at least two ways you can prevent those errors in the future.
 - c. Errors you mention should be errors that you can do something about, not mystical errors that probably didn’t happen.
- 5.) Use past tense and passive voice for science reports.
- 6.) This is the most important part of the report. It’s where you tie everything together and show me what you know.

Appendix D

Lab Grade Sheet

Student Name: _____

Lab Title: _____

<u>Appearance</u>	<u>Point Value</u>
Lab information - Written in the table of contents.	0 1 2
Date and title - Written on the first page of the lab.	0 1 2
Lab report is neat.	0 1 2 3 4
<u>Purpose</u>	
Reason for performing the lab is clear.	0 1 2
<u>Hypothesis</u>	
The hypothesis is an if, then statement.	0 1 2
<u>Materials</u>	
Materials list - Complete.	0 1 2
Labeled sketch of the lab equipment is provided (IA).	0 1 2
<u>Procedure</u>	
Every step of the experiment is included.	0 1 2
<u>Results</u>	
Quantitative (numerical) data arranged in a meaningful data table.	0 1 2
Qualitative (non-numerical) data arranged in a meaningful data table.	0 1 2
Experimental notes and observations included.	0 1 2
<u>Analysis</u>	
Properly labeled graph.	0 1 2
All calculations are correct and complete (IA).	0 1 2
<u>Questions</u>	
Lab questions answered properly (IA).	0 1 2
<u>Conclusion</u>	
Restate hypothesis - Tell if it was supported or not.	0 1 2
If the hypothesis did not work – Explain what went wrong. Show at least two sources of error and possible ways of compensating for them.	0 1 2
If the hypothesis did work – Explain what went well. Show at least two things that went well and why they worked.	0 1 2
<u>Total Points:</u>	/

IA = If Applicable

Appendix E

Worksheet – Electron Configuration

Electron Configurations Worksheet

Write the complete ground state electron configurations for the following:

- 1) Lithium $1s^2 2s^1$
- 2) Oxygen $1s^2 2s^2 2p^4$
- 3) Calcium $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
- 4) Titanium $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$
- 5) Rubidium $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^1$
- 6) Lead $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^2$
- 7) Erbium $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{12}$

Write the abbreviated ground state electron configurations for the following:

- 8) Helium $1s^2$ (this one cannot be abbreviated)
- 9) Nitrogen $[\text{He}] 2s^2 2p^3$
- 10) Chlorine $[\text{Ne}] 3s^2 3p^5$
- 11) Iron $[\text{Ar}] 4s^2 3d^6$
- 13) Barium $[\text{Xe}] 6s^2$
- 14) Polonium $[\text{Xe}] 6s^2 4f^{14} 5d^{10} 6p^4$