



Activity 4

Are Atoms Indivisible?

What Do You See?



Do not try this at home. It may ruin your TV.

GOALS

In this activity you will:

- Observe or learn 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.

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? What might they have 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. This tube was a forerunner of the television and the computer monitor. Alternatively, look at the diagram of the demonstration on the next page.

- 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 happens to the path of the cathode rays when the orientation of the horseshoe magnet is reversed.
2. For the particles that make up the cathode rays to change direction, the magnet must be exerting a force on these electrically charged particles. In 1897, Joseph John (J. J.) Thomson showed that the cathode rays were made of electrons. Electrons are negatively charged, tiny particles. He also discovered that identical electrons were emitted regardless of the metal of which the cathode was made.

Discovery of electrons emerging from the atoms of any metal gave scientists new information about the atom. The atom is divisible. It has internal parts, one of which is the electron.

- a) In a sentence or two, describe the relationship between cathode rays, the electron, and the structure of atoms.

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

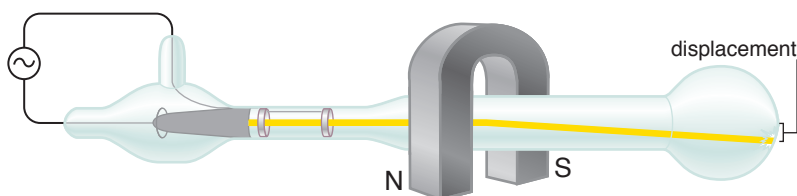
You and your classmate should each construct an 8-by-10 grid of squares. You can label the columns of the grid with letters A, B, C... Label the rows of the grid 1, 2, 3... Without letting your classmate see your grid, color in a section of ten squares. The squares must touch each other. To make the simulation relatively simple, begin with a compact design. This shape (colored region) represents your target.

You and your partner will try to guess the shape of each other's target 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 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



Always use the minimum voltage and current necessary to operate the Crooke's tube to limit the hazard of x-ray production. In addition, maximize distance and minimize time for the demonstration.

Cathode-ray tube with electrons being deflected by a magnetic field





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 two adjacent squares. Record the number of turns taken.
4. Now do a thought experiment. The same-size game grid is divided into smaller squares. Suppose there are 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 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 grid.
6. In 1911, Lord Ernest Rutherford conducted an experiment similar to your game of battleship. Rutherford sought to learn something about the structure of the atom by bombarding gold atoms with energetic particles given off by certain atoms.

	A	B	C	D	E	F	G	H	I	J
1										
2										
3										
4										
5										
6										
7										
8										

In Rutherford's game of battleship, it seemed that he was required to send an incredibly large number of missiles to get a "hit." He concluded that the grid of the atom must be composed of very tiny cells and only one cell contains all of the positive charge of the atom.

- a) In your *Active Chemistry* log, explain why you think he concluded this.



ChemTalk

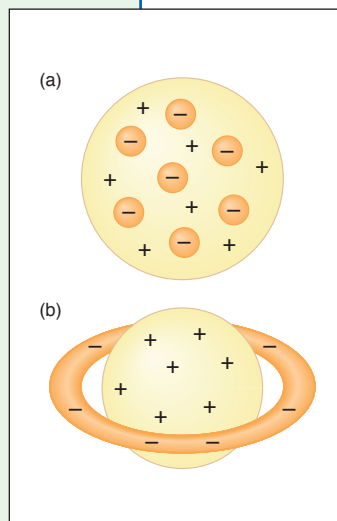
THE CHANGING MODEL OF AN ATOM

J.J. Thomson's Model of an Atom

As was 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 negative charges **electrons**. Using this new information, Thomson then proposed a model of an atom. This model 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. These models show that scientists agreed that atoms contain electrons. They also agreed that atoms were electrically neutral. To maintain this electric neutrality, an atom must contain an equal number of positive and negative charges.

Chem Words

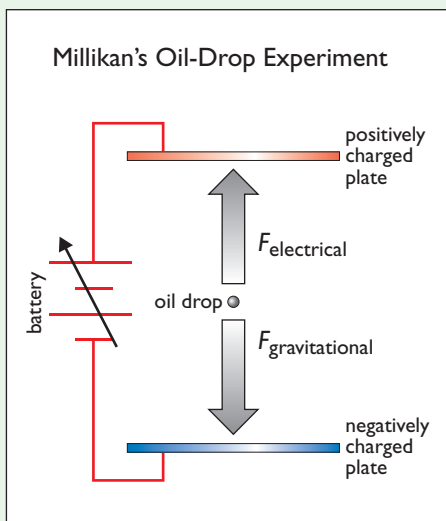
electron: the negatively charged subatomic particle of an atom.



Millikan Determines the Mass and Charge of an Electron

Thomson was able to measure only the ratio of mass-to-charge for an electron, not the mass itself. The American physicist Robert A. Millikan devised a method for determining the mass of an electron. His famous experiment is called the Millikan oil-drop experiment.

First, Millikan produced small droplets of oil by spraying them from a nozzle into a box. The tiny mist of negatively charged droplets was allowed to fall between two charged metal plates. It was possible to stop the drops from falling by having the plates exert an upward electrical force on the drops. Millikan was able to calculate the charge of an electron as $1.6 \times 10^{-19} \text{ C}$ (coulombs). He then used Thomson's charge-to-mass ratio to determine the mass of an electron to be $9.10 \times 10^{-28} \text{ g}$. This is about 1/2000 of the mass of a proton. Thomson remarked that these electrons were very, very tiny.





Chem Words

alpha particle: helium ions that are positively charged.

nucleus: the very small dense region in the center of an atom that contains all the positive charge and most of the mass.

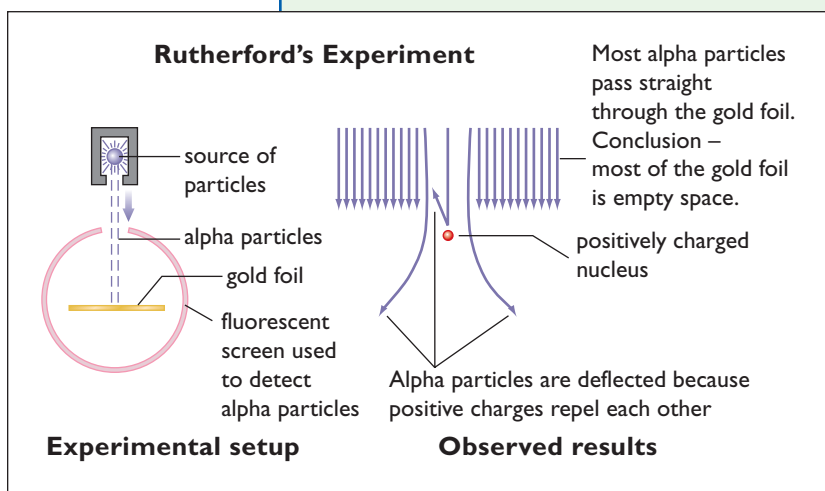
proton: the positively charged subatomic particle contained in the nucleus of an atom.



Ernest Rutherford

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, positively charged **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 very thin sheet. Most of the positively charged 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. Some of the alpha particles were deflected slightly. However, most interesting to Rutherford was that occasionally one of the alpha particles "hit" the gold sheet and bounced straight back at the source. This was unexpected. The conclusion was that 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. He called this center part the **nucleus**. He used the term **proton** to name the smallest unit of positive charge in the nucleus.



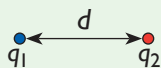
The story of Rutherford's discovery of the atomic nucleus is best told by Rutherford himself. Examining the deflection of high-speed alpha particles as they passed through sheets of gold foil, Rutherford and his student Hans Geiger noticed that some particles were scattered through larger angles than 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 (a missile) at a piece of tissue paper and it came back and hit you."

A Physics Connection

What was responsible for the wide-angle scattering of the alpha particles and their bouncing back? Well, the major forces involved in chemistry are electrical. They are based on the physics associated with Coulomb's Law of electrostatics.

The force between two charged particles (q_1 and q_2) is inversely proportional to the square of the distance (d) between them.



where k is a constant $= 9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$

$$F = \frac{kq_1q_2}{d^2}$$

If the particles are of opposite charge, then the force is attractive. If the particles are of the same charge, then the force is repulsive. Opposite charges attract, and like charges repel. The closer the positively charged alpha particle gets to the positively charged nucleus, the larger the force. This causes a larger deflection of the alpha particle.

In this activity, you learned about experimental evidence for the existence of electrons and a nucleus. Think back to when you first heard about electrons and the nucleus. Was it in elementary school? Often, theories about the structure of the atom are presented as facts without explaining any of the evidence that led to the theory. Science involves the accumulation of evidence and the building of a model and theory. It is not memorizing a set of facts.

Checking Up

1. What is an electron?
2. Thomson's model of an atom is sometimes referred to as the "plum-pudding" model. You would probably call it the "raisin bread" model. Explain why this is an appropriate comparison.
3. Why was Rutherford surprised that some alpha particles bounced back from the gold foil?
4. What is the nucleus of an atom?



What Do You Think Now?

At the beginning of the activity you were asked:

- If you could observe a single atom of gold and a single atom of lead, how do you think they would be different? What might they have in common?

Compare and contrast an atom of gold and an atom of lead using what you learned in this activity.

Chem Essential Questions

What does it mean?

Chemistry explains the macroscopic phenomenon (what you observe) with an explanation of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your *Active Chemistry* log.

MACRO	NANO	SYMBOLIC
<i>Describe your observations of the cathode rays and their interaction with a magnet.</i>	<i>Chemistry uses the structure of the atom to describe reactions of one material with another. What explanations at the atomic level did Thomson and Rutherford each make based on their evidence?</i>	<i>In chemistry, you create symbolic structures. How could you build a model that shows a tiny positively charged nucleus that takes up only 1/100,000 of the total space?</i>

How do you know?

What evidence do you have for the existence of a nucleus in the atom?

Why do you believe?

The electrons in a cathode ray are also used to create a picture on your TV screen and your computer monitor. How could you test to see if those electrons behave similarly to those in the cathode-ray tube?

Why should you care?

The periodic table will be a symbolic structure that summarizes much of what you know about atoms. What three things would you want the players of your periodic-table game to know at the end of the game?



Do not carry out your idea without your teacher's permission. You can damage the TV.

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. The result is an electrically neutral atom. Mendeleev's Periodic Table of the Elements provided insights into the structure of matter and atoms. Your periodic-table game will also reveal information about the structure of the atom and the role of evidence in creating models.

Chem 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. The element chlorine, with an atomic number of 17, has 17 protons in the nucleus. How many electrons does chlorine have? Support your answer with a logical explanation of how you could arrive at this answer.
5. Lead has an atomic number (the number of protons) 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?
6. An atom is neutral and an electron has a charge of -1.6×10^{-19} C. What is the charge of a proton? Explain why you chose this value.
7. Sketch the outside 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.
 - d) Which grid most closely relates to the nucleus found in Rutherford's experiment? Explain your answer.
8. Cathode rays (electrons) originate at the cathode (negative) terminal. They move in a straight line.
 - a) What will happen when you bring a magnet near the cathode ray?
 - b) How can you get it to deflect it in the opposite direction?
 - c) If the cathode-ray beam travels between a positive and a negative plate, which plate will the cathode rays be attracted towards?
9. In Millikan's oil-drop experiment, you wish to suspend the negatively charged oil drop. Since gravity pulls the oil drop down, should the negative plate be placed above or below the negatively charged oil drop?



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 (hypotheses). They were 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 a ratio of small whole numbers.

From his postulates, the Law of Conservation of Mass would be supported. His postulates state that atoms cannot be destroyed but they can be moved around and combine with other atoms to form compounds. That means that the mass of the compound must be the sum of the atoms of the compound. This law still exists with a slight change for nuclear reactions.

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

3. Avogadro's number and a mole

Chemists are interested in keeping track of quantities of particles. However, the particles are very small so chemists use a particular quantity that is convenient for counting particles. The quantity is called a *mole*. The quantity of particles in a mole is 602,000,000,000,000,000,000,000. The mole can be represented more easily in scientific notation as 6.02×10^{23} . This is a very large number because many, many small particles (atoms or molecules) make up a mole. The number 6.02×10^{23} is sometimes called Avogadro's number.

Research to find the significance of Avogadro's number and a mole. Record your findings in your *Active Chemistry* log.

Then, to appreciate how huge a mole is, answer the following question:

Imagine there are 7 billion people (7×10^9 people, which is approximately the human population of the world) and they are given the task of dropping \$1-bills once every second into a large hole. How long will it take 7×10^9 people to drop one mole of dollar bills into the hole? How old will you be when they complete this task?