1.3

1 FOCUS

Objectives

1.3.1 **Describe** how Lavoisier transformed chemistry.

1.3.2 **Identify** three steps in the scientific method.

1.3.3 **Explain** why collaboration and communication are important in science.

Guide for Reading

Build Vocabulary L2

Word Forms When discussing the two types of variables, explain that one meaning of *manipulate* is "to manage or control" and one meaning of *response* is "to answer or act in turn."

Reading Strategy L2

Use Prior Knowledge Before students read the section, ask them what they know about the scientific method.

2 INSTRUCT

Connecting to Your World

Have students read the opening paragraph and look at the photo. Ask, **What made Fleming different from other scientists who had seen this mold?** *(Fleming recognized the importance of this discovery. He assumed that the mold had released a chemical that prevented the growth of bacteria.)*

Alchemy

Relate L2

Students who have read the Harry Potter books will be familiar with the name of one alchemist, Nicolas Flamel (1330–1414), who wrote a book about the philosopher's stone. Alchemists believed that the philosopher's stone could change base metals into gold.

1.3 Thinking Like a Scientist

Guide for Reading

Key Concepts

- How did alchemy lay the groundwork for chemistry?
- How did Lavoisier help to transform chemistry?
- What are the steps in the scientific method?
- What role do collaboration and communication play in science?

Vocabulary

scientific method
observation
hypothesis
experiment
manipulated variable
responding variable
theory
scientific law

Reading Strategy

Building Vocabulary After you read this section, explain the difference between a theory and a scientific law.

Connecting to Your World

In 1928, Alexander Fleming, a Scottish scientist, noticed that a bacteria he was studying did not grow in the presence of a yellow-green mold. Other scientists had made the same observation, but Fleming was the first to recognize its importance. He assumed that the mold had released a chemical that prevented the growth of the bacteria. That chemical was penicillin, which can kill a wide range of harmful bacteria. In 1945, Fleming shared a Nobel Prize for Medicine with Howard Florey and Ernst Chain, who led the team that isolated penicillin. In this section you will study the methods scientists use to solve problems.

Alchemy

The word *chemistry* comes from *alchemy.* Long before there were chemists, alchemists were studying matter. Alchemy arose independently in many regions of the world. It was practiced in China and India as early as 400 B.C. In the eighth century, Arabs brought alchemy to Spain, from where it spread quickly to other parts of Europe.

Alchemy had a practical side and a mystical side. Practical alchemy focused on developing techniques for working with metals, glass, and dyes. Mystical alchemy focused on concepts like perfection. Because gold was seen as the perfect metal, alchemists were searching for a way to change other metals, such as lead, into gold. Although alchemists did not succeed in this quest, the work they did spurred the development of chemistry.

Alchemists developed the tools and techniques for working with chemicals. Alchemists developed processes for separating mixtures and purifying chemicals. They designed equipment that is still used today, including beakers, flasks, tongs, funnels, and the mortar and pestle in Figure 1.15. What they did not do was provide a logical set of explanations for the changes in matter that they observed. That task was left for chemists to accomplish.

Figure 1.15 A bowl-shaped mortar and a club-shaped pestle are used to grind or crush materials such as herbs, spices, and paint pigments. The mortar and pestle in the photograph is made of porcelain, which is a hard material.

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 1.3
- **Core Teaching Resources,** Section 1.3 Review
- **Transparencies,** T5–T6
- **Laboratory Manual,** Lab 1
- **Small-Scall Chemistry Laboratory Manual,** Lab 1

Technology

- **Interactive Textbook with ChemASAP,** Assessment 1.3
- **Go Online,** Section 1.3

An Experimental Approach to Science

By the 1500s in Europe, there was a shift from alchemy to science. Science flourished in Britain in the 1600s, partly because King Charles II was a supporter of the sciences. With his permission, some scientists formed the Royal Society of London for the Promotion of Natural Knowledge. The scientists met to discuss scientific topics and conduct experiments. The society's aim was to encourage scientists to base their conclusions about the natural world on experimental evidence, not on philosophical debates.

In France, Antoine-Laurent Lavoisier did work in the late 1700s that would revolutionize the science of chemistry. **Lavoisier helped to transform chemistry from a science of observation to the science of measurement that it is today.** To make careful measurements, Lavoisier designed a balance that could measure mass to the nearest 0.0005 gram.

One of the many things Lavoisier accomplished was to settle a long-standing debate about how materials burn. The accepted explanation was that materials burn because they contain phlogiston, which is released into the air as a material burns. To support this explanation, scientists had to ignore the evidence that metals can gain mass as they burn. By the time Lavoisier did his experiments, he knew that there were two main gases in air—oxygen and nitrogen. Lavoisier was able to show that oxygen is required for a material to burn. Lavoisier's wife Marie Anne, shown in Figure 1.16, helped with his scientific work. She made drawings of his experiments and translated scientific papers from English. Figure 1.17 shows a reconstruction of Lavoisier's laboratory in a museum in Paris, France.

At the time of the French Revolution, Lavoisier was a member of the despised royal taxation commission. He took the position to finance his scientific work. Although he was dedicated to improving the lives of the common people, his association with taxation made him a target of the revolution. In 1794 he was arrested, tried, and beheaded.

Checkpoint ***What long-standing debate did Lavoisier help settle?***

Figure 1.16 This portrait of Antoine Lavoisier and his wife Marie Anne was painted by Jacques Louis David in 1788. The painting includes some equipment that Lavoisier used in his experiments.

Figure 1.17 This reconstruction of Lavoisier's laboratory is in a museum in Paris, France.
Interpreting Photographs ***What objects do you recognize that are similar to objects that you use in the laboratory?***

21

Facts and Figures

How Oxygen Got Its Name

The ancient Greeks thought that flammable objects contained the element fire, which George Stahl (1660–1734) named *phlogiston.* During burning, phlogiston transferred to the air. Phlogiston-rich air (now called nitrogen) did not support burning; objects burned brightly in phlogiston-poor air. Lavoisier measured the mass of metals before and after heating in a closed container. He showed that the mass gained by the metal was lost by the air. Thus, the process of burning involved a gain of matter, not a loss of phlogiston. Lavoisier named the portion of air that supported combustion *oxygen.*

An Experimental Approach to Science

CLASS Activity

Invisible Ink L2

Purpose Students make hypotheses based on a set of observations.

Materials phenolphthalein, 70% solution of 2-propanol, small artist's paintbrush, sheets of copy paper or white butcher paper, household glass cleaner containing ammonia

Advanced Prep Prepare a solution of phenolphthalein in alcohol (250 mg of phenolphthalein in 250 mL of 70% 2-propanol). Use the brush to letter messages on sheets of paper. Try messages such as "CHEM-IS-TRY" and "This is a LABOR-atory, not a lab-ORATORY." Allow the paper to dry until the messages are invisible. Then post the messages around the room in well-ventilated areas.

Procedure At intervals, spray each sheet with the glass cleaner. Ask students to hypothesize why the pink messages appear, disappear after a few minutes, and then reappear when the paper is sprayed again.

Expected Outcome Students are likely to infer that something in the cleaner caused a reversible change to something on the paper. They may infer that the material in the cleaner is volatile.

FYI

The Royal Society is the oldest scientific society in continuous existence. Robert Boyle (1627-1691) was a founding member. In *The Sceptical Chymist*, Boyle emphasized the necessity of doing experiments to test ideas that were obtained by reason. The motto of the Royal Society is *nullius in verba,* which literally means "nothing in words." The motto stresses the need for evidence.

Answers to...

Figure 1.17 Students are most likely to recognize the two-pan balance

Checkpoint how materials burn

CLASS Activity

Lorenzo's Oil L2

The story of how Augusto and Michaela Odone, on their own, developed an oil that relieved the symptoms of adrenoleukodystrophy (ALD), an inherited neurological disease afflicting their son, is an excellent example of "ordinary people" applying the scientific method. This story is told in the movie *Lorenzo's Oil*. Rent or borrow a copy of the movie. Ask students to take notes as they watch the movie on how the Odones use observations, hypotheses, and experiments to help their son.

Word *Origins* L2

An expert is a person who has considerable knowledge about a particular field. This knowledge is built on experience. Scientists gain experience by doing experiments or reading about experiments done by other scientists.

Discuss L2

Students often think that an experiment is a failure if they do not get the "right" (expected) results. As students do experiments, help them analyze results that do not fit a hypothesis or vary widely from those of other students. Often, you can identify experimental errors that explain deviation. Also point out that scientists can gain important insights from "failed" experiments.

Using Visuals L1

Figure 1.19 If students are not clear on the difference between compare and contrast, tell students that *compare* comes from a Latin word *comparare,* meaning "to make equal with." When you compare two items, you focus on how they are similar. Then say that *contra* means "against" in Latin. Ask, **When you contrast two items, what do you focus on?** *(how the objects differ)*

Figure 1.18 Observation is an essential step in the scientific method.

The Scientific Method

A Nobel Prize winner in science once said that science is about "ordinary people doing ordinary things." Scientists have a powerful tool that they can use to produce valuable, sometimes spectacular, results. Like all scientists, the biochemist shown in Figure 1.18 is using the scientific method to solve difficult problems. The **scientific method** is a logical, systematic approach to the solution of a scientific problem. **Steps in the scientific method include making observations, testing hypotheses, and developing theories.** Figure 1.19 shows how these steps fit together.

Making Observations The scientific method is useful for solving many kinds of problems because it is closely related to ordinary common sense. Suppose you try to turn on a flashlight and you notice that it does not light. When you use your senses to obtain information, you make an **observation.** An observation can lead to a question: What's wrong with the flashlight?

Testing Hypotheses If you guess that the batteries are dead, you are making a hypothesis. A **hypothesis** is a proposed explanation for an observation. You can test your hypothesis by putting new batteries in the flashlight. If the flashlight lights, you can be fairly certain that your hypothesis is true. What if the flashlight does not work after you replace the batteries? A hypothesis is useful only if it accounts for what is actually observed. When experimental data does not fit a hypothesis, the hypothesis must be changed. A new hypothesis might be that the light bulb is burnt out. You can replace the bulb to test this hypothesis.

Replacing the bulb is an **experiment,** a procedure that is used to test a hypothesis. When you design experiments, you deal with variables, or factors that can change. The variable that you change during an experiment is the **manipulated variable,** or independent variable. The variable that is observed during the experiment is the **responding variable,** or dependent variable. If you keep other factors that can affect the experiment from changing during the experiment, you can relate any change in the responding variable to changes in the manipulated variable.

For the results of an experiment to be accepted, the experiment must produce the same result no matter how many times it is repeated, or by whom. This is why scientists are expected to publish a description of their procedures along with their results.

Word *Origins*

Experiment contains the Latin root *peri,* meaning "to try or test." The words *expert* and *experience* contain the same root. **How could experiments provide the experience for someone to become an expert?**

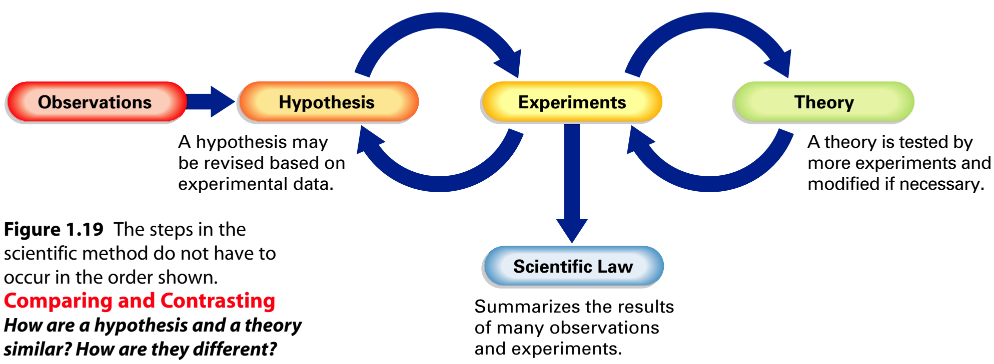


Figure 1.19 The steps in the scientific method do not have to occur in the order shown.
Comparing and Contrasting ***How are a hypothesis and a theory similar? How are they different?***

Differentiated Instruction

English Learners L1

Have English learners work with a partner to describe, act out, or illustrate in a drawing the different steps that make up the scientific method. Challenge students to identify how they used each step to solve problems in the past.

Quick LAB

Bubbles!

Purpose
To test the hypothesis that bubble making can be affected by adding sugar or salt to a bubble-blowing mixture.

Materials
- 3 plastic drinking cups
- liquid dish detergent
- measuring cup and spoons
- water
- table sugar
- table salt
- drinking straw

Procedure
1. Label three drinking cups 1, 2, and 3. Measure and add one teaspoon of liquid dish detergent to each cup. Use the measuring cup to add two thirds of a cup of water to each drinking cup. Then swirl the cups to form a clear mixture. **CAUTION** *Wipe up any spills immediately so that no one will slip and fall.*
2. Add a half teaspoon of table sugar to cup 2 and a half teaspoon of table salt to cup 3. Swirl each cup for one minute.
3. Dip the drinking straw into cup 1, remove it, and blow gently into the straw to make the largest bubble you can. Practice making bubbles until you feel you have reasonable control over your bubble production.
4. Repeat Step 3 with the mixtures in cups 2 and 3.

Analyze and Conclude
1. Did you observe any differences in your ability to produce bubbles using the mixtures in cup 1 and cup 2?
2. Did you observe any differences in your ability to produce bubbles using the mixtures in cup 1 and cup 3?
3. What can you conclude about the effects of table sugar and table salt on your ability to produce bubbles?
4. Propose another hypothesis related to bubble making and design an experiment to test your hypothesis.

Developing Theories Once a hypothesis meets the test of repeated experimentation, it may be raised to a higher level of ideas. It may become a theory. A **theory** is a well-tested explanation for a broad set of observations. In chemistry, one theory addresses the fundamental structure of matter. This theory is very useful because it helps you form mental pictures of objects that you cannot see. Other theories allow you to predict the behavior of matter.

When scientists say that a theory can never be proved, they are not saying that a theory is unreliable. They are simply leaving open the possibility that a theory may need to be changed at some point in the future to explain new observations or experimental results.

Scientific Laws Figure 1.19 shows how scientific experiments can lead to laws as well as theories. A **scientific law** is a concise statement that summarizes the results of many observations and experiments. In Chapter 14, you will study laws that describe how gases behave. One law describes the relationship between the volume of a gas in a container and its temperature. If all other variables are kept constant, the volume of the gas increases as the temperature increases. The law doesn't try to explain the relationship it describes. That explanation requires a theory.

Go Online NSTA SCiLINKS
For: Links on Scientific Methods
Visit: www.SciLinks.org
Web Code: cdn-1012

Checkpoint ***When can a hypothesis become a theory?***

Quick LAB

Bubbles! L2

Objective After completing this activity, students will be able to:
- test the hypothesis that bubble making can be affected by adding sugar or salt to the bubble-blowing mixture.

Skills Focus Observing, formulating hypotheses, drawing conclusions

Prep Time 5 minutes
Class Time 15 minutes

Safety Remind students to be careful not to draw any liquid into their mouth through the straw.

Expected Outcome Students conclude that sugar has no effect on bubble production and salt prevents bubble production.

Analyze and Conclude
1. no
2. Yes; no bubbles formed from the liquid in cup 3.
3. Sugar has no effect on bubble production, but salt stops it completely.
4. Answers might include examining the effect of temperature or dilution of the bubble-making mixture. For example, diluting the mixture can reverse the salt effect.

For Enrichment L3

Facilitate a class discussion about the experiments that students proposed for Question 4. Discuss whether or not the experiments will work. Perform two of the experiments and discuss the results. Emphasize the need to learn from "failed" experiments.

Go Online NSTA SCiLINKS

Download a worksheet on **Scientific Methods** for students to complete, and find additional teacher support from NSTA SciLinks.

Answers to...

Figure 1.19 A hypothesis and theory are both explanations. A hypothesis is only a proposed explanation; a theory is a well-tested explanation for a broad set of observations.

Checkpoint When a hypothesis meets the test of repeated experimentation, it may be become a theory.

Collaboration and Communication

CLASS Activity

Researching Collaborative Science Projects L2

Have students do research to find examples of successful collaborative projects that involved a multidisciplinary approach to solving a scientific problem. One example is the series of NASA missions to the moon in the 1970s.

Discuss L2

Stress that students should not avoid reading about science, but they should look for reliable sources and approach the news with a certain amount of healthy skepticism. Ask, **How can the Internet help people learn about advances in science?** *(Anyone can access information on the Internet.)* **What is one disadvantage of getting information from the Internet?** *(The information is not always reliable.)*

Figure 1.20 For a volleyball team to win, the players must collaborate, or work together.

Collaboration and Communication

No matter how talented the players on a team, one player cannot ensure victory for the team. Individuals must collaborate, or work together, for the good of the team. Think about the volleyball players in Figure 1.20. In volleyball, the person who spikes the ball depends on the person who sets the ball. Unless the ball is set properly, the spiker will have limited success. Many sports recognize the importance of collaboration by keeping track of assists. During a volleyball game, the players also communicate with one another so it is clear who is going to do which task. Strategies that are successful in sports can work in other fields, such as science. **When scientists collaborate and communicate, they increase the likelihood of a successful outcome.**

Collaboration Scientists choose to collaborate for different reasons. For example, some research problems are so complex that no one person could have all the knowledge, skills, and resources to solve the problem. It is often necessary to bring together individuals from different disciplines. Each scientist will typically bring different knowledge and, perhaps, a different approach to bear on a problem. Just talking with a scientist from another discipline may provide insights that are helpful.

There may be a practical reason for collaboration. For example, an industry may give a university funding for pure research in an area of interest to the industry. Scientists at the university get the equipment and the time required to do research. In exchange, the scientists provide ideas and expertise. The industry may profit from its investment by marketing applications based on the research.

Collaboration isn't always a smooth process. Conflicts can arise about use of resources, amount of work, who is to receive credit, and when and what to publish. Like the students in Figure 1.21, you will likely work on a team in the laboratory. If so, you may face some challenges. But you can also experience the benefits of a successful collaboration.

Figure 1.21 Working in a group can be challenging, but it can also be rewarding.
Applying Concepts ***What steps in the scientific method are these students using?***

24 Chapter 1

Communication The way that scientists communicate with each other and with the public has changed over the centuries. In earlier centuries, scientists exchanged ideas through letters. They also formed societies to discuss the latest work of their members. When societies began to publish journals, scientists could use the journals to keep up with new discoveries.

Today, many scientists, like those in Figure 1.22, work as a team. They can communicate face to face. They also can exchange ideas with other scientists by e-mail, by phone, and at international conferences. Scientists still publish their results in scientific journals, which are the most reliable source of information about new discoveries. Articles are published only after being reviewed by experts in the author's field. Reviewers may find errors in experimental design or challenge the author's conclusions. This review process is good for science because work that is not well founded is usually not published.

The Internet is a major source of information. One advantage of the Internet is that anyone can get access to its information. One disadvantage is that anyone can post information on the Internet without first having that information reviewed. To judge the reliability of information you find on the Internet, you have to consider the source. This same advice applies to articles in newspapers and magazines or the news you receive from television. If a media outlet has a reporter who specializes in science, chances are better that a report will be accurate.

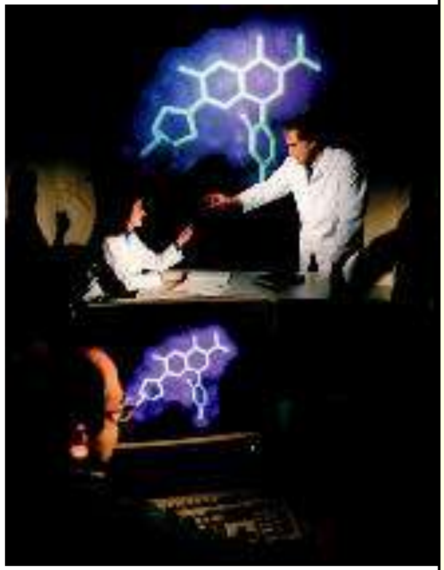


Figure 1.22 Communication between scientists can occur face to face. These chemists are using the model projected on the screen to discuss the merits of a new medicine.

1.3 Section Assessment

16. **Key Concept** What did alchemists contribute to the development of chemistry?

17. **Key Concept** How did Lavoisier revolutionize the science of chemistry?

18. **Key Concept** Name three steps in the scientific method.

19. **Key Concept** Explain why collaboration and communication are important in science.

20. How did Lavoisier's wife help him to communicate the results of his experiments?

21. Why should a hypothesis be developed before experiments take place?

22. Why is it important for scientists to publish a description of their procedures along with the results of their experiments?

23. What is the difference between a theory and a hypothesis?

24. What process takes place before an article is published in a scientific journal?

25. In Chapter 2, you will learn that matter is neither created nor destroyed in any chemical change. Is this statement a theory or a law? Explain your answer.

Connecting Concepts

Being an Informed Citizen Write a paragraph explaining how you can learn about the research that is done by scientists. Then explain how this information could help you be an informed citizen.

Interactive Textbook

Assessment 1.3 Test yourself on the concepts in Section 1.3.

with ChemASAP

FYI

The peer review of journal articles can be painful for a scientist, but it is good for science as a whole because work that is not well founded is usually not published. Some journals publish preliminary results on the Internet because the review process can take from six months to a year, or even longer. Preliminary results should be treated with caution because such results are subject to change.

3 ASSESS

Evaluate Understanding L2

Ask students to choose an everyday type of problem and explain how they would use the scientific method to solve the problem.

Reteach L1

Students may mistakenly infer that a theory "grows" into a law by constant testing and refinement. Or they may confuse a theory with a hypothesis. To clarify these concepts, ask students to describe *theory* and *law* in their own words.

Connecting Concepts

Students can learn about research from news reports, from specialized journals, and from the Internet. The more reliable information people have, the better able they are to effectively address public issues related to technology

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 1.3.

with ChemASAP

Section 1.3 Assessment

16. They developed the tools and techniques for working with chemicals.

17. He helped transform chemistry from a science of observation to a science of measurement.

18. making observations, testing hypotheses, and developing theories

19. They help increase the likelihood of a successful outcome.

20. She made drawings of his experiments and translated scientific papers.

21. It guides the design of the experiments.

22. so that other scientists can repeat the experiments and confirm the results

23. A theory is a well-tested explanation of a broad set of observations; a hypothesis is a proposed explanation for an observation.

24. Articles are reviewed by experts in the author's field of research.

25. a law. It is not an explanation.

Answers to...

Figure 1.21 testing a hypothesis and making observations

Small-Scale LAB

Laboratory Safety

L2

Objective After completing this activity, students will be able to
- demonstrate their knowledge of safe laboratory practices.

Class Time 40 minutes

Skills Focus
Observing, communicating results

Teaching Tips
- Students need to read Appendix D to answer the questions in the lab.
- Use this activity as part of an orientation in which you present your rules for working in the laboratory.
- Provide a floor plan of the room and have students record the location of safety equipment such as an eyewash fountain or a fire extinguisher.
- After you discuss the safety rules, have students sign a safety contract. For an example, see the safety contract in the *Small-Scale Chemistry Laboratory Manual*, p. 15.

Answers to Questions

Wear safety goggles at all times when working in the lab.

Tell your teacher and nearby classmates. Dispose of the glass as instructed by your teacher.

Stand back, notify your teacher, and warn other students.

Tie back long hair and loose clothing. Never reach across a lit burner. Keep flammable materials away from the flame.

Wash your hands thoroughly with soap and water.

It isn't always appropriate to dispose of chemicals by flushing them down the drain. Follow your teacher's instructions for disposal.

Small-Scale LAB

Laboratory Safety

Purpose
To demonstrate your knowledge of safe laboratory practices.

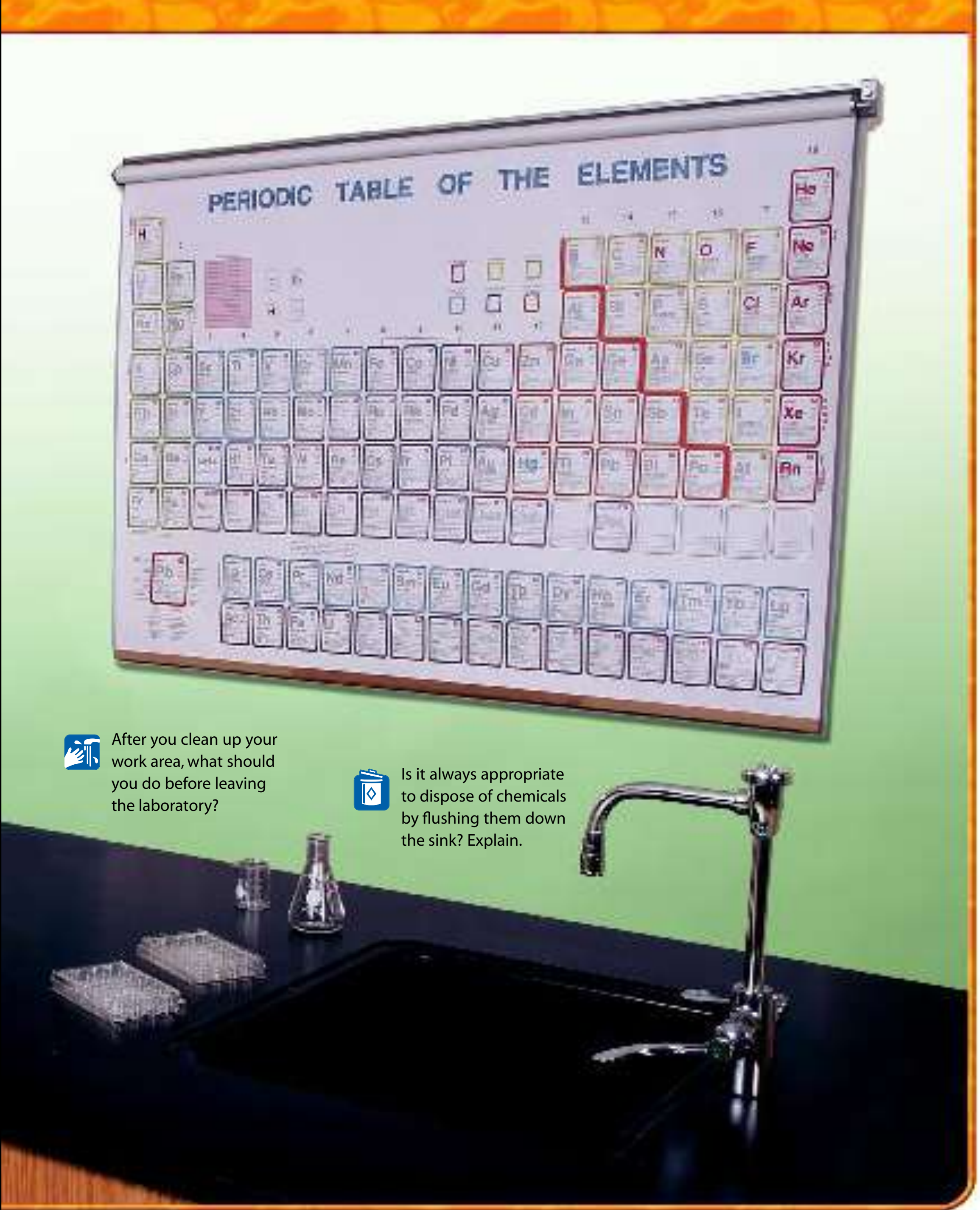
Procedure
While doing the chemistry experiments in this textbook, you will work with equipment similar to the equipment shown in the photographs. Your success, and your safety, will depend on following instructions and using safe laboratory practices. To test your knowledge of these practices, answer the question after each safety symbol. Refer to the safety rules in Appendix D and any instructions provided by your teacher.

When should safety goggles be worn?

What should you do if glassware breaks?

What precautions should you take when working near an open flame?

If you accidentally spill water near electrical equipment, what should you do?



After you clean up your work area, what should you do before leaving the laboratory?

Is it always appropriate to dispose of chemicals by flushing them down the sink? Explain.

Background

The small-scale chemistry experiments in this book are designed to help you teach students important chemical principles, not just process. For most experiments, the procedure is short and simple. In many cases students are asked to construct a grid, place a small-scale reaction surface over the grid, do the experiment, and record their results in a similar grid. Sometimes the students are told to mark the grid with black Xs. These Xs provide black and white backgrounds against which students can observe reaction mixtures.

The YOU'RE THE CHEMIST activities ask students to apply what they learned in the basic experiment. Some of these activities could be used for performance-based assessment.

For Enrichment L3

Have students look at the safety rules in Appendix D. Have each student choose five of the rules in Appendix D and make a list of what things could happen if the rule is not followed. Divide students into groups of 3 and have them share their answers with each other.