



**Figure 2.13** Alchemists believed that “base” (meaning lower value) metals, such as lead and copper, could be changed into gold.

From very early times, people have wondered why matter behaves as it does. Ancient Greek philosophers thought that all matter was made out of fire, water, earth, and air. They called these four substances “elements.” In their view, everything in the physical world was a combination of these four elements, and had varying properties of hotness, dryness, coldness, and wetness.

Hands-on investigations of matter were carried out for many centuries by people known as alchemists (see Figure 2.13). Part pharmacist, part mystic, alchemists practised their craft in Europe and the Middle East. Alchemists developed many useful procedures, such as distillation, and described the properties of many materials. They were secretive about their findings, however. Many invented their own shorthand symbols and secret codes so nobody else could understand their findings.

The current view of the elements began to develop several hundred years ago. Sir Francis Bacon (1561–1626) published a book arguing that science should be built on experimental evidence rather than on thought. Robert Boyle (1627–1691) recognized that elements could be combined to form compounds. Although he did not identify which materials were elements and which were compounds, his description laid the groundwork for our modern definition.

Bacon’s ideas about scientific inquiry and Boyle’s ideas about elements and compounds led to a widespread search for elements. Can you guess what kinds of discoveries followed?

### Taking Matter Apart

How did scientists search for elements? They learned to take matter apart by ordinary chemical means until it would not break down any further. In this way, they were able to determine if a substance was a pure substance or a mixture.

During the seventeenth and eighteenth centuries, scientists worked with matter by heating, burning, mixing, and cooling. Antoine Lavoisier (1743–1794) was a pioneer in the field (see Figure 2.14). He defined elements as pure substances that cannot be decomposed (broken down) into simpler substances by means of a chemical change. We still use part of his definition today. Lavoisier identified 23 pure substances as elements.

### Did You Know?

In Lavoisier’s time it was not easy to make a living as a chemist. To support his family and his work in chemistry, Lavoisier took on a second job, working for a tax-collecting firm. However, there was a revolution in France, and people were angry about being taxed. Lavoisier was arrested, thrown into jail, and guillotined (beheaded). The world will never know what other secrets of chemistry Lavoisier could have uncovered.

One of Lavoisier's most successful techniques as an experimenter was his careful measurement of mass. He measured the mass of all the substances involved in a chemical change. These measurements helped him make accurate inferences about what was happening to the substances.

Lavoisier was one of the earliest chemists to use this "balanced" view of chemical changes. What Lavoisier observed during his experiments is what we now call the law of conservation of mass. You can repeat Lavoisier's observations in the next investigation.

#### The Law of Conservation of Mass

- In a chemical change, the total mass of the new substances is always the same as the total mass of the original substances.

Lavoisier's emphasis on measuring mass inspired other scientists to decompose compounds into elements and to measure the mass of each element. The results of their experiments led to the development of the **law of definite composition**.

#### The Law of Definite Composition

- Compounds are pure substances that contain two or more elements combined together in fixed (or definite) proportions.

Water is one example of the law of definite composition. Pure water always contains the elements hydrogen and oxygen combined together in the following proportions: 11% hydrogen and 89% oxygen by mass. These proportions hold true no matter where the water is obtained. Hydrogen peroxide, which is very different from water, contains the same two elements but in different proportions: 6% hydrogen and 94% oxygen. These proportions hold true for every sample of hydrogen peroxide.

Pure substances have constant composition, and therefore they also tend to have constant, unvarying properties. An unknown substance can be identified by measuring a property and comparing it to known values. For example, you might determine the density or melting point of an unknown metal and compare this value to the value found in a scientific table, such as Appendix C.

**Figure 2.14** Marie-Anne Lavoisier was invaluable to her husband's research. She read the scientific articles in English and translated the articles she thought would interest her husband.



## INQUIRY

## INVESTIGATION 2-B

# Mass and Chemical Change

The greatest challenge when investigating mass during a chemical change is to collect and measure all of the products. Be sure to carefully measure the mass of all the starting materials and all the products.

## Question

What happens to mass during a chemical change?

## Hypothesis

On the basis of what you know about the law of conservation of mass, state a hypothesis about the relationship of the mass of the reactants and the mass of the products.

## Safety Precautions



- Handle the chemicals with care. If you spill copper (II) sulfate solution on your skin, wash it off immediately with cool water and inform your teacher.

## Apparatus

balance  
Erlenmeyer flask  
rubber stopper for flask  
graduated cylinder  
scoopula

## Materials

steel wool (2 cm<sup>3</sup>)  
copper (II) sulfate solution

## Procedure

- Obtain all supplies needed.
- Put on safety goggles and aprons.
- Make an observation chart like the one shown below.
- Describe the reactants (copper [II] sulfate solution and steel wool) on your chart.
- Measure** the mass of the empty Erlenmeyer flask, stopper, and steel wool. **Record.**
- Measure** 20 mL of copper (II) sulfate solution in a graduated cylinder. Pour the solution into the Erlenmeyer flask. **Measure** the mass. **Record.**

	Starting Substances (Reactants)			Products
	copper (II) sulfate solution	steel wool	flask and stopper	
General Observations				
Mass				



- 7 Calculate** the mass of the solution by subtracting the mass of the flask from the combined mass of the flask and solution. **Record.**
- 8 Drop** the steel wool in the Erlenmeyer flask with the copper (II) sulfate solution. Quickly place the stopper on the flask. Gently swirl the flask so the solution completely covers the steel wool.
- 9 Make observations** immediately and after 5 min.
- 10 Measure** the mass of the entire system (flask, solution, stopper, etc.). **Record.**
- 11 Pour** the remaining solution and steel wool into a special bucket provided by the teacher. You may need to use the scoopula to help retrieve the steel wool. **Do not pour the solution down the sink.** Chemicals poured down the drain will eventually end up in the water system or react with the pipes of the sewage system.
- 12 Clean** all equipment and return it to the correct location.

### Skill

#### FOCUS

For tips on estimating and measuring, turn to Skill Focus 5.

## Analyze

1. Did a chemical change take place? How do you know?
2. What was the mass of the starting materials in the reaction?
3. What was the mass of the products in the reaction?

## Conclude and Apply

4. Do your observations support your hypothesis? Why or why not?
5. Experimental errors affect the accuracy of measurements and calculated results. These errors mainly come from limitations of the equipment used and from the design of the experiment. What were your sources of experimental error in this investigation?

## Extend Your Skills

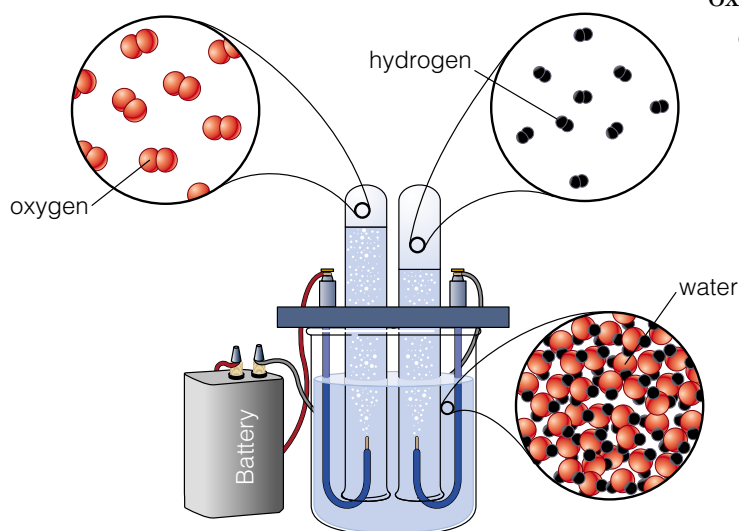
6. You could mix baking soda with vinegar to create carbon dioxide, water, and sodium acetate. If you started out with 5.6 g of baking soda and 4.9 g of vinegar, could you create 10.5 g of carbon dioxide gas? Why or why not? Design an investigation to check your answer. Carefully consider your selection of apparatus. How will the apparatus you use affect the accuracy of your results?

## Career **CONNECT**

If you think that all chemists work in laboratories, think again! You can find chemists at work as teachers, technical writers, patent lawyers, geologists, dentists, food and drug inspectors, soil scientists, and X ray technicians. In what other fields is a background in chemistry necessary? Name five other professions in which a knowledge of chemistry is required. Then choose a career in chemistry that interests you and research the type of training needed for the job. Why does the job appeal to you? What would a chemist in your chosen occupation do on a day-to-day basis?

## New Discoveries

By the nineteenth century, there was a new way to investigate matter. The “voltaic pile” — a device we now call a battery — was invented. The voltaic pile was not as convenient as today’s dry cells, but it delivered a reliable supply of electric current. Scientists began using voltaic piles to pass electricity through water. They discovered hydrogen and oxygen gases were produced, and that the water level fell slightly. The scientists inferred that water had been decomposed into hydrogen and



oxygen. The process of decomposing a chemical compound by passing an electric current through it is called **electrolysis** (see Figure 2.15). Scientists used electrolysis to isolate the elements potassium, sodium, magnesium, calcium, strontium, and barium.

**Figure 2.15** Water can be decomposed into the elements hydrogen and oxygen through the process of electrolysis. The two inverted test tubes were full of water when the experiment began. This drawing represents the results after about 10 min. Notice the volume of hydrogen produced is twice that of oxygen.

## Collect the Elements

The most plentiful elements in Earth’s crust include oxygen, silicon, aluminum, iron, magnesium, calcium, phosphorus, and sodium. What do you know about these elements? What would you like to know about them?

### Procedure Communication and Teamwork

1. Choose any three of the elements listed above and start an “element collection.” Write the name of each element you have chosen on an index card, or choose another way to record what you learn. You may want to use a computer program.
2. Use print and electronic resources to research your chosen elements. Find out the following information for each of your elements: major physical properties, major chemical properties, who discovered the element and in what year, current uses,

## Find Out ACTIVITY

and interesting facts. Record the information you find. Include a photograph or drawing of the element. You might even be able to obtain a sample of the element.

3. Make a class list of recommended web sites or other resources that are a good source of information about the properties of elements.
4. Share your information with other students. You may wish to exchange cards, make a bulletin board display, or have a class presentation.

### Extension

Add cards for other elements you learn about in this unit.

## Dalton's Atomic Theory

In earlier studies, you used the particle model of matter to explain your observations of matter. However, the particle model cannot explain everything you have just learned about pure substances. It cannot, for example, explain what happens in the electrolysis of water. The properties of the compound, water, are different from the properties of the elements that make it up, hydrogen and oxygen. Therefore, the particles of water must be different from the particles of hydrogen and the particles of oxygen. The particle model of matter cannot account for particles of different substances combining or decomposing. John Dalton (1766–1844) introduced a new way of explaining chemical facts and laws in his atomic theory.



Figure 2.16 John Dalton

### Dalton's Atomic Theory

- All matter is made up of small particles called atoms.
- Atoms cannot be created, destroyed, or divided into smaller particles.
- All atoms of the same element are identical in mass and size. Atoms of one element are different in mass and size from the atoms of other elements.
- Compounds are created when atoms of different elements link together in definite proportions.

Dalton's model (see Figure 2.17) uses the idea that elements are different because their “particles” (atoms) are different. This model led to more accurate definitions of element and compound.

An **element** is a pure substance made up of one type of particle, or atom. Each element has its own distinct properties and cannot be broken down into simpler substances by means of a chemical change. **Compounds** are pure substances that are made up of two or more elements chemically combined together. Compounds can be broken down into elements again by chemical means.

### DidYouKnow?

The history of chemistry is filled with tales of nearly simultaneous discovery. For example, the English scientist Joseph Priestley and the Swedish researcher Karl Wilhelm Scheele discovered oxygen at about the same time. Priestley published first and got all the credit for its discovery. The name “oxygen” was suggested by the French chemist Antoine Lavoisier.

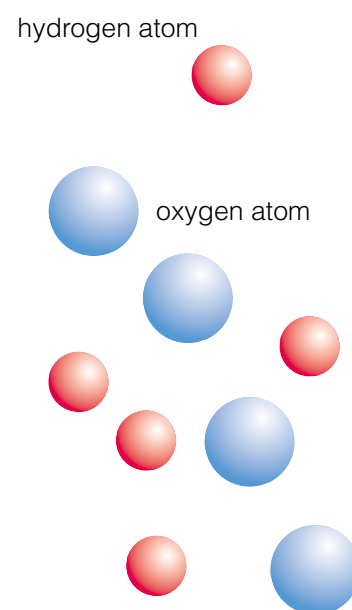
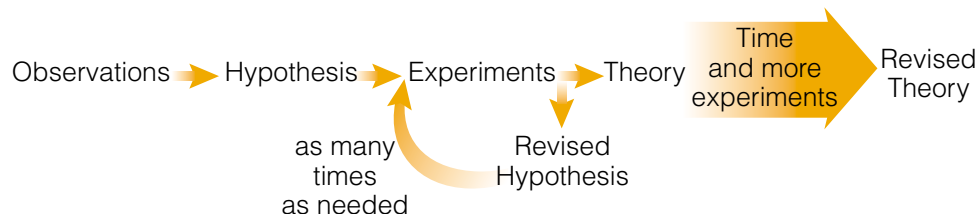


Figure 2.17 Dalton thought of atoms as billiard balls. He pictured water with equal numbers of smaller hydrogen and larger oxygen atoms.

## Laws, Theories, Models, and Observations

In science, *laws* do not explain anything. Laws just *describe* and *summarize* what happens. Theories are imaginative ways to *explain why* something happens. During scientific experiments, scientists observe how matter behaves and reacts. Thousands of observations and hundreds of experiments are often made before a theory is accepted by scientists (see Figure 2.18).



**Figure 2.18** Many observations and experiments are needed before a hypothesis can become an accepted theory.

Scientific ideas may change over time as more evidence is gathered. Most of Dalton's atomic theory has stood the test of time. However, scientists have discovered that atoms are not the smallest particles. What do you suppose could be smaller than an atom?

Scientists who investigate the structure of the atom are faced with several challenges. How can they describe something they cannot see? What tests can reveal the inner workings of such tiny particles? Even with modern instruments, it is impossible to directly observe many aspects of atomic behaviour.

Scientific models help to picture structures or processes that cannot directly be seen. A good model can give a satisfactory explanation of what can be observed indirectly, and of what scientists can infer from these observations. Making inferences and constructing mental models requires practice and good reasoning skills.

It took many years and the work of scientists from many countries to devise the model of atomic structure in use today. Read the story of some of their discoveries on the next page. Notice how each scientist built on the achievements of other scientists in other parts of the world.

### INTERNET CONNECT

[www.mcgrawhill.ca/links/sciencefocus9](http://www.mcgrawhill.ca/links/sciencefocus9)

The discovery of sub-atomic particles inspired many scientists to ask new questions. What else would *you* like to know about atomic structure? Make a list of three questions. Go to the web site above, and click on **Web Links** to find out where to go next. Research to find answers for your questions. If you have asked questions which science is not yet able to answer, speculate which discoveries are necessary in order for to establish the answers.

## A Brief History of Atomic Models

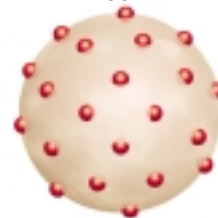
British physicist J.J. Thomson studied rays in gas discharge tubes. He inferred that the rays were streams of negatively charged particles (**electrons**). Since atoms do not normally have a charge, Thomson reasoned there must also be positively charged particles in the atom. Thomson's model is sometimes called the “plum pudding” or “raisin bun” model, because he pictured the negatively charged electrons stuck in the positively charged mass like raisins in a bun. How was this model different from Dalton's “billiard ball” model in Figure 2.17 on page 111?

Ernest Rutherford was a scientist from New Zealand who worked for a while at McGill University in Montreal. He hypothesized that almost all of the mass of the atom was in the centre of the atom, which he named the **atomic nucleus**. The rest of the atom was mostly empty space occupied by very small electrons. The name **proton** was given to the positively charged particles making up the nucleus. Rutherford predicted there was another particle in the nucleus, along with the proton. Years later, British physicist James Chadwick proved him right. Chadwick discovered **neutrons**, uncharged particles in the nucleus with a mass slightly greater than protons.

The Danish physicist Niels Bohr studied with Rutherford. Both Bohr and Rutherford pictured the atom like a miniature solar system. Electrons rotated around the nucleus like planets rotating around the Sun. Although this model described hydrogen atoms, it was not useful in describing many of the atom's properties, so Bohr refined the model. He suggested that electrons move around the nucleus in fixed pathways called electron shells. The exact path and position of electrons could not be determined precisely, but their energy level could be determined.

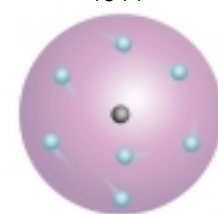
A further refinement to the model of atomic structure came through the work of French physicist Louis de Broglie, Austrian physicist Erwin Schrödinger, and many others. They agreed that electrons have distinct energy levels. They suggested that there was an area around the nucleus where electrons were most likely to be found. This region was called the electron cloud. In the electron cloud model, electrons are more likely to be closer to the nucleus than farther away. Schrödinger and de Broglie also developed a mathematical model. They suggested that the electron's behaviour could be described with equations very similar to those that describe waves. The answers to the equations give the probability of finding the electrons at certain places in the atom.

1897



**Figure 2.19A** Thomson's “plum pudding” model

1911



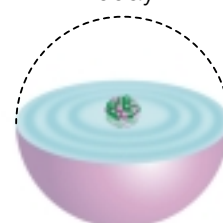
**Figure 2.19B** Rutherford's planetary model

1913



**Figure 2.20A** Bohr's atomic model

Today



**Figure 2.20B** The electron cloud model



# Across Canada

The metallic element cobalt can be used in the treatment of cancer. Canada led the world in this life-saving application, and Dr. Sylvia Fedoruk was one of its pioneers. She was chief medical physicist for the Saskatchewan Cancer Foundation for 35 years, and during this time she helped pioneer one of the world's first nuclear medicine scanning machines.

Sylvia was born in Canora, Saskatchewan. As a teenager, she loved sports, including hockey, basketball, volleyball, track, and curling. She has remained active in athletics, and in 1986 she was inducted into the Canadian Curling Hall of Fame. Sylvia has also been active in public life. From 1988 to 1994, she served as Lieutenant-Governor of Saskatchewan. She has promoted causes such as environmental conservation and excellence in education.

When Sylvia Fedoruk entered physics, there were few women in the field. When she became Saskatchewan's Lieutenant-Governor, she was the first woman in that office. What is her advice to young women of today? "Set personal goals. Dream of doing better than you ever thought you could. If you dream of accomplishing the impossible, you can!"



Dr. Sylvia Fedoruk

## Off the Wall

How much of the atom is empty space? Consider this analogy: If the nucleus were the size of a grain of sand, the atom would have a diameter bigger than a football field.

## TOPIC 3 Review

1. How did methods of scientific inquiry help in the search for elements?
2. In your own words, write out the two laws mentioned in this topic.
3. Compare the particle model of matter and Dalton's atomic theory.
4. What is the difference between a law and a theory?
5. Define element and compound.
6. Name the scientists who discovered the proton, the electron, and the neutron. Why were these discoveries significant?
7. Copy and complete the following table to summarize what you know about the parts of an atom.

	Electron	Proton	Neutron
<b>Charge</b>			
<b>Mass</b>	very light	heavy	
<b>Location</b>			

8. **Apply** Air contains some carbon dioxide, but you exhale more carbon dioxide than you inhale. How would you design an experiment to confirm this statement?

## STRETCH Your Mind

Could there be particles even smaller than a proton or electron? What would such a particle do? What would it be called? Make some guesses about the answers to these questions. Then use the library or Internet to research "quarks" and Canadian Nobel Prize winner, Richard E. Taylor.



Have you met with your group yet to design your End of Unit Investigation: Tough as Nails?

If you need to check an item, Topic numbers are provided in brackets below.

## Key Terms

chemistry	physical change	electrolysis	electrons
caustic	chemical change	Dalton's atomic theory	atomic nucleus
homogeneous	law of conservation of mass	element	proton
heterogeneous	law of definite composition	compounds	neutrons

## Reviewing Key Terms

- In your notebook, write the difference between each of the following terms.
  - a heterogeneous mixture and a homogeneous mixture (1)
  - a physical change and a chemical change (2)
  - the law of conservation of mass and the law of definite composition (3)
  - an element and a compound (3)
  - an observation and a theory (3)
- Copy the following sentences in your notebook, and fill in the blanks. (1–3)
  - If a substance has the ability to burn in oxygen, it has the property of \_\_\_\_\_. (2)
  - A homogeneous mixture can also be called a \_\_\_\_\_. (1)
  - A heterogeneous mixture can also be called a \_\_\_\_\_. (1)
  - A substance that cannot be broken down into simpler substances is an \_\_\_\_\_. (3)
  - The physical property of matter known as mass per unit volume is called \_\_\_\_\_. (2)
- List the main points of Dalton's atomic theory. (3)
- What is the difference between a compound and a mechanical mixture? Give an example of each. (3)
- Make a sketch of the electron cloud model. Label the locations of the electrons, protons, neutrons, and atomic nucleus. (3)
- When a fire burns a log of wood, the mass of the ashes left behind is much less than the mass of the original log. Is this an exception to the law of conservation of mass? Explain (3).
- Several famous chemists have been discussed in Topics 1–3. Whose discovery did you find most interesting? Explain your choice. (1–3)
- The element bismuth has a low melting point. How does this physical property help explain how the automatic sprinkler (shown below) works? (2)



The trigger in this overhead sprinkler is made from bismuth.

## Understanding Key Concepts

- What does WHMIS stand for? Why was the WHMIS system developed? (1)
- List three examples of chemical changes and three examples of physical changes. (2)
- Explain electrolysis. (3)