Activity 4 Are Atoms Indivisible?

What Do You Think?
Ever since Democritus from ancient Greece hypothesized the existence of atoms, a major question was how atoms of different elements were different.

• If you could observe a single atom of gold and a single atom of lead, how do you think they would be different? How could they have something in common?

Record your ideas about these questions in your Active Chemistry log. Be prepared to discuss your responses with your small group and the class.

Investigate
1. Your teacher will demonstrate the behavior of what were called cathode rays a hundred years ago. They were called cathode rays because they were emitted from the negative terminal, or cathode of what was known as a cathode-ray tube, a forerunner of the television or the computer monitor tube.

GOALS
In this activity you will:

• Observe the behavior of a cathode ray in the presence of a magnet.
• Discuss Thomson’s conclusions from 1897 about cathode rays.
• Simulate an experiment from 1911 by Rutherford in which he learned more about the structure of atoms.
• Organize your understanding of some of the different particles that comprise matter.
a) What happens to the path of the cathode rays when a horseshoe magnet is placed near the tube? Record your observation in your *Active Chemistry* log.

b) Record what you think will happen to the path of the cathode rays when the orientation of the horseshoe magnet is reversed.

c) Observe the path of the cathode rays as your teacher reverses the magnet. Record what does happen.

2. Magnets exert a force on moving electrically charged particles. The effect of the magnet on the cathode rays therefore shows that these rays are moving electrically charged particles. Cathode rays, which have a negative electric charge, are made up of electrons. In 1897, Joseph John (J. J.) Thomson showed that identical rays (electrons) were emitted from the cathode of a cathode-ray tube, regardless of the metal of which the cathode was made.

Discovery of electrons emerging from the atoms of the cathode gave scientists new information about the atom. The atom is not indivisible. It has internal parts, one of which is the electron.

3. In order to investigate the other components of an atom, you will take part in the following simulation, similar to the game *Battleship*. You will work with a partner for this activity.

You and your classmate should each construct a grid of squares, 8 by 10. Without letting your classmate see your grid, color in a section of ten squares. The squares must touch each other. To make the simulation relatively simple, begin with a fairly compact design. This shape (colored region) represents your target.

You and your partner will try to guess the shape of each other’s targets by sending “missiles” onto any of the 80 squares in this array. For the purpose of this description, designate one person to be Player X and the other person to be Player Y. To begin, Player X will tell Player Y the destination (number and letter) of

![Cathode-ray tube with electrons being deflected by a magnetic field](image)
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1. The missile being sent. Player Y will respond, indicating that the missile “hit” or “missed” the target shape. Player X will make note of the response. Then Player Y sends the next missile, noting the response. Continue this process until one player identifies the other player’s target.

   a) Record the number of turns taken to complete the game.

   b) Repeat the game with a target of only 2 adjacent squares. Record the number of turns taken.

4. Now do a thought experiment. The same-size game grid is divided into smaller squares—100 squares across and 100 squares down. There are now 10,000 squares in the same size board as before. A target of only one square is chosen.

   a) Record an estimate of how many turns will be required to identify the target square amongst the 10,000 squares in the game grid.

5. Now modify the thought experiment. The same-size grid is now 1000 rows across and 1000 squares down. That is a total of 1,000,000 squares.

   a) Record an estimate of how many turns will be required to identify the target square among the 1,000,000 squares in the game grid.

6. An experiment similar to your game of “Battleship” was carried out in 1911 by Lord Ernest Rutherford. Rutherford sought to learn something about the structure of the atom by bombarding gold atoms with energetic particles given off by certain atoms.

   In Rutherford’s game of “Battleship,” it seemed that he was required to send an incredible number of missiles to get a “hit.” He concluded that the grid of the atom must be composed of tiny, tiny cells and only one cell contains all of the positive charge of the atom.

   a) Explain why you think he concluded this.
The Changing Model of an Atom

J.J. Thomson’s Model of an Atom

As you noted in this activity, in the late 1800s J.J. Thomson, an English physicist, found evidence for the existence of negatively charged particles that could be removed from atoms. He called these subatomic particles with a negative charge electrons. Using this new information, Thomson then proposed a model of an atom that was a positive sphere, with electrons evenly distributed and embedded in it, as shown in the diagram. Using the same evidence, H. Nagaoka, a Japanese scientist, modeled the atom as a large positively charged sphere surrounded by a ring of negative electrons.

Rutherford’s Discovery of the Nucleus

For several years there was no evidence to contradict either Thomson’s or Nagaoka’s atomic models. However, in the early 1900s, Ernest Rutherford, a New Zealand-born scientist, designed experiments to test the current model of an atom. In Rutherford’s experiment, alpha particles were sent as “missiles” toward a thin sheet of gold. Gold was used because it is malleable and could be hammered into a thin, thin sheet. Most of the alpha particles went through the sheet and were not deflected. It is as if they missed the target. This was expected since it was assumed that the atom’s charge and mass...
was spread evenly throughout the gold. Occasionally one of the alpha particles that “hit” the gold sheet bounced back. This was the big surprise. The conclusion: there must be tiny places containing lots of charge and mass. Since the bouncing back was so unusual, it was assumed that the places where all the charge and mass were concentrated were only 1/100,000 of the area of the gold. Rutherford concluded that almost all the mass and all of the positive charge of the atom is concentrated in an extremely small part at the center, which he called the nucleus. He also coined the term proton to name the smallest unit of positive charge in the nucleus.

The story of Rutherford’s discovery of the atomic nucleus is best told by Rutherford himself. Examining the deflection of high-speed alpha particles as they passed through sheets of gold foil, Rutherford and his student Hans Geiger noticed that some particles were scattered through larger angles than predicted by the existing theory of atomic structure. Fascinated, Rutherford asked Geiger’s research student Ernest Marsden to search for more large-angle alpha scattering. Rutherford did not think that any of the alpha particles in his experiment would actually bounce backward. “Then I remember two or three days later Geiger coming to me in great excitement and saying, ‘We have been able to get some of the alpha particles coming backwards . . . ’ It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.”

**Chem Words**

- **nucleus**: the very dense core of the atom that contains the neutrons and protons.
- **proton**: a positively charged subatomic particle contained in the nucleus of an atom. The mass of a proton is $1.673 \times 10^{-24}\text{g}$ and it has a charge of $+1$. 
A Physics Connection

What was responsible for the wide-angle scattering of the alpha particles and their bouncing back? The force between the positive nucleus and the positive alpha particle is the coulomb force. Positive charges repel one another according to the coulomb force law.

\[ F = \frac{kq_1q_2}{d^2} \]

where \( k \) is Coulomb’s constant, \( (k = 9.0 \times 10^9 \text{ N m}^2/\text{C}^2) \), \( q \) is the charge in coulombs, and \( d \) is the distance between the charges.

The closer the alpha particle gets to the nucleus, the larger the force and the larger the deflection of the alpha particle.
Reflecting on the Activity and the Challenge

In this activity you learned of evidence that atoms are made of a positively charged nucleus and negatively charged electrons. The nucleus contains most of the atom’s mass and its positive charge is balanced by the combined negative charge of the electrons, resulting in an atom that is electrically neutral. The number of protons of the neutral atom plays a very important role in the periodic table. Called the atomic number, it supports the order in which Mendeleev arranged the elements in his periodic table, long before anything was known about the structure of the atom or atomic number. How will your game reflect your new knowledge about atomic structure and its relationship to the periodic table?

Chemistry to Go

1. Since the electron has a negative electric charge and the nucleus has a positive electric charge, where would you expect to find electrons in atoms?
2. Are atoms indivisible? Support your answer using information from this activity.
3. Construct a chart or diagram to summarize what you have learned in this activity about the particles that make up an atom. Include electric charge and location of the particles.
4. Lead has an atomic number of 82; iron has an atomic number of 26; and copper has an atomic number of 29. How do the charges of the nuclei of these three elements compare?
5. The element chlorine has an atomic number of 17. How many electrons does chlorine have? Support your answer with a logical explanation of how you could arrive at this answer.
6. Sketch the outline of three grids. Pretend that each grid has 100,000 squares.
   a) If the target was 50,000 squares, draw the target.
   b) If the target was 25,000 squares, draw the target.
   c) If the target was only 1 square, draw the target.
Which grid most closely relates to Rutherford’s experiment? Explain your answer.
Inquiring Further

1. An atomic timeline

Construct a timeline that reflects how scientists’ views of the atom have changed through the ages. Identify significant scientists, their beliefs, and experimental findings as mentioned in this chapter. You may also wish to consult other resources. Add information to your timeline as you continue to work through this chapter.

2. John Dalton’s Atomic Theory

John Dalton, an English scientist, developed his atomic theory in the early 1800s. This theory was based on the Greek concept of atoms and the studies of Joseph Proust’s Law of Definite Proportions or Law of Constant Composition. Dalton’s atomic theory contained a series of postulates based on the data of his time and his observations:

- Matter consists of small particles called atoms.
- Atoms of one particular element are identical and the properties are identical.
- Atoms are indestructible. In chemical reactions, the atoms rearrange or combine, but they are not destroyed.
- Atoms of different elements have a different set of properties.
- When atoms of different elements combine to form compounds, they combine in a fixed numerical ratio.

From his postulates, the Law of Conservation of Mass would be supported. Since his postulates state that atoms cannot be destroyed but they can be moved around and combine with other atoms to form compounds, then the mass of the compound must be the sum of the atoms of the compound. This law still exists with a slight modification for nuclear reactions. So, you can conclude that if water has a certain mass today, it will have the same mass any other day (unless evaporation occurs).

Investigate whether all of Dalton’s postulates are presently accepted or describe how some have been modified based on our current understanding.