# Activity 4 Are Atoms Indivisible?

## 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.

## 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.

## What Do You Think?

Students might wonder if they are to assume that they can see an atom of the metal. The metals have nearly the same density, conductivity, and hardness. Gold and lead atoms will have different boiling points, melting points, color, and relative mass.

## Student Conceptions

This activity gives students an historical perspective by presenting them with evidence for the existence of electrons in atoms and a simulation of the experiments responsible for the discovery of the atom's nucleus. Students are directed to make logical conclusions based on the evidence. The science introduced is entirely conceptual, but not difficult for students to believe. Students naturally agree that positive and negative charges attract, more so if they have had experience playing with magnets. Some students have difficulty with the concept that an atom is neutral even though it contains charged particles. The root of this misunderstanding is usually that the students do not understand a number line, with positive and negative numbers on opposite sides of zero.

# Investigate

## Teaching Suggestions and Sample Answers

### Teaching Notes

While doing the demonstration with the cathode tube, it should be pointed out that the electrons released from the cathode are the same regardless of what metal is used for the cathode. If you do not have a cathode-ray tube available, Thomson's series of experiments should be explained to the class, and students should be informed of Thomson's major findings. These include:

- Cathode rays could not bend when they were passed through an electric field when surrounded by a conductor, such as copper metal. They could also not be bent when the gas contained in the tube acted as a conductor.
- The cathode rays could be bent in an electric field if most of the gas in the container was evacuated.
- Cathode rays are charges of negative electricity carried by particles of matter.
- Thomson was unable to determine the mass of a negative particle. However, he did find that cathode rays were deflected by bringing a magnet near them. With the latter information, he was able to calculate the m/e of the negative particle.
- By changing the metal electrode to a different metal, he obtained the same results.

**Active Chemistry** The Periodic Table

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.

Do not to try to see the effect of a magnet on an actual television or computer monitor; you may damage the monitor.

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.

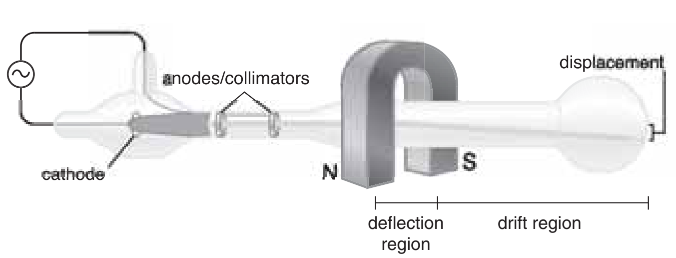
a) In a sentence or two, describe the relationship between cathode rays, the electron, and the structure of atoms.

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



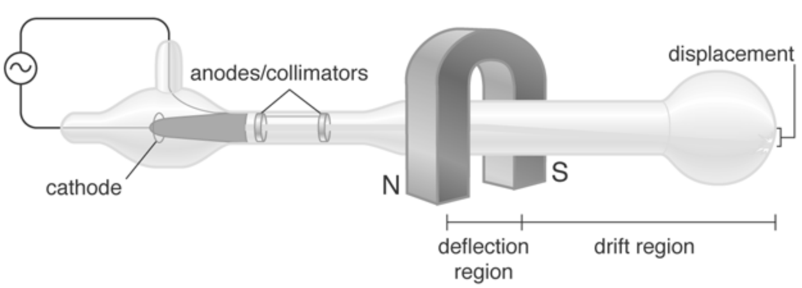
1. a) The cathode rays are deflected. TV and computer monitors are cathode-ray tubes and one must realize that bringing a magnet near the tube could permanently damage the tube. We have found that you can use a discharge tube and bring the magnet near one of the poles and see the deflection. Canal- ray tubes may be another possibility to work in seeing the deflection.

   b) It will be deflected in the opposite direction.

   c) Make certain that the magnet is strong and when it is brought near the cathode tube it does deflect in the opposite direction.

2. a) The cathode rays are emitted from the negative terminal (cathode) of a cathode-ray tube. The beam of electrons would pass through the slit and travel to the positive terminal (anode). If a magnet is brought near the tube it was found that it would cause the beam to be deflected. These negative particles were called electrons and Thomson's model of an atom had the electrons evenly spaced with the protons. This model was called the Plum-Pudding model.

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




It is helpful to make a Blackline Master of the above diagram, so students will gain a clearer perspective of the information contained in the investigation.

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

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.

3. **a–b**) We suggest that you try other arrangements of the squares. Each square must touch two other squares or each square must touch at least one other square.

4. **a**) Answers will vary but you could say that your worst estimate would be that it will take you 10,000 tries to hit the target. However, assuming that the target is probably closer to the center area, one could be lucky and hit it in 5000 tries.

5. **a**) 1 in 1,000,000 would be the worst situation and they should hit it within 500,000 tries.

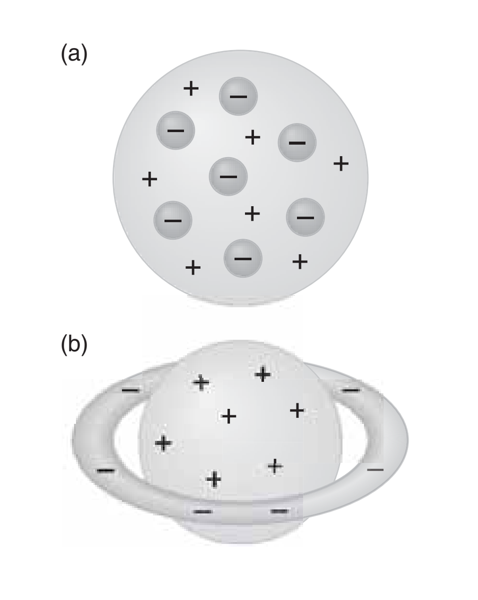
6. **a**) Rutherford was shooting alpha particles at the gold sheet and from the information he found that almost all of the positive particles had very little or no deflection. However, those that hit the center of the target were totally repelled. He also knew that like charges repel and so it was easy for him to draw this conclusion.

**Active Chemistry** The Periodic Table

## Chem Talk

### 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.

**Chem Words**

**electron:** a subatomic particle that occurs outside of the nucleus and has a charge of –1 and mass of $9.109 \times 10^{-28}$g

#### 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

**Chem Tip:**

The Greeks said that the atom was uncuttable and used the word "a-tom." The book written by Leon Lederman, *The God Particle* discusses the history of a-tom. Lederman points out that scientists have searched for the a-tom over the centuries and of course they have not found that particle that cannot be broken down any further. Scientist have now gone beyond protons, electrons, neutrons of the atom and look at the quarks, leptons, etc. The more we know the further we are able to go and so the search for the "a-tom" will continue. A video that is recommended to introduce the concept of small and large sizes is called " Powers of Ten."

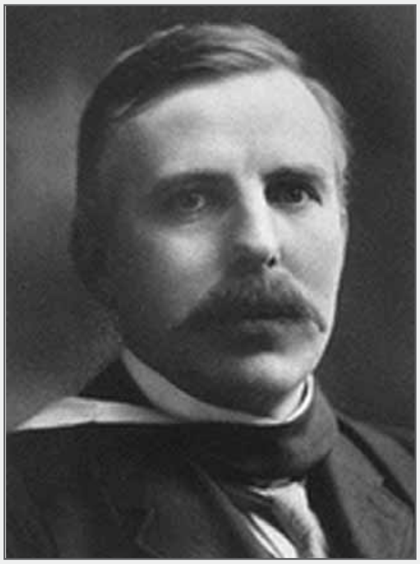
Prior to Thomson's work with cathode rays many scientists were not sure that the cathode rays that were being produced were negatively charged. Scientists used partially evacuated tubes and a high-voltage source to produce radiation in the tube. Since the rays originated at the negative terminal or the cathode they were called cathode rays. They could not see these rays without the help of glass or other materials that could cause them to fluoresce. They also noted that the rays traveled in a straight line and if a magnetic or electric field were brought near the rays, it would cause them to be deflected. Thomson found that the cathode rays would bend toward the positive pole, and from this evidence it was concluded that the cathode rays were negatively charged and were then called electrons.

Thomson tried to determine the charge of an electron but was unable to arrive at a satisfactory answer. What he did succeed in doing was finding the ratio of the charge to mass of an electron. Thomson determined that this ratio was $1.759\ 10^8$ C/g. (A coulomb (C) is defined as an amp-sec.)

Robert Millikan followed up on Thomson's work and did an experiment that was called the "Oil-drop Experiment."

From this experiment he was able to calculate the charge of an electron as $1.60 \times 10^{-19}$ C, and using Thomson's charge-to-mass ratio he was able to determine the mass of an electron:

$$\text{Mass of electron} = \frac{(-1.60 \times 10^{-19}\ \text{C})}{(-1.759 \times 10^{8}\ \text{C/g})}$$
$$= 9.10 \times 10^{-28}\ \text{g.}$$



Ernest Rutherford

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.

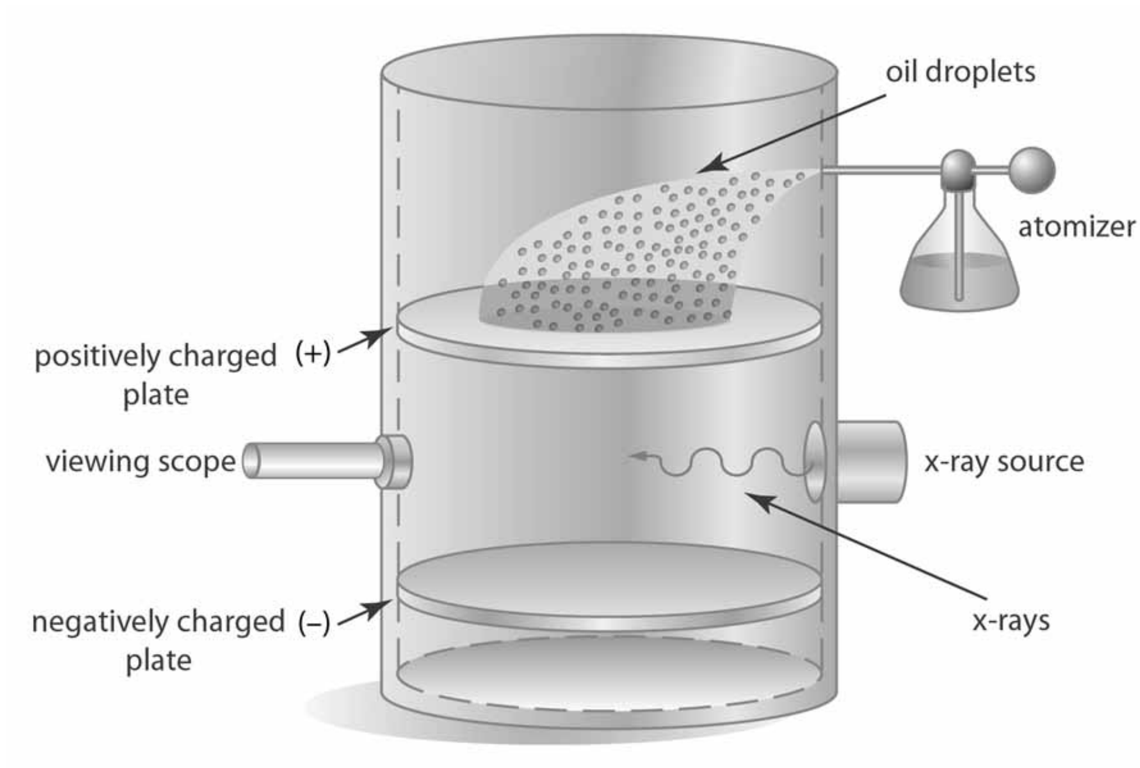
The story of Rutherford's discovery of the atomic nucleus is best told by Rutherford himself. Examining the deflection of high-speed alpha particles as they passed through sheets of gold foil, Rutherford and his student Hans Geiger noticed that some particles were scattered through larger angles than 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 $1.673 \times 10^{-24}$g and it has a charge of +1

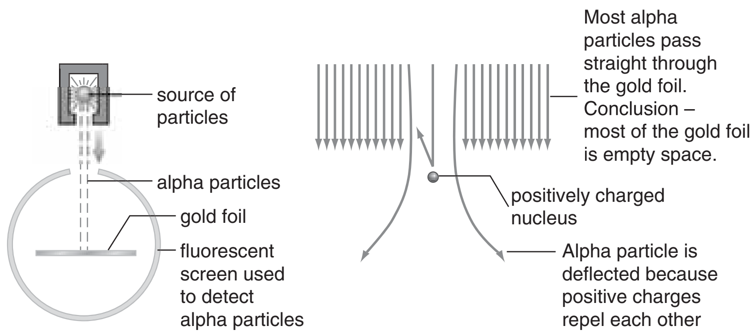
Experimentation that was done a few years later showed that the mass of an electron is about 1/1836 of the mass of a proton.




*The atomizer is used to spray oil droplets in the cylinder. A small opening allows a droplet to fall through. By knowing the charge on the plates Millikan was able to determine the charge on the particle. He found that the simplest charge would be* $1.60 = \times 10^{-19}$ *C.*

**Active Chemistry** The Periodic Table

**RUTHERFORD'S EXPERIMENT**




**Experimental setup** **Observed results**

## Checking Up

1. What is an electron?
2. Thomson's model of an atom is sometimes referred to as the "plum-pudding" model. (A plum pudding is a heavy pudding with raisins mixed into it.) 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?

### 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
($k = 9.0 \times 10^9$ N $m^2/C^2$),
$q$ 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.

# ChemTalk

## Checking Up

1. An electron is a subatomic particle of the atom and is located outside of the nucleus.
2. Thomson felt that the electrons were evenly distributed around the atom with an even number of protons evenly distributed.
3. Rutherford was surprised because he was using Thomson's model and he expected the alpha particles to be deflected only when they came near a proton.
4. The nucleus of the atom at this time was said to be very dense and contained the positive charge due to the presence of protons. The nucleus also made up most of the mass of the atom.

## 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.

## Chemistry to Go

1. The students' backgrounds have probably already helped them in arriving at acceptable answers. They know that unlike charges attract each other and this would probably lead the students to think that the electrons and protons are close to each other. More information is needed before they will realize and understand that the electrons can be at different distances outside the nucleus of the atom and still be at ground-state energy level.

2. If students think of the atom consisting of protons and electrons, then they would conclude that the atom could be broken down into smaller particles. However, we want to make sure that they understand that the properties of the element are lost when the atom is broken down into electrons and protons.

3.

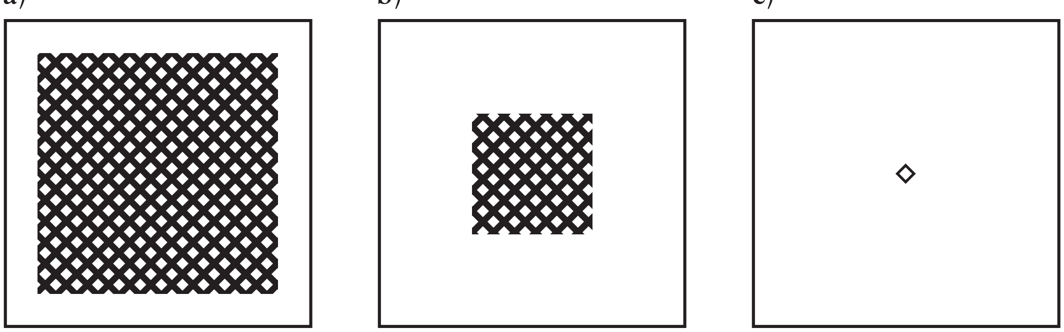
| Particle of the Atom | Location | Purpose |
|---|---|---|
| Proton | Nucleus | Positive part of atom |
| Electron | Near but outside the nucleus | Negative part of atom |

4. The atomic number was defined in the **Reflecting on the Activity and the Challenge** as the number of electrons the neutral atom would contain. Then it should seem obvious that you need the same number of protons in the atom in order for it to be neutral. The protons reside in the nucleus so we can say that lead has 82 protons, iron has 26 protons, and copper has 29 protons.

5. Chlorine would have 17 electrons because an atom is defined as being a neutral particle. The atomic number implies that it contains 17 protons and would require 17 electrons to make the atom neutral.

6. The choice is "c" and this would best represent Rutherford's experiment. He found that most of the alpha particles passed straight through with some being slightly deflected. However, in some cases the alpha particle would be totally repelled and he drew the conclusion that there must be a very small dense site of where the nucleus was located and this nucleus contained protons.

a) b) c)



## 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.

*Joseph Proust*

## Inquiring Further

1. **An atomic timeline**
   - The ancient Greeks started the process when they thought that materials must be made up of small or tiny indivisible particles and they called them *atomos*.
   - Dalton established the atomic theory and what he called the postulates.
   - The laws of conservation of matter and mass were supported by Dalton's atomic theory.
   - Thomson was given credit for the discovery of the electron.
   - Rutherford's work with gold foil and bombarding it with alpha particles was able to establish that the atom contained a very dense nucleus.
   - The future waits for Bohr's work and the development of the quantum theory.

2. **John Dalton's Atomic Theory**

   We have learned how to break the atom up into sub particles, like electrons, protons, and neutrons. And now we are able to go further and find quarks, leptons, etc. Overall, the theory still holds and it is still used even though we have shown that the atom can be broken down.