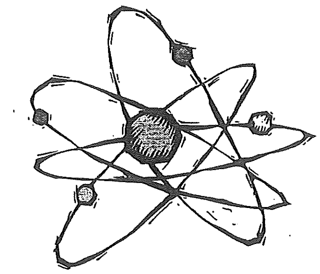
Quantum Leap Lab
Probability and Electron Structure

Introduction

The picture at the right illustrates a popular view of the electron structure of the atom—electrons orbiting the nucleus in fixed paths. The picture is wrong! It is impossible to know the precise location of an electron around the nucleus of an atom at any given time. The location of an electron can only be described in terms of the total probability of finding an electron within a region of space.



Bohr Model of Atom

Concepts

- Quantum mechanics
- Heisenberg uncertainty principle
- Electron energy levels
- Atomic orbitals

Background

Throughout the years, significant progress has been made in our knowledge of the atom. Atoms were originally described as the smallest particles of matter. The discoveries, in turn, of the electron, the proton, and the neutron destroyed the notion of the indivisible atom. Knowledge of the subatomic particle make-up of the atom raised new questions—where are the electrons? In 1913, Niels Bohr 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 electrons 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 model of electron structure.

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. The exact location of the electron at any given time can never be known with certainty. The *Heisenberg uncertainty principle* states that there is a fundamental limitation to how precisely both the position and the momentum of an electron can be known. Quantum mechanics describes the probability of finding an electron within a given region of space. 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 atomic orbitals or electron clouds, which represent the most probable areas where an electron may be found, depending on the amount of energy that the electron possesses. The size and shape of atomic orbitals are derived from calculations that assume that the electron acts as a wave rather than as a particle.

Experiment Overview

The purpose of this activity is to investigate by analogy the relationship between probability and the electronic structure of an atom. A marble will be dropped repeatedly onto 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. The activity will be carried out at two distances from the target representing different energy levels. A small-scale version of the target is shown in Figure 1.

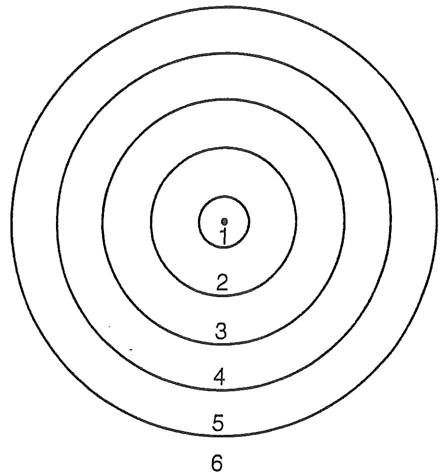


Figure 1. Target Areas (1–6)

The pattern of spots on each target sheet will be used to imagine the three-dimensional properties of an atomic orbital. Thus, each spot will represent 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 size and shape of the orbital.

re-Lab Questions

1. What is the fundamental difference between an electron *orbit* and an atomic *orbital*?
2. In this activity, the marble will be dropped from two heights—knee-level (0.5 m) and eye-level (1.5 m). Which height represents a higher energy level? Explain.
3. Form a hypothesis to predict how increasing the energy of the marble will affect the overall size of the area where the marble is likely to land. Relate this hypothesis to the energy and size of 1s and 2s orbitals.

aterials

Target Sheet, Knee-Level, carbonless, 2-sheet set
Target Sheet, Eye-Level, carbonless, 2-sheet set
Marble
Meter stick

ıfety Precautions

Although this laboratory activity is considered nonhazardous, please observe all normal laboratory safety guidelines.

Procedure

Knee-Level Target (Target Distance = 0.5 m)

1. Obtain a target sheet set labeled "knee-level" and a marble. The target sheet set contains carbonless paper that will leave an imprint on the bottom sheet when an object strikes the top sheet.
2. Trace the bull's-eye target pattern with marked areas on the top sheet of the 2-sheet set.
3. Choose one person to be the "Dropper" and one person to be the "Catcher." Lay the knee-level target sheet on a smooth, hard floor.
4. The "Dropper" should hold the marble in one hand and bend down on one knee over the center of the target. The approximate distance or height from which the marble should be dropped is 0.5 m.
5. Have the "Catcher" sit down next to the target sheet and be prepared to catch the marble immediately after the first bounce. *Note:* Practice bouncing the marble on the floor first to be sure the "Catcher" can catch it before the second bounce.
6. The "Dropper" should carefully drop (do not throw!) the marble from the waist (about 0.5 m), aiming for the bull's-eye. The "Catcher" should catch the marble immediately after the first bounce to be sure the marble doesn't leave more than one mark per drop on the target sheet.
7. Repeat this procedure approximately 100 times over the same target. For ease of counting, the "Dropper" should make a tally mark after each drop in the Tally Box on the Quantum Leap Data Sheet. Each hit will leave a mark on the bottom "copy" sheet.
8. After 100 drops, carefully separate the bottom "copy" sheet from the top sheet. Note the pattern of marks on the copy sheet.

Eye-Level Target (Target Distance = 1.5 m)

9. Repeat steps 1–8 using an eye-level target sheet set, with the "Dropper" and the "Catcher" switching jobs. The "Dropper" should drop the marble with the arm fully extended from eye level, aiming for the bull's-eye. Try to drop the marble from a distance of about 1.5 m.
10. Carefully separate the bottom "copy" sheet from the top sheet. Again, note the pattern of marks on the copy sheet.

Name: ______________________________

Class/Lab Period: ______________________

Quantum Leap Data Sheet

Knee-Level

Tally Box

Eye-Level

Tally Box

esults Table

Knee-level Target Distance = 0.5 m		Eye-level Target Distance = 1.5 m	
Area Number	Number of Hits	Area Number	Number of Hits
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	

Post-Lab Questions *(Use a separate sheet of paper to answer the following questions.)*

1. Circle each mark made by the marble on both target sheets. For each sheet, count the number of hits in each target area (1–5) by counting the number of circles. Count any hits made outside areas 1–5 as area 6. If a marble landed exactly on the line between two areas, count its location as the higher number area. Record the results in the Results Table.

2. Construct a bar graph for each target 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.

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

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

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

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

7. The two-dimensional pattern of spots on the paper is intended to simulate a three-dimensional atomic orbital. What shape would the pattern have in three-dimensional space?

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

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

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