Quantum Leap Lab

Student Laboratory Kit

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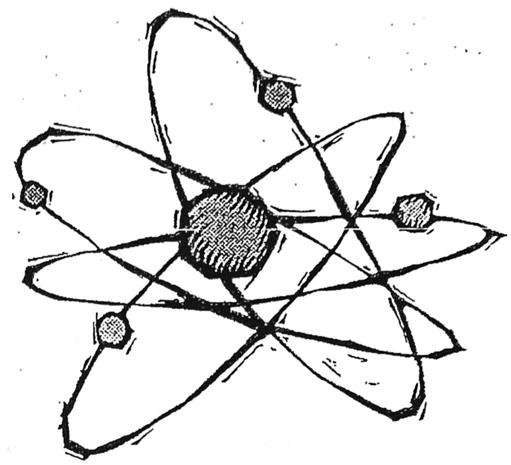

Introduction

Can we know the precise location of an electron around the nucleus of an atom at any given time? This activity will help you to gain an understanding of the concept of probability, and visualize the shapes and relative positions of the 1s and 2s orbitals in a hydrogen atom.

Chemical Concepts

- Quantum mechanics
- Heisenberg's uncertainty principle
- Electron energy levels
- Orbital shapes

Background

Throughout the years, significant progress has been made in our knowledge of the atom. Atoms were originally described by John Dalton (1766–1844), who stated "Thou canst not split an atom!"—revealing the belief at the time that the atom was the smallest particle of matter. Since that time, J. J. Thomson (1856–1940), Ernest Rutherford (1871–1937), and James Chadwick (1891–1974) discovered, in turn, the electron, the proton, and the neutron. The structure of the atom was then described as consisting of electrons orbiting a dense, positively-charged nucleus. In turn, Niels Bohr (1885–1962) developed a model for the hydrogen atom in which the electron was assumed to move in definite orbits, called energy levels, about the atomic nucleus. The amount of energy the electron possessed depended on its distance from the nucleus, with the outer orbitals having the most energy. While Bohr's theory for the structure of the hydrogen atom was very successful, it failed to hold true for atoms with two or more electrons. Hence there was a need for an improved atomic model.

The quantum mechanical model, or *quantum mechanics,* was developed as a way to describe the motion of small particles (electrons) confined to tiny regions of space. The exact position of an electron at any given instant is not specified; nor is the exact path that the electron takes about the nucleus. Therefore, it is uncertain as to the exact location of the electron at any given time. *Heisenberg's uncertainty principle* states that there is a fundamental limitation as to just how precisely both the position and the momentum of a particle can be known at any given time. Quantum mechanics deals only with the *probability* of finding a particle within a given region of space at any given time. In other words, no longer should we think of definite orbits of electrons around the nucleus (as in the Bohr model). Rather, we should think of regions of space, commonly called orbitals or electron clouds, which represent the most probable location where an electron can be found at any given time around the nucleus, depending on the amount of energy that electron possesses.

In this lab activity, a marble will be dropped repeatedly (100 times) from a specified distance (either waist-level or eye-level) to a bull's-eye target. The regions of space around the central bull's-eye will be defined, as shown on the target sheet (Areas 1–6). In each region, there will be a specific probability of locating a spot resulting from the impact of the marble drop. Imagine that each spot represents a point in **three-dimensional** space around the bull's-eye (analogous to the *nucleus*) where the marble (analogous to the *electron*) is capable of landing (or most likely to be found). The region of space (analogous to an *atomic orbital*) in which the marble has a high probability of landing will define the shape of the orbital. The maximum probability (as shown by the *maximum spot density*) will be determined by plotting the number of times the spots appear in each region (analogous to the region of three-dimensional space where an electron is most likely to be observed at any given time).

The activity is repeated at a higher height (eye-level) from the bull's-eye target. This increased height represents a higher energy level (i.e., 2s orbital) compared to the previous lower energy level (i.e., 1s orbital). The shapes and relative sizes of the 1s and 2s orbitals in an atom can then be illustrated.

(*Note:* This background provides only a brief overview of the history and development of atomic theory. For additional information, please consult a chemistry textbook.)

Materials (for each student group)

Target Sheet, Waist-Level, carbonless 2-sheet set

Target Sheet, Eye-Level, carbonless 2-sheet set

Glass marble

Pen or pencil, fine-lined

Procedure

(*Note:* Work in teams for the gathering of data. The procedure is written for teams of two; however, it can be easily modified for teams of three, if necessary.)

Waist-Level Target

1. Obtain one waist-level target sheet set for your group and place your names at the top. (*Note:* Carbonless paper is a special "non-carbon" paper consisting of two attached sheets—one white, one yellow—that make an imprint on the bottom sheet when an object strikes the top sheet.)
2. Choose one person to be the "Target Aimer" and one person to be the "Marble Catcher." Lay the waist-level target sheet on a smooth, hard floor.
3. The "Target Aimer" should hold a glass marble in one hand and stand over the center of the target. Bend the elbow at the waist so that the forearm is parallel to the floor and perpendicular to the body.
4. Have the "Marble Catcher" kneel down next to the target sheet and be prepared to catch the marble *after* the first bounce. (*Note:* Practice bouncing the marble on the floor first to be sure the "Catcher" catches it.)
5. The "Target Aimer" should carefully drop (do not throw!) the marble from waist level, aiming for the bull's-eye. The "Marble Catcher" should catch the marble after the first bounce to be sure the marble doesn't leave more than one mark per drop on the target sheet.
6. Repeat this dropping procedure approximately 100 times over the same target. The "Catcher" should make a tally mark after each drop in the Tally Box on the Quantum Leap Data Sheet for ease of counting. Each hit should leave a mark on the bottom yellow sheet. (*Note:* If three people are in a team, the third person can be the "Tally Marker.")
7. After 100 drops, carefully separate the bottom yellow sheet from the top white sheet. Notice the pattern of marks on the yellow sheet.

Eye-Level Target

8. Obtain one eye-level target sheet set for your group and place your names at the top. This consists of two attached sheets—one white and one pink.
9. Repeat steps 2–8 above, with the "Target Aimer" and the "Marble Catcher" switching jobs. This time, use the eye-level target sheets. The "Target Aimer" should drop the marble with the arm fully extended from ***eye level***, aiming for the bull's-eye. Try to drop the marble from the same eye-level height each time (100 drops).
10. When done, carefully separate the bottom pink sheet from the top white sheet. Again, notice the pattern of marks on the pink sheet.

Analysis of Data

11. Using a fine-lined pen or pencil, circle each mark made by the marble on both target sheets (yellow waist-level and pink eye-level sheets).
12. Count the number of hits in each target area (1–5) by counting the number of circles. Be sure to also count the hits made outside areas 1–5 as area 6. For those spots that landed exactly on the line between two areas, count it as the lower number.
13. Record all data on the Quantum Leap Data Sheet.
14. Construct a bar graph for each target sheet on the Quantum Leap Graph Sheet. Label the horizontal axis as the ***area number***, and the vertical axis as the ***number of hits***. Space the bars evenly, making each the same width. Draw the height of each bar proportional to the number of hits in that area. The marble dropped from eye level represents an electron having greater energy than one dropped from waist level.
15. Answer the post-lab questions on page 5.

YOUR DATA should look like this in lab Book

Name: ______________________

Quantum Leap Data Sheet

Waist-Level

Tally Box

Area #	# of Hits
1	
2	
3	
4	
5	
6	

Eye-Level

Tally Box

Area #	# of Hits
1	
2	
3	
4	
5	
6	

Quantum Leap Graph Sheet

Waist-Level

Eye-Level

Name: ____________________

Quantum Leap Post-Lab Questions

Answer the following questions in the space provided below. Attach additional paper, if necessary.

1. Which area on *each* target sheet (Areas 1–6) received the most hits?

2. Why don't all the marbles dropped from a specified height land in the same spot?

3. As the distance from the nucleus (bull's-eye) increases, what happens to the probability of finding an electron (marble)?

4. Where is there zero probability of finding an electron in an atom? (*Hint:* Consider the charge on an electron.)

5. What is the overall shape that the spots made on the target sheet? What differences can be seen between the waist-level target sheet and the eye-level target sheet?

6. Compare the heights of the bars on the waist-level graph and the eye-level graph. Explain the shift in the heights of the bars toward or away from the origin (Area 1).

7. Is there any way to predict the exact location of any *one* marble drop on the target? Explain.

8. Describe the relationship between the energy of an electron (drop height), and its probable distance (area number) away from the nucleus of an atom (bull's-eye).