Guide for Reading

After you read the following sections, you will be able to

1–1 What Is Chemistry?
- Explain why a knowledge of chemistry is central to many human endeavors.

1–2 The Scientific Method
- List and describe the steps of the scientific method.

1–3 Safety in the Laboratory
- Explain the basic safety rules that must be followed when working in the chemistry laboratory.

Math Tool Kit

1–4 Units of Measurement
- Identify the metric units of measurement used in chemistry.

1–5 Uncertainty in Measurement
- Explain what causes uncertainty in measurements.
- Compare accuracy and precision.

1–6 Working With Numbers
- Explain how to use significant digits and scientific notation.
- Calculate percent error.
- Define density and explain how it is calculated.

1–7 Problem Solving
- Explain how dimensional analysis and conversion factors are used to solve problems in chemistry.

Integration

Physics (page 19)
Biology (page 30)

Chem Journal

YOU AND YOUR WORLD

Do you think chemistry has anything to do with your day-to-day life? In your journal, describe a typical day. Then try to identify situations during the day in which chemistry somehow played a part. After you finish this chapter, go back to your journal and ask yourself if you would change or add to your entry based on what you learned in the chapter.

1–1 What Is Chemistry?

Guide for Reading

- Why is chemistry often called the central science?

Medicines that cure diseases, fibers that go into your clothing, even the complex substances that make up your body—all are chemicals. Chemistry is the study of substances such as these. In fact, **chemistry** is the study of all substances and the changes that they can undergo.

Like all sciences, chemistry begins with curiosity. Why does a match burst into flame when it is scraped against a rough surface? Why can a stain on your favorite shirt be removed by laundry bleach? As you know, even quite ordinary substances can undergo dramatic changes. In this textbook, you will learn the reasons for changes such as these and many others.

Chemistry in Action

Chemistry is a broad science that touches nearly every aspect of human life. Throughout this textbook you will find many examples of professions and hobbies that require or use a knowledge of chemistry. We will give just two examples here.

EXAMINING A WETLANDS HABITAT As Joanie guides her canoe to an open patch of water, a light wind twitches the cattails

Figure 1–1 *Under hot, dry conditions, just one tiny spark—whether from lightning or from a neglected campfire—may result in a devastating forest fire. A fire is a drastic example of how everyday substances can undergo dramatic changes.*

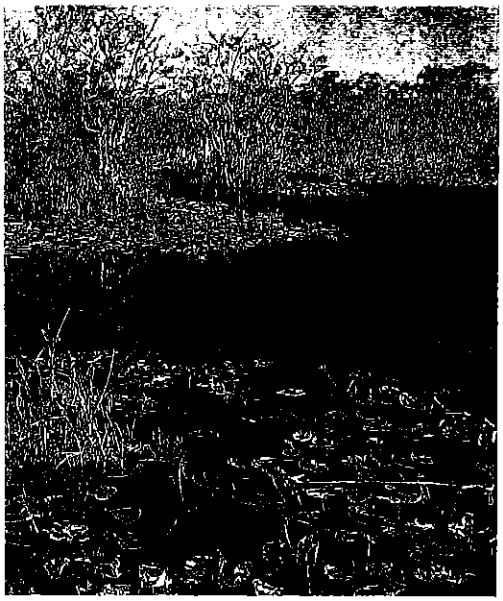


Figure 1–2 *This peaceful wetlands scene may look tranquil and inviting, but has the swamp been damaged by harmful chemicals from an oil spill? Careful analysis of samples in the chemistry laboratory may provide the answer.*

on the banks of the swamp. Picking up a long-handled scoop, she leans over the side to collect some sediment. The black ooze she brings up goes into a collection jar, which joins other jars of water and soil samples in a box at her feet. The samples will help her decide how badly the swamp has been damaged by fuel oil that leaked from a storage tank some distance away.

Joanie does not call herself a chemist—she is a wetlands ecologist—but when she returns to the laboratory, she will focus on the chemicals in her samples. She will measure the amount of oil in the water and the soil. She is trying to determine how quickly the oil is breaking down into less toxic, or harmful, substances in the water and soil.

Joanie's chemical analysis suggests that oil-eating bacteria are active in the swamp. With help from these tiny organisms and other natural processes, Joanie hopes, the habitat will gradually rid itself of the contamination.

PRESERVING HISTORICAL ARTIFACTS Joanie is not the only person interested in the swamp. Linda and Spencer are also working there, studying a canoe that sank 300 years ago.

Like Joanie, Linda and Spencer are not chemists—they are archaeologists—but they are also concerned with chemistry. They must decide what chemicals they should use to preserve the canoe. The wood looks strong, but it is not. Tiny gaps have formed in the wood where some of the fibers have decayed. The canoe is like a house with every other brick knocked out. It will collapse if it is simply hauled out of the swamp and left to dry.

The method they choose for preserving the canoe is simple and inexpensive, and the process creates no chemical hazards. These are all important considerations. First the canoe is removed from the swamp and placed into a long tank. Over a period of months, Linda and Spencer soak the canoe in a sugar solution. The sugar gradually fills the gaps in the wood and hardens. Now the canoe can be safely dried and exhibited. But one potential problem still remains. Can you guess what this might be? At the museum, the canoe is put into a special "bug-proof" case. Why? Because to some insects, the canoe now looks like a huge candy bar!

The Central Science

As you have seen, archaeologists such as Linda and Spencer must understand the properties of the materials they are trying to preserve. Similarly, wetlands ecologists such as Joanie must know how to analyze substances that threaten the environment.

Chemistry plays a role in these professions and in many others as well. **Chemistry has been called the central science because it overlaps so many sciences.** Whether your career interests are in science, engineering, public service, or some other occupation, chances are good that you will need a knowledge of

Figure 1–3 *Here you see two different aspects of chemistry. A research chemist working in a pharmaceutical laboratory searches for new drugs to treat disease and improve the quality of human life. How do you think a knowledge of chemistry helps the firefighters in their job?*

chemistry. Hair stylists, for example, need to know some chemistry so that they can handle hair relaxers and permanent wave solutions safely and correctly. Construction engineers use chemistry when they select the right cement for a particular job. Biologists learn chemistry so that they will understand the chemical processes that go on in living things. Can you think of any other occupations in which a knowledge of chemistry might be helpful?

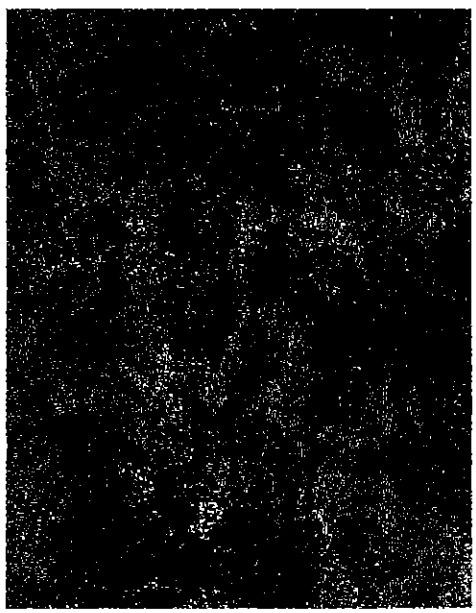
If you have a strong interest in chemistry itself, you may decide to become a professional chemist. But what kind of chemist? Chemists are employed in dozens of occupations. Chemists work for police departments to help solve crimes and for perfume makers to help formulate new fragrances. Some chemists, called research chemists, investigate new substances that may not have any practical use yet. Research chemists create new scientific knowledge. The applications of this knowledge, if any, lie in the future. It is research chemists who have given us many of the wonderful new materials that have made our lives easier.

Why Study Chemistry?

You have seen that chemistry can play a role in many different areas of life. But there is another reason why you should learn chemistry. Chemistry is fun! Chemistry will help you to understand what makes leaves change color in the fall, why icebergs float, and how the food you eat turns into muscle (and sometimes fat) in your body. Chemistry can help you look at the world in ways you may never have imagined. We hope that by the time you finish this textbook, you will see why chemistry can and should play an important role in your life.

The work ahead may seem overwhelming now, but you should not be discouraged. Here are a few hints to keep in mind as you begin your study of chemistry. First, do not try to memorize a collection of isolated facts. You will find the task much easier if you concentrate on understanding concepts, not memorizing facts. Second, remember that chemistry is first and

Figure 1–4 *Autumn brings with it a spectacular transformation in the appearance of the northeastern forests, as leaves exchange their ordinary green color for a blaze of red, orange, and yellow.*



CONNECTION

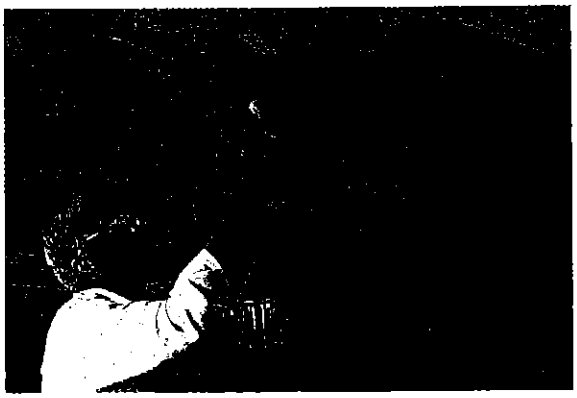
SCIENCE TECHNOLOGY AND SOCIETY

Cleaning Priceless Art

The dramatic scenes that Michelangelo depicted on the ceiling and upper walls of the Sistine Chapel are among the finest artistic achievements in history. Since they were first unveiled in 1512, generations of art lovers have gone to Rome to see Michelangelo's masterpiece. Over time, however, dust and greasy soot from burning candles and oil lamps gradually covered Michelangelo's work, darkening the paintings.

A visitor to the Sistine Chapel when the paintings were new described a typical reaction: "It was such as to make everyone speechless with astonishment." Now, after nearly 500 years, visitors can once again view Michelangelo's paintings in the same bright, glowing colors that they originally had.

What took Michelangelo, working alone, four years to paint required a team of specialists more than 14 years to clean and restore. One of the most useful materials in the restoration effort was a mild cleanser made of baking soda and other ingredients mixed with water to form a dripless gel. Several applications of the cleanser were often needed to remove the grime completely from sections of the ceiling and walls. This cleaning agent, which has been



available to art restorers for only about 20 years, was particularly suited to the job of restoring the Sistine Chapel. Its dripless formula allowed exact quantities to be applied where they were needed without the chance of streaks spreading any dirt away from the area being cleaned.

But some people actually miss the old, dirty look. They feel that the paintings had more depth and mystery when they were covered with dust and soot. And some art historians fear that much of Michelangelo's original work has been damaged in the cleaning process. What do you think?

foremost a process of discovery. Think of it as a journey into the unknown. Many fascinating and exciting sights await you. So sit back, relax, and enjoy the trip!

1–1 Section Review

1. What is chemistry?
2. How can a knowledge of chemistry help a wetlands ecologist or an archaeologist do her job?
3. Suppose you know a hair stylist who tells you that in his profession he has no need to understand chemistry. What arguments would you use to convince him that he is mistaken?
4. **Theme Trace—Unity and Diversity** In your own words, explain why chemistry is sometimes called the central science.

1–2 The Scientific Method

Guide for Reading

- What is the scientific method?
- What are the steps of the scientific method?

More than 150 years ago, the English chemist and physicist Michael Faraday (1791–1867) made crucial discoveries that led to the invention of the electric motor. Think how important electric motors are today: refrigerators, automobile starters, hair dryers, and video equipment all rely on electric motors. Yet when Faraday demonstrated his discoveries, none of these machines had been invented. Houses were not even wired for electricity! The new scientific knowledge Faraday gathered did not have any immediate practical value. The value of Faraday's work lay in its potential for further growth and future applications. As it turned out, although he could not have imagined it, Faraday's discoveries changed the world completely.

The tremendous potential of science comes from the way in which scientific knowledge is gathered. Scientists follow an orderly and systematic approach called the **scientific method** to gather knowledge. With this approach, new ideas about the world are constantly checked against reality. Just what is the scientific method? **The scientific method is a way of answering questions about the world we live in.** Refer to Figure 1–6 on page 8 as you read about the steps of the scientific method.

Figure 1–5 *When Michael Faraday made the basic discoveries that led to the invention of the electric motor, he could not possibly have imagined the many applications his work would have in the future.*

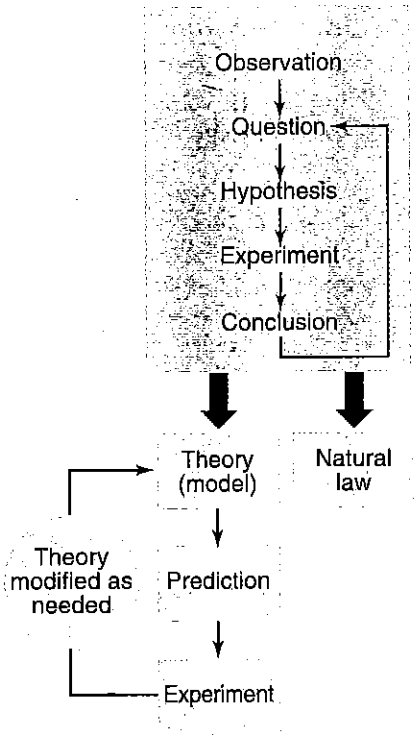


Figure 1–6 *This diagram outlines the steps of the scientific method. It is important to remember that although the scientific method appears clear-cut and orderly, in real life the process is not always so tidy! Scientists do not always follow the steps in exactly this order and they may occasionally skip a step. Remember that the real value of the scientific method is that it provides a framework for learning about nature.*

Steps of the Scientific Method

The scientific method consists of a series of steps that can be summarized as follows:

- First a scientist makes an **observation.**
- The observation leads to a question. (Because science begins with curiosity, the question may come first.)
- Thinking about the question produces a **hypothesis,** a tentative answer to the question.
- The scientist tests the hypothesis with an **experiment.** As part of an experiment, the scientist carefully records and analyzes data, or information, gathered in the experiment.
- The experiment produces a result, or a **conclusion,** which the scientist interprets carefully. The result may raise new questions and lead to new hypotheses and new experiments.
- After a number of experiments, the scientist may be able to summarize the results in a **natural law,** which describes how nature behaves but does not explain why nature behaves in that particular way.
- Finally, the scientist may be able to formulate a **theory.** The theory explains why nature behaves in the way described by the natural law. It answers not only the original question, but also any other questions that were raised during the process. The theory also predicts the results of further experiments, which is how it is checked.

Let's see how the scientific method might work in practice. Where could we go to make our first observation? The kitchen might be a good place to start!

Making an Observation

You are going to cook an onion. If you cannot actually do this activity now, read along anyway and perform it when you can.

Before you begin, a word of caution: Accidents can happen in the kitchen (and in the chemistry laboratory) when you are tired, trying to hurry, or unsure of the correct procedure. Read the recipe below carefully, stay alert, and work patiently. Ask an adult to help you get started if you are not accustomed to working alone in the kitchen. Working in a small group might also be helpful.

Obtain an onion, a knife and cutting board, a frying pan, a long-handled wooden spoon, and some vegetable oil or margarine. Chop the onion into pieces. Be very careful in using the knife. If the onion is fresh, watch out! Your eyes may sting from a sharp, smelly gas that is released when the onion is cut. Now taste a small piece of the onion. Some people actually like the strong taste of a raw onion. Do you?

Put a tablespoon of oil in the pan and cook the onion slowly over medium heat. Stir the pieces with the spoon so they heat evenly. In about 10 minutes, the onion should start turning brown. Continue cooking for another 10 minutes, then put the onion on a plate and let it cool.

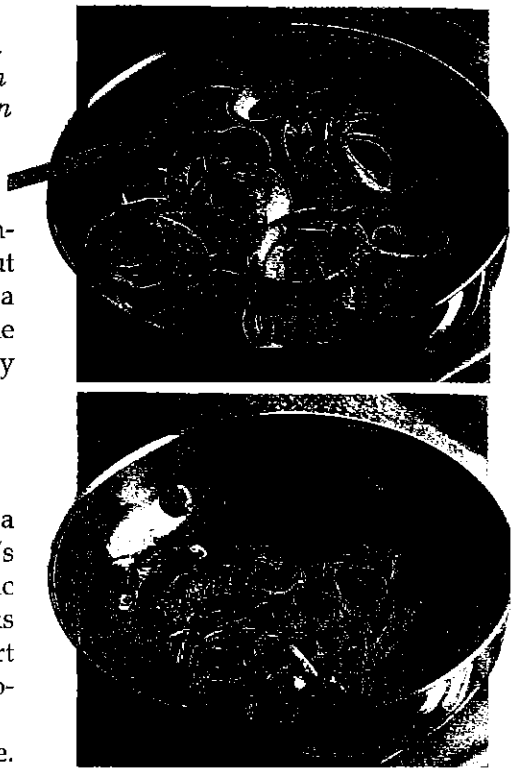


Figure 1–7 *Have you ever wondered why cooked onions taste different from raw onions? It may surprise you to learn that you can follow the scientific method in your own kitchen in an attempt to answer this question. What observations can you make about sliced onions before (top) and after (bottom) they are cooked?*

Now taste the cooked onion. Notice that the flavor is completely different from the raw onion. In fact, it tastes sweet! But you never added sugar. All you did was heat the onion for a few minutes with a little oil. So here is your observation: The cooked onion tastes sweet. And the question is simply this: Why does a cooked onion taste sweet?

Forming a Hypothesis

Following the scientific method, you should now form a hypothesis to answer your question. Before you do, though, let's notice two things. First, the observation is not especially exotic or "scientific." All you have done is notice something curious about the flavor of a cooked onion. Scientific inquiries often start in this rather humble way—by simply wondering about day-to-day occurrences.

Second, notice that the question carries some emotional force. You want to know the answer. You have no idea whether it will be useful or important, but you want to know the answer anyway. Humans are naturally curious. The scientific method gives us a framework in which we can productively exercise our natural curiosity.

Recall that a hypothesis is a tentative answer to a question. A hypothesis is usually expressed in the form of a "cause-and-effect" statement. Remember, you must be able to test your hypothesis with an experiment. The experiment must be conducted openly, of course, with no hidden tricks or secret procedures, so that anyone who repeats the experiment can obtain the same results.

In this case, you want to know what causes the sweet taste of the cooked onion. One possibility is that the onion contains sugar. Because the raw onion does not taste sweet, the sugar might be in the form of starch. Starch is a substance made of sugar that many plants (such as potatoes) use to store food. You might guess that cooking the onion converts some of the starch into sugar. So your hypothesis would be as follows: The sweet taste is caused by the presence of starch in the onion, which is converted to sugar by cooking.

The next step is to test your hypothesis. Beware of hypotheses that cannot be tested! They are not true hypotheses at all because they break the chain of steps in the scientific method. Hypotheses that cannot be tested by an experiment do not belong in science. Let's stop for a moment to explore this important idea further in the following Sample Problem.

Observations on Paper

A Frenchman visiting North America in 1719 observed some paper wasps building a nest. He made the following entry in his diary: "The American wasps form a very fine paper. . . . They teach us that paper can be made from the fibers of plants without the use of rags and linens, and seem to invite us to try whether we cannot make fine and good paper from the use of certain woods." How would you apply the scientific method to study this observation? Write a paragraph describing an investigation you could perform, including the question, hypothesis, and experiments you would propose.

SAMPLE PROBLEM 1

Which of the following hypotheses about the sweet taste of a cooked onion are testable? (More than one correct choice is possible.)

(a) The sweet taste is caused by a chemical reaction between the onion and the oil.
(b) A bitter spirit that inhabits the raw onion is driven away when the onion is cooked. The cooked onion tastes sweet because the bitter spirit is no longer present in the onion.
(c) The sweet taste is caused by cooking the onion.
(d) The sweet taste comes from the oil. It has nothing to do with the onion.

STRATEGY	SOLUTION
1. Analyze	You are given several possible hypotheses and asked to decide which are testable. Recall that a hypothesis is a "cause-and-effect" statement that poses a tentative answer to the question. The hypothesis is tested by an experiment. The experiment must be designed so that anyone can repeat it and obtain the same result.
2. Plan	Read each hypothesis carefully and try to imagine how it could be tested.
3. Solve	Answer (a) could be tested by cooking the onion without oil in a "no-stick" frying pan. Answer (b) cannot be tested because it is impossible to design an experiment to detect a "bitter spirit." Answer (c), although it is a true statement, merely restates the question, so it is not a hypothesis. Finally, answer (d) could be tested by heating the oil alone for the same length of time and at the same temperature used to cook the onion. Thus, the only testable hypotheses are (a) and (d).
4. Evaluate	The word cause is used in a particular way in science, whereas the word can have a broader meaning in general. Although answer (b) is not an acceptable hypothesis in a scientific sense, it is possible to imagine a society that did believe in such spirits. In that society, answer (b) could be thought correct. Should you dismiss the statement as

"wrong" because it cannot be tested? No. It is better to say instead that the statement is not scientific. Scientific knowledge, for all its power and potential, is just one branch of human understanding. Hypotheses that are not testable have no value in science, yet they may be very valuable in other aspects of human life.

Practice Problems

1. In 1786, Benjamin Franklin wrote a letter to an English friend describing some observations he had made. Here is part of the letter:

   "In America I have often observ'd that on the Roofs of our shingled Houses, where Moss is apt to grow in northern Exposures, if there be anything on the Roof painted with white Lead, there is constantly a streak on the Shingles from such Paint down to the Eaves, on which no moss will grow, but the wood remains constantly clean and free from it."

   Think of a question and a hypothesis for this observation. *(Be sure your question is logical and your hypothesis is testable.)*

2. Think of a question and a hypothesis for each of the following observations:
   (a) You sneeze every time you visit your best friend's house.
   (b) On a cold morning, the air pressure in the tires of an automobile measures 34 pounds per square inch. After several hours of high-speed driving, the pressure measures 38 pounds per square inch. *(Be sure your question is logical and your hypothesis is testable.)*

Performing an Experiment

How can you test your hypothesis about the sweet taste of a cooked onion? There are at least two ways. One way is to see whether onions do in fact contain starch. Can you think of another way?

Let's see what happens if you choose the first way to test your hypothesis. Starch will be the **variable,** or the factor being tested, in your experiment. A sensitive test for starch is called the starch-iodine test. A drop of iodine solution will turn blue-black in the presence of even tiny amounts of starch.

The result of the starch-iodine test on a slice of raw onion is shown in Figure 1–8. As you can see, a drop of iodine solution does not turn blue-black when it is added to a slice of onion.

Figure 1–8 *Here you see the results of the starch-iodine test for onion, cornstarch, and potato. How would you describe the results of this test for each sample?*

Results of Iodine Test

Substance Tested	Color*
Onion slice	Red
Cornstarch	Blue-black
Potato slice	Blue-black

*Blue-black indicates presence of starch.

Figure 1–9 *The table lists the results of the starch-iodine test shown in Figure 1-8. Scientists often find it helpful to record their results in a data table such as this. Why do you think summarizing results in a table is a useful way to record data?*

Interpreting the Result

The result of the starch-iodine test on raw onion suggests that there is no starch in an onion after all. But you should be careful not to jump to this conclusion. How do you know that the starch-iodine test actually works? To answer this question, you could place a drop of iodine solution on a small amount of cornstarch, also shown in Figure 1–8. This test acts as an **experimental control.** A control responds in a predictable way to the experiment. In this case, the iodine turns blue-black in the presence of cornstarch, just as expected. So you can be confident that the iodine solution is capable of detecting starch in the onion. But just to be really certain, let's try one more test. You know that potatoes are "starchy" vegetables. In fact, potatoes are just one of many plants that store sugar in the form of starch. What do you think would happen if you placed a drop of iodine solution on a slice of raw potato? You are correct if you said that the iodine would turn blue-black. The table in Figure 1–9 summarizes the results of the starch-iodine test.

Even with an experimental control, however, you need to interpret the experiment carefully. All you can really say is that the amount of starch in the onion may be less than the smallest amount that the starch-iodine test can detect. Nevertheless, because the starch-iodine test is very sensitive, it seems doubtful that the hypothesis is correct.

To pursue the problem further, you would have to formulate a new hypothesis based on more thinking, questioning, and observing. As before, you would perform an experiment to test your new hypothesis. Finally, you might see the results of many experiments start to fit together like the scattered pieces of a jigsaw puzzle.

Laws and Theories

When the pieces of a jigsaw puzzle are in place, a picture emerges that could not be seen in the separate pieces. Likewise, a natural law draws together many observations and the results of many experiments into a "big picture." But the natural law does not explain what the picture means. A theory provides this explanation. You can think of a theory as a sort of "super-hypothesis."

Can a theory be wrong, even after all the work that goes into it? Yes. Knowledge gained through the scientific method is tentative. This means that it is open to revision. A theory about the flavor of cooked onions, for example, might make false predictions. If it did, you would have to modify the theory or discard it.

Some theories are so well established that their predictions are not expected to be disproven. The atomic theory, which underpins all of chemistry, is such a theory. Even the atomic theory continues to evolve, however, as scientists learn more

Exploration

A Secret Message

1. Using a toothpick as a pen and milk as your ink, write a secret message on a blank sheet of white paper.
2. Observe what happens to your message as the milk dries.
3. Turn on a desk lamp and hold the paper close to the light bulb. Observe what happens.
4. State your observations in the form of a question and formulate a hypothesis to explain your observations.
5. Design an experiment to test your hypothesis.

about atomic structure. We will discuss the atomic theory in more detail in Chapter 3.

Are you still curious about what really makes a cooked onion taste sweet? The sweet flavor is due to several different kinds of sugar that are present in a raw onion, but not in the form of starch. It will probably surprise you to learn that a slice of onion can contain up to half as much sugar as a slice of ripe fruit! You cannot normally taste the sugar in a raw onion because the onion's sharp, tear-provoking gas overwhelms your sense of taste. Cooking destroys the ability of the onion to make the gas and allows you to taste the sugar.

Doing Science

Science is a process—something that people do. Do you think you can "do science" in your daily life? The answer is yes. You have many opportunities for observing and wondering about natural events around you. For example, suppose you are walking down a city street and you notice big blue garbage bags filled with plastic bottles piled high on the sidewalk. You might wonder: What happens to all the plastic products we throw away every day? How would you go about finding out?

It does not matter whether you live in a big city, in a small town, or on a farm in the country. It does not matter whether the events occur inside your kitchen or outside your home. When you notice something interesting, let your natural curiosity—and the scientific method—help you to investigate.

There is one more important thing to keep in mind when you think about doing science. You know that when you cook something in your kitchen, you must follow certain commonsense safety rules. In the same way, when you work in a laboratory, you must follow some safety rules and procedures. Because you will be performing many laboratory investigations as you study chemistry, we will examine safety in the chemistry laboratory next.

Figure 1–10 *Wherever you are—at home, at school, or just walking along a beach—try to find the time to observe and ask questions about the world around you.*

1–2 Section Review

1. What is the scientific method?
2. List the steps of the scientific method.
3. What is a variable? An experimental control?
4. What is the difference between a natural law and a scientific theory?
5. **Connection—You and Your World** Use the steps of the scientific method to explain this observation: A steel wool soap pad eventually becomes rusty after you use it several times.

Guide for Reading

- What are the basic safety rules you must follow in the chemistry laboratory?

1–3 Safety in the Laboratory

As a part of daily living, you have a lot of experience working with tools. In the kitchen, for example, you may use a knife and a cutting board to chop vegetables for a salad. With a little common sense, these tools are safe to handle and the kitchen is a safe, even fun, place to be. The chemistry laboratory is very much the same.

Listed below are ten of the most important rules for safe conduct in the chemistry laboratory. An Appendix in the reference section provides further information and instructions regarding safety procedures.

- **Follow Your Teacher's Directions**
- **Notify Your Teacher of Problems**
- **Know How to Use the Safety Equipment in the Laboratory**
- **Wear Approved Safety Goggles**
- **If You Have Long Hair, Tie It Back**
- **Avoid Awkward Transfers of Chemicals**
- **If It's Hot, Let It Cool**
- **Carry Chemicals With Caution**
- **Dispose of Chemical Wastes Properly**
- **Clean up Afterward**

This short set of basic rules cannot anticipate every possible laboratory hazard, so your teacher will announce special safety precautions for particular experiments. Even so, having a safe laboratory environment always means more than just following rules. You should "think safety." That is, always keep safety in mind when you work in the laboratory.

The safety symbols that will be used in the laboratory investigations throughout this textbook are shown in Figure 1–12. An explanation of each symbol is also provided. As you may imagine, you should be familiar with these symbols before you first set foot in the laboratory.

CHEMISTRY IN ACTION

YOU AND YOUR WORLD

Familiar Symbols

Before beginning your work in the chemistry laboratory, you must become familiar with the safety symbols used in this textbook. But the idea of using symbols to transmit information should come as no surprise to you. In fact, you are probably already familiar with the use of many different types of symbols in your everyday life—from traffic signs to road maps. What other types of symbols can you think of?

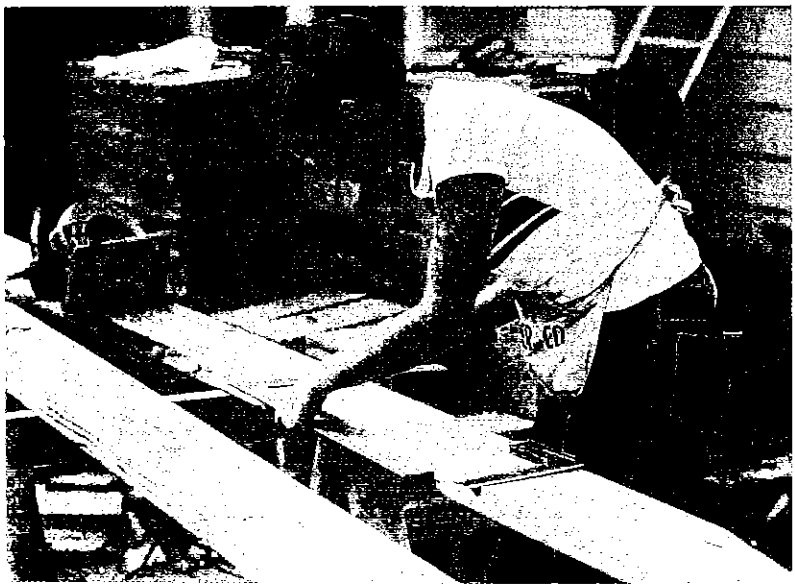


Figure 1–11 *In the chemistry laboratory, as in a woodworking shop, safety should be a prime consideration! What safety precautions would you recommend in this situation?*

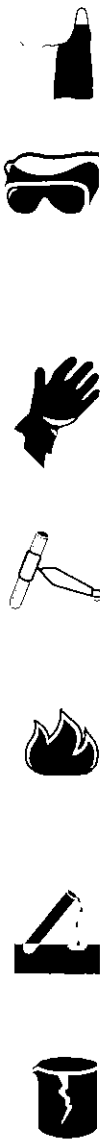
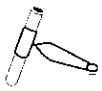


Figure *many o again i Investig each ch Study t now so which s follow c*

SAFETY CLOTHING
This symbol is to remind you to wear a laboratory apron over your street clothes to protect your skin and clothing from spills.

SAFETY GOGGLES
This symbol is to remind you that safety goggles are to be worn *at all times* when working in the laboratory. For some activities, your teacher may also instruct you to wear protective gloves.

GLOVES
This symbol is to remind you to wear gloves to protect your hands from contact with corrosive substances, broken glass, or hot objects.



HEATING
This symbol indicates that you should be careful not to touch hot objects with your bare hands. Use either tongs or heat-proof gloves to pick up hot objects.

FIRE
This symbol indicates the presence of an open flame. Loose hair should be tied back or covered, and bulky or loose clothing should be secured in some manner.

CORROSIVE SUBSTANCE
This symbol indicates a caustic or corrosive substance—most frequently an acid. Avoid contact with skin, eyes, and clothing. Do not inhale vapors.

BREAKAGE
This symbol indicates an activity in which the likelihood of breakage is greater than usual, such as working with glass tubing, funnels, and so forth.

DANGEROUS VAPORS
This symbol indicates the presence of or production of poisonous or noxious vapors. *Use the fume hood* when directed to do so. Care should be taken not to inhale vapors directly. When testing an odor, use a wafting motion to direct the vapor toward your nose.

EXPLOSION
This symbol indicates that the potential for an explosive situation is present. When you see this symbol, read the instructions carefully and *follow them exactly*.

POISON
This symbol indicates the presence of a poisonous substance. Do not let such a substance come in contact with your skin and do not inhale its vapors.

ELECTRICAL SHOCK
This symbol indicates that the potential for an electrical shock exists. Read all instructions carefully. Disconnect all apparatus when not in use.

RADIATION
This symbol indicates a radioactive substance. Follow your teacher's instructions as to proper handling of such substances.

DISPOSAL
This symbol indicates that a chemical should be disposed of in a special way. Dispose of these chemicals as directed by your teacher.

HYGIENE
This symbol is to remind you to always wash your hands after completing a laboratory investigation. Never touch your face or eyes during a laboratory investigation.

Figure 1–12 *You will see many of these safety symbols again in the Laboratory Investigations at the end of each chapter in this textbook. Study the symbols carefully now so that you will know which safety precaution to follow as you proceed.*

1–3 Section Review

1. List ten basic safety rules that you must follow in the chemistry laboratory.
2. Why do you think it is important to tie back long hair and roll up loose sleeves when you are working in the laboratory?
3. **Connection—You and Your World** How could you apply the basic safety rules for performing an experiment in a chemistry laboratory to baking a cake in your kitchen or changing a tire on a car?

MATH TOOL KIT

Focusing on the Basics

The lake near your home is slowly becoming polluted by an oil-tank leak. You want to determine how quickly the water is being polluted. Each time you return from the lake, you carefully analyze the water and soil samples to determine the amounts of various chemicals present. You then compare these measurements with the data from previous visits, and also with similar data from other sources. From these comparisons, you will be able to draw significant conclusions about the current condition of the lake. Your studies may raise other questions, leading to several hypotheses and further experimentation.

Only by the use of accurate measurements can scientists like you "do science." From making observations and gathering and analyzing data, to comparing and confirming results, scientists rely on accurately measured numbers. Almost always, a series of calculations must be performed on the data to obtain meaningful results.

To help you acquire the basic math skills that will enable you to succeed in chemistry, we have organized the rest of Chapter 1 into a Math Tool Kit. The Math Tool Kit will help you practice and apply simple math concepts to your study of chemistry. The Math Tool Kit contains the following topics:

1–4 Units of Measurement

1–5 Uncertainty in Measurement

1–6 Working With Numbers

1–7 Problem Solving

You may want to go through the next four sections of this chapter at your own pace, making sure that you have mastered the concepts and acquired the skills as you proceed.

Avogadro's number	6.02×10^{23}
Speed of light in a vacuum	3.00×10^{8} m/s
Atomic mass unit (amu)	1.66054×10^{-27} kg
Charge of an electron	1.60×10^{-19} C
Mass of an electron	9.11×10^{-31} kg 0.0006 amu
Mass of a proton	1.6726×10^{-27} kg 1.0073 amu
Mass of a neutron	1.6749×10^{-27} kg 1.0087 amu
Planck's constant (h)	6.6262×10^{-34} J-s
Gas Constant (R)	0.08206 atm-L/mol-K 8.314 Pa-m^3/mol-K 8.314 J/mol-K
Molar volume of a gas at STP	22.4 L

$T(K) = T(°C) + 273$

Density = Mass/Volume

Planck's Equation: $E = h\nu$

Ideal Gas Law: $PV = nRT$

$pH = -\log[H_3O^+]$

$\Delta G = \Delta H - T\Delta S$

MATH TIP

As you read this textbook, look for the Math Tip feature in the margin. The Math Tip will provide information that will aid you in your study of chemistry. It will help you solve sample and practice problems or simplify mathematical operations or concepts presented in the textbook.

INTERNET RESOURCES

Visit the Prentice Hall Web site at **http://www.phschool.com** to find material that will support, enhance, and enrich your study of chemistry.

1–4 Units of Measurement

Guide for Reading

- What units are used in science for measuring length, mass, and volume?
- What are metric prefixes? How are they used?

As you will find, measurements are an integral part of science. A measurement consists of a number and a unit. For example, a basketball player might easily be seven feet tall. In this measurement, "seven" is the number and "feet" is the unit. Both a number and a unit are always needed to make sense of a measurement. You would know there was something wrong if you read that someone was six inches tall. And what would you think if you read that someone was six tall?

How tall are you? You probably know this measurement best in units of feet and inches. These units are part of the English system of measurement. (Actually, this name is misleading because the English have now abandoned it.) The English system is not used in science. Instead, an international system of measurement called the **metric system** is preferred.

Recall what you read about Joanie's research in Section 1–1. When Joanie returned to the laboratory after collecting her soil and water samples, she made several measurements using the units of the metric system. This system is like an international language spoken by all scientists because it establishes a common system of measurement that all scientists understand. When Joanie uses the metric system for her measurements, other scientists who read her results will understand the significance of her work more easily.

Figure 1–13 *Workers at the New York Zoological Society must make careful temperature measurements in order to preserve the frozen embryos of endangered species (left). Without a system of measurement, you would have no way of knowing just how tall basketball star Alonzo Mourning (right) really is.*

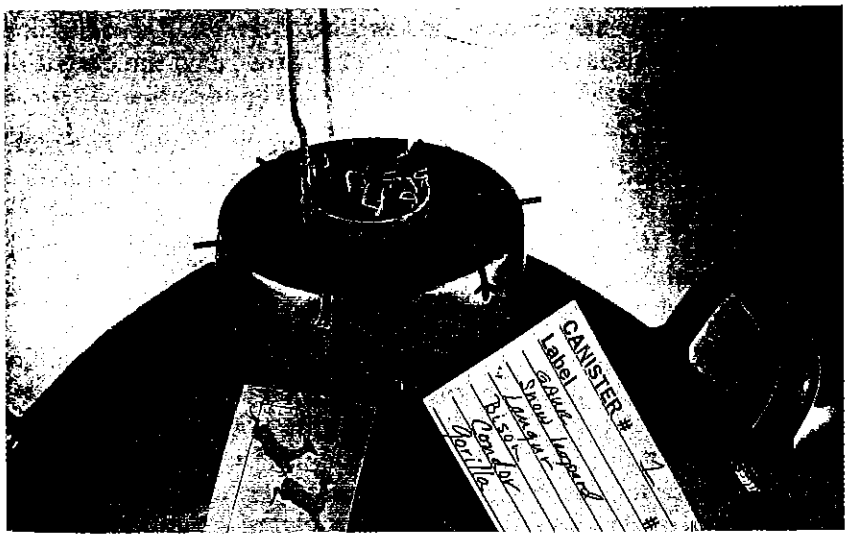


Figure 1–14 *The table lists the SI base units as well as some derived units. What is the basic SI unit of temperature?*

SI Base Units

Physical Quantity	Unit Name and Symbol
mass	kilogram, kg
length	meter, m
time	second, s
count, quantity	mole, mol
temperature	kelvin, K
electric current	ampere, A
luminous intensity	candela, cd

Derived Units Commonly Used in Chemistry

Physical Quantity	Unit Name and Symbol
area	square meter, m^2
volume	cubic meter, m^3
force	newton, N
pressure	pascal, Pa
energy	joule, J
power	watt, W
voltage	volt, V
frequency	hertz, Hz
electric charge	coulomb, C

Figure 1–15 *Although these floating astronauts have lost weight, their mass is the same in orbit as it was on Earth. What is the difference between mass and weight?*

The International System of Units

In 1960, the units of the metric system were streamlined by an international conference. The conference created a system of units called the **International System of Units,** abbreviated **SI** (after the French *Système International d'Unités*). The SI is built upon a set of seven metric units, which are called the **base units** of the SI. These base units are listed in Figure 1–14.

LENGTH The SI base units are carefully defined. **The meter (abbreviated m) is the basic SI unit of length.** One meter is currently defined as the distance that light travels in a vacuum during a time interval of 1/299,792,458 of a second. This is approximately the distance between a doorknob and the floor, or in English units, 3.3 feet—a little more than one yard.

MASS AND WEIGHT The amount of material in an object is called its **mass.** Like the unit of length, the SI unit of mass is carefully defined. **The unit of mass, the kilogram (abbreviated kg), is a base unit of the SI.** At the surface of the Earth, one kilogram weighs about 2.2 pounds. But note that mass and weight are not the same. As you have just read, the mass of an object

is simply the amount of material in the object. The weight of an object is equal to the force of gravity pulling on the object.

If a 1-kilogram wrench is carried into space, it no longer weighs 2.2 pounds. The force of attraction due to Earth's gravity—the weight of the wrench—depends on the distance between the wrench and the Earth. In space, the wrench is "weightless" because it is so far from Earth that the force of gravity seems to disappear. The amount of material in the wrench, however, is the same on Earth and in space, so its mass does not change.

AREA AND VOLUME: DERIVED UNITS In addition to the seven base units, other SI units can be made from combinations of the base units. In the SI, a combination of base units is called a **derived unit.** To find the area of a rectangle, for example, you would multiply its length by its width. The area of a rectangle 5.0 meters long and 3.0 meters wide would be

$$\begin{aligned} \text{area} &= \text{length} \times \text{width} \qquad \textbf{(Eq. 1)} \\ &= 5.0\ \text{m} \times 3.0\ \text{m} \\ &= 15\ (\text{m} \times \text{m}) \\ &= 15\ \text{m}^2 \end{aligned}$$

Notice that both the numbers and the units are multiplied together in calculating the area. The derived SI unit for area is the square meter (m^2). It is a derived unit because it is a combination of base units.

Other common derived units are summarized in the table in Figure 1–14. **The SI unit of volume is the cubic meter (abbreviated m^3).** The **volume** of an object is the amount of space that it occupies. A washing machine has a volume of about one cubic meter (1 m^3).

The Units Used in This Textbook

Following international practice, most of the units used in this textbook will be SI units. However, there are some exceptions. These exceptions are listed in the table in Figure 1–16. This might be a good time to mention exceptions in science. We would like to be able to tell you that science is based on rules and that once you learn these rules, you will know everything there is to know about science. Unfortunately, this is not the case! Science is a process, not a collection of rules. You will find as you study chemistry that there are exceptions to most rules.

A non-SI unit frequently encountered in chemistry is the liter (L), which is a unit of volume. One liter is slightly larger than a quart. There are exactly 1000 liters (1000 L) in 1 cubic meter.

Another non-SI unit often used in chemistry is the Celsius degree (C°), which is a unit of temperature. We will discuss this unit and other non-SI units as they are needed in your study of chemistry.

INTEGRATING PHYSICS

Have you ever wondered why astronauts in orbit appear weightless?

Figure 1–16 *The table lists some common non-SI units that are often used in chemistry. You will encounter some of these units in this textbook.*

Non-SI Units Frequently Encountered in Chemistry

Physical Quantity	Unit Name and Symbol*
volume	liter, L
pressure	atmosphere, atm
	millimeters of mercury, mm Hg
temperature	Celsius degree, C°
energy	calorie, cal

*For conversion factors between these units and SI units, see Figure 1–29 on page 38.

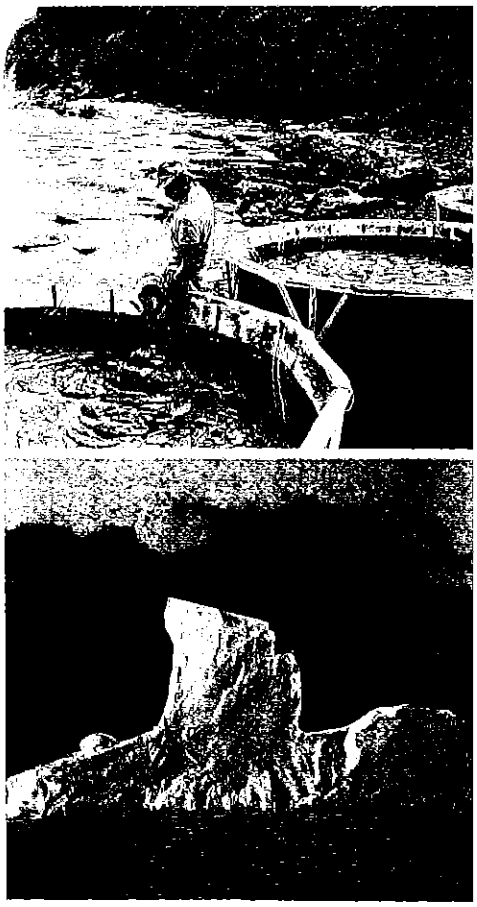
Figure 1–17 *Metric prefixes—word parts used to make a unit larger or smaller—are shown in this table. What is the prefix that means one thousandth?*

Common Metric Prefixes Used in Chemistry

Prefix	Abbreviation	Meaning*	
mega-	M	1 000 000	or 10^6
kilo-	k	1 000	or 10^3
		1	
deci-	d	0.1	or 10^{-1}
centi-	c	0.01	or 10^{-2}
milli-	m	0.001	or 10^{-3}
micro-	μ	0.000 001	or 10^{-6}
nano-	n	0.000 000 001	or 10^{-9}
pico-	p	0.000 000 000 001	or 10^{-12}

*Scientific, or exponential, notation used in the last column is reviewed in Section 1–6.

Figure 1–18 *Do you think milliliters would be an appropriate unit to use to measure the volume of oil that must be removed after a spill? What unit might you use to measure the mass of an iceberg?*



Metric Prefixes

The base SI units are not always convenient to use. For example, to travel from her laboratory to the swamp, Joanie must drive about 10,000 meters (a little more than 6 miles). This measurement can be written in a more compact way using a **metric prefix.** (Recall from your study of language arts that a prefix is a word attached to a base word to change its meaning.) A metric prefix is attached to the base unit, creating a more convenient, easier-to-use unit. Prefixes can make the new unit larger or smaller than the base unit.

PREFIXES THAT MAKE THE UNIT LARGER The prefix *kilo-* (k) means 1000. Therefore, 1 kilometer (1 km) equals 1000 meters. In kilometer units, Joanie's 10,000-meter trip could be written as 10 kilometers.

$$10\ \text{km} = 10 \times 1000\ \text{m} = 10{,}000\ \text{m} \qquad \textbf{(Eq. 2)}$$

Other metric prefixes that make a unit larger are shown in the table in Figure 1–17.

PREFIXES THAT MAKE THE UNIT SMALLER Metric prefixes can also decrease the size of a unit. As part of an experiment to measure the amount of oxygen dissolved in the swamp water, for instance, Joanie adds small volumes of several chemicals to a sample of the swamp water. The metric prefix *milli-* (m) means one thousandth, 1/1000, or 0.001. One milliliter (1 mL) is equal to 0.001 liter (0.001 L). When small volumes are involved, the milliliter unit is more convenient than the liter unit. For example, 3 milliliters is easier to write and remember than 0.003 liter.

Another common metric prefix is *centi-* (c) meaning one hundredth, 1/100, or 0.01. One cubic centimeter (1 cm^3) is the same volume as one milliliter (1 mL). Other metric prefixes that make

a unit smaller are also shown in the table in Figure 1–17. What does the prefix *mega-* mean? What is the abbreviation for the prefix *nano-*?

SAMPLE PROBLEM 2

Express a time interval of 5 microseconds (5 μs) in seconds.

STRATEGY	SOLUTION
1. Analyze	You are asked to convert a measurement from units of microseconds (μs) to units of seconds (s).
2. Plan	Figure 1–17 gives the definition of the prefix *micro-*. You can use this definition to solve this problem.
3. Solve	According to Figure 1–17, the prefix *micro-* means 0.000 001. So 1 μs is 0.000 001 s: $$1\ \mu s = 0.000\ 001\ s$$ Therefore, $$5\ \mu s = 0.000\ 001\ s \times 5$$ $$= 0.000\ 005\ s$$
4. Evaluate	According to the definition of the prefix *micro-*, 5 μs should be a much smaller unit of time than 5 s, as you have found.

PRACTICE PROBLEMS

3. Convert a volume of 8 deciliters into liters. Use the correct abbreviations for each unit. *(Answer: 0.8 L)*
4. Is 5 centimeters longer or shorter than 8 millimeters? Explain your answer. *(Answer: 5 cm is longer than 8 mm because 0.05 m (5 cm) is greater than 0.008 m (8 mm).)*

Remember that metric-to-metric conversions simply involve moving the decimal point the correct number of places in the proper direction. When converting from a smaller unit to a larger unit, move the decimal point to the left. When converting from a larger unit to a smaller unit, move the decimal point to the right.

1–4 Section Review

1. What are the SI units for length, mass, and volume?
2. What is a metric prefix? What does the metric prefix *centi-* mean? The prefix *deci-*?
3. What is the difference between mass and weight?
4. **Critical Thinking—Making comparisons** What is the difference between a base unit and a derived unit in the metric system? Give one example of each type of unit.

Guide for Reading

- What causes uncertainty in measurements?
- What is the difference between accuracy and precision?

1–5 Uncertainty in Measurement

In this section, you will begin to explore a crucial aspect of science: making measurements. Many different kinds of measuring equipment are commonly found in the chemistry laboratory. Three simple kinds of measurements are frequently made in the laboratory: mass, volume, and temperature. Many other kinds of measurements are also made, including pressure, voltage, and time. Learning how to make different kinds of measurements correctly is an important part of learning chemistry.

Making Measurements

In making a measurement, you write down all of the certain (or exact) digits that the instrument can give you and also one uncertain digit that you estimate. Why, you might ask, are any digits in a measurement uncertain? **Measurements are uncertain for two reasons: Measuring instruments are never completely free of flaws and measuring always involves some estimation.** How the estimation is done depends on the instrument you are using. Instruments either have digital displays or they have scales (a kind of number line such as a ruler).

ESTIMATING WITH A DIGITAL DISPLAY Instruments such as electronic balances have digital displays. The final digit on a digital display is the estimated digit.

With a digital display, the estimation of the uncertain digit is done for you electronically. However, the estimated digit can sometimes flicker when the instrument cannot "make up its

Figure 1–19 *Chemists need to be able to make accurate and precise measurements.*

mind." If this happens, you should record the reading that the instrument seems to "prefer."

Remember that you must always include a number and a unit when you are recording a measurement. If an electronic balance reads 2.705, for example, check the instrument for the unit of the measurement. Is the measurement 2.705 grams, 2.705 kilograms, or what? Simply writing down 2.705 is not enough!

ESTIMATING WITH A SCALE An example of an instrument that uses a scale is a graduated cylinder. A graduated cylinder measures liquid volume. With liquids such as water, the bottom of the curved surface of the liquid (called the meniscus) is the point where the reading is taken.

The graduated cylinder shown in Figure 1–20 has a scale that is marked in 1-milliliter increments. On this scale, every whole milliliter is an exact, or certain, digit in the measurement. You can see that the liquid in Figure 1–20 has a volume greater than 31 milliliters but less than 32 milliliters. To get a better reading of the volume, you must make an estimation. First, imagine ten more divisions on the scale between 31 milliliters and 32 milliliters. With these imaginary divisions, you can estimate the volume to be 31.7 milliliters. Which digit in this measurement is the estimated digit?

THE UNCERTAINTY OF A MEASUREMENT It is doubtful that the volume of liquid in Figure 1–20 is exactly 31.7 milliliters. Because the last digit of the measurement was estimated, the true volume could be a little larger or a little smaller than 31.7 milliliters. In chemistry, the uncertainty of a measurement such as this one is usually taken to be 0.1 milliliter. In other words, we assume that the true volume could be somewhere between a high of 31.8 milliliters and a low of 31.6 milliliters.

A plus-or-minus symbol, $\pm$, is sometimes used to show the uncertainty of a measurement as follows: 31.7 ± 0.1 milliliters. This measurement is read, "Thirty-one and seven tenths plus-or-minus one tenth milliliters." When this symbol is not used, you should assume that the uncertainty is plus-or-minus one in the estimated digit of the measurement.

Even though measurements are always uncertain, you should try to make your measurements as reliable as possible. Read the scales and digital displays of your instruments carefully and keep the instruments themselves clean and in top working order. Other steps should also be taken to ensure that your measurements are reliable, as we will now explain.

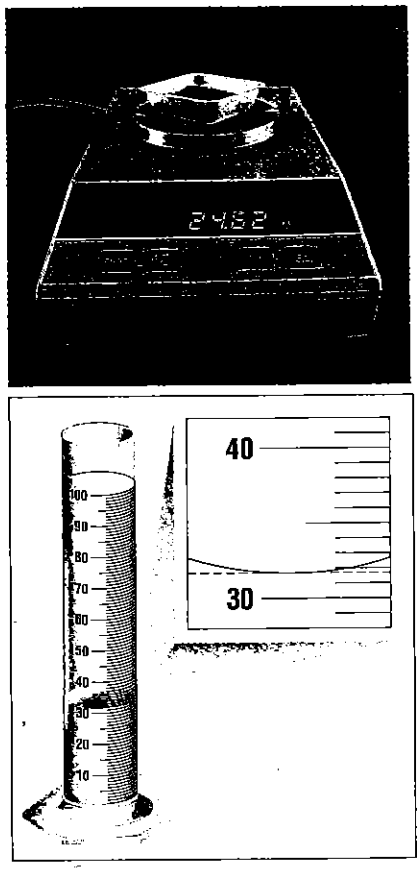


Figure 1–20 *In a digital display, the last digit shown is the estimated digit. Notice that the display also includes the unit for the measurement. The volume of liquid in this graduated cylinder is 31.7 mL. What is the curved surface of the liquid called?*

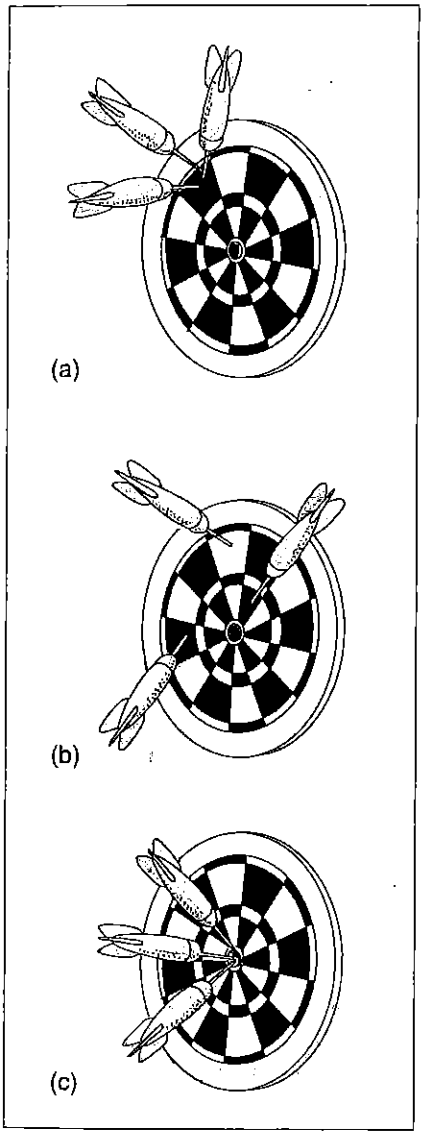


Figure 1–21 *In (a) the darts are clustered together (high precision), but they are far from the bull's-eye (low accuracy). In (b) the darts are closer to the bull's-eye (higher accuracy), but they are more widely scattered (lower precision). In (c) the darts are close to the bull's-eye (high accuracy) and clustered together (high precision).*

Reliability in Measurement

When a scientist like Joanie makes a measurement, she needs to know that it is reliable. There are two ways she can check her work.

PRECISION One way is to repeat the measurement several times. A reliable measurement will give about the same result again and again under the same conditions. When it does, it is said to be precise, or to have high **precision.**

ACCURACY The second way of checking a measurement's reliability is to test it against a standard. Joanie can make a standard by adding a known amount of oil to a sample of clean water. If she now measures how much oil is in the water, she knows what the result should be. The correct answer is called the **accepted value** for the measurement. If Joanie's measuring technique is good, she will obtain a result that is close to the accepted value. A measurement that is accurate, or that has high **accuracy,** is one that is close to the accepted value.

A DARTBOARD ANALOGY A game of darts is a good analogy for the difference between precision and accuracy. (An analogy is a way of explaining something by comparing it to something else.) Throwing three darts at a dartboard could produce a number of different patterns, as shown in Figure 1–21.

As you can see from this analogy, reliable measurements should be both highly accurate and highly precise. Making reliable measurements is a source of pride as well as a practical necessity for scientists. In your own experiments, the quality of your laboratory work will be judged in part by the precision and accuracy of your measurements. What steps do you think you could take to ensure the precision and accuracy of the laboratory work you will do?

1–5 Section Review

1. Explain why measurements are always uncertain.
2. Describe two ways to check the reliability of a measurement.
3. How would you find the uncertain digit in a measurement using a digital display? Using a scale?
4. **Critical Thinking—Applying concepts** The dartboard analogy is commonly used to explain the difference between accuracy and precision. Can you think of a different analogy to compare these two concepts?

1–6 Working With Numbers

A measurement is rarely meaningful by itself. More commonly, measurements are combined by adding, subtracting, multiplying, or dividing them to produce the values of mass, volume, or temperature needed in a scientific investigation. In your study of chemistry, you will often be asked to combine numbers and measurements mathematically. Several mathematical tools, which we will now describe, will help you in this process.

Significant Digits

When measurements are combined mathematically, the uncertainty of the separate measurements must be correctly reflected in the final result. A set of rules exists for this task, which depends on keeping track of the **significant digits,** or significant figures, in each separate measurement.

What are the significant digits in a measurement? **The certain digits and the estimated digit of a measurement are together called the significant digits of the measurement.** For example, there are three significant digits in 31.7 milliliters: two certain digits (the 3 and the 1) plus one estimated digit (the 7). When are digits significant or not significant? The rules for significant digits are given below. Here we have another example of "rules" in science. Remember that rules exist to help you understand a concept. They are not an end in themselves.

WHEN A ZERO IS NOT SIGNIFICANT A zero that is simply a place keeper in a measurement is not a significant digit. Suppose you wanted to find the mass of some fruit using a single-beam balance. To use the balance, a slider is moved along the scale until the arm balances horizontally. Since each division on the scale is 100 grams, the balance can determine the mass of the

Figure 1–22 *Do you think you would be able to measure the mass of fruits and vegetables with a great deal of certainty using the balance shown in the photograph? Why or why not?*

Guide for Reading

- What are significant digits?
- How are the significant digits in a measurement found?
- What information is needed to calculate the density of an object?

fruit to the nearest 10 grams by estimation. Now suppose the fruit has a mass of 1040 grams. How many of the digits in this measurement are significant?

From the way the measurement was made, you know that the 1 and the middle zero are exact digits and the 4 is the estimated digit. Thus, there are three significant digits in this mass measurement.

The final zero, though it is part of the measurement, is not a significant digit. Why not? It is a place keeper that only shows the location of the decimal point. The final zero is not significant because it is not one of the certain or estimated digits of the measurement.

THE ATLANTIC-PACIFIC RULE A rule that can help you identify the significant digits in a measurement is called the Atlantic-Pacific rule. The Atlantic-Pacific rule divides measurements into two kinds: those that are written with a decimal point, like 31.7 milliliters, and those that are written without a decimal point, like 1040 grams. To use the Atlantic-Pacific rule, first sketch (or imagine) a map of North America, similar to the one in Figure 1–23, with the Pacific Ocean on the left and the Atlantic Ocean on the right.

Now write the measurement on the map itself. If a decimal point is present in the measurement, count significant digits from the "Pacific" side; that is, from the left. (Think to yourself: "If the decimal point is present, count from the Pacific side.") If a decimal point is absent, count from the "Atlantic" side; that is, from the right. ("If the decimal point is absent, count from the Atlantic side.") You should start counting with the first nonzero digit you find. All the digits from here to the end, including any zeros, are significant digits. An advantage of the Atlantic-Pacific rule is that you can tell which digits of a measurement are significant without knowing exactly how the measurement was carried out.

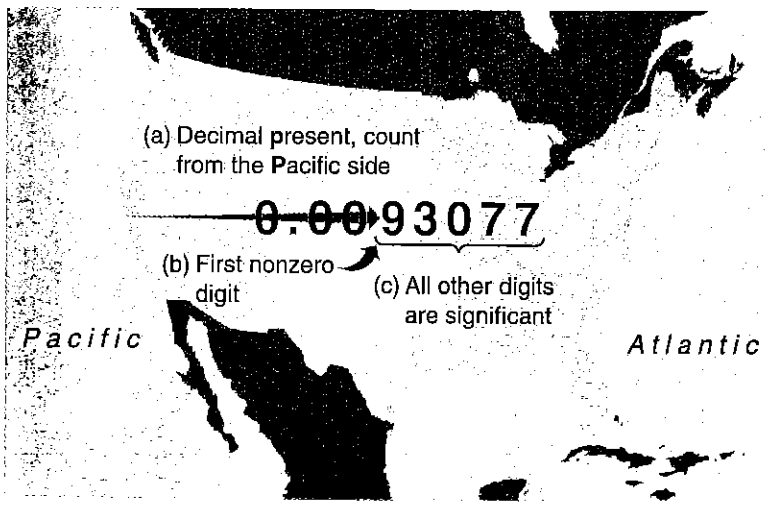


Figure 1–23 *Here you see an example of how to use the Atlantic-Pacific rule to help you determine the number of significant digits in a measurement.*

SAMPLE PROBLEM 3

Identify the number of significant digits in 0.057 010 gram.

STRATEGY	SOLUTION
1. Analyze	You are asked to find the number of significant digits in a measurement of mass.
2. Plan	You can use the Atlantic-Pacific rule to count significant digits. Figure 1–23 shows an example of how the Atlantic-Pacific rule is used.
3. Solve	The measurement 0.057 010 g has a decimal point, so you will count significant digits from the left. Start counting with the first nonzero digit. All the digits from there to the end of the number are significant: 0.057010 ①②③④⑤ Thus, there are five significant digits in 0.057 010 g.
4. Evaluate	According to the Atlantic-Pacific rule, if a decimal point is present, you should start counting from the Pacific, or left, side beginning with the first nonzero digit, which you did. So the answer is reasonable.

PRACTICE PROBLEMS

5. Count the number of significant digits in the following measurements:
   (a) 0.002 6701 m *(Answer: 5 significant digits)*
   (b) 19.0550 kg *(Answer: 6 significant digits)*
   (c) 3500 V *(Answer: 2 significant digits)*
   (d) 1,809,000 L *(Answer: 4 significant digits)*
6. Explain why 2.07 mL is a different measurement from 2.070 mL. In your answer, be sure to compare the uncertainty and the number of significant digits in each measurement. *(Answer: 2.07 mL has 3 significant digits and an uncertainty of ±0.01 mL; 2.070 mL has 4 significant digits and an uncertainty of ±0.001 mL.)*

In this textbook, you will often see measurements such as 100. milliliters and 250. grams. Why have we placed a decimal point after the numbers? By placing a decimal point after the

number, the zeros become significant digits. According to the Atlantic-Pacific rule, 100. and 250. both have three significant digits. Without the decimal point, the number 100 has only one significant digit and 250 has only two.

Significant Digits in Calculations

Now that you know how to find the number of significant digits in a measurement, let's see what happens when several measurements with different numbers of significant digits are combined. When measurements are combined in a mathematical equation, the number of significant digits that are allowed in the final answer is found by applying the following rules:

- When an exact number appears in a calculation, it does not affect the number of significant digits in the final answer. Exact numbers are not measurements, but arise instead from a definition. For example, there are exactly 100 meters in a kilometer. This is a definition, not a measurement. A definition has an infinite number of significant digits.
- In multiplication and division, the measurement with the smallest number of significant digits determines how many digits are allowed in the final answer. To find the volume of a box, for example, the length, width, and height of the box are multiplied.

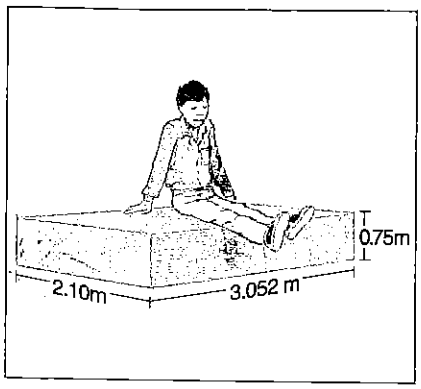
$$\begin{aligned} \text{volume} &= \text{length} \times \text{width} \times \text{height} \qquad \textbf{(Eq. 3)} \\ &= 3.052\ \text{m} \times 2.10\ \text{m} \times 0.75\ \text{m} \\ &= 4.8069\ \text{m}^3 \\ &= 4.8\ \text{m}^3 \end{aligned}$$

The final answer is rounded to two significant digits because your answer should have no more significant digits than the measurement with the fewest significant digits (0.75 meter). Electronic calculators typically give extra digits when they are used for multiplying and dividing. The numbers from a calculator must always be examined critically. Only a few of the digits will usually be significant.

- In addition and subtraction, the number of significant digits allowed depends on the number with the largest uncertainty. For example, suppose you added up the mass of everything you were wearing. Your list might look like this:

shoes	951.0	g
clothing	1407	g
ring	23.911	g
eyeglasses	158.18	g
total	2540.	g

Figure 1–24 *Your answer to a calculation can never have more significant digits than the factor with the fewest significant digits. Which measurement in this example—length, width, or height—has the fewest significant digits? Explain.*



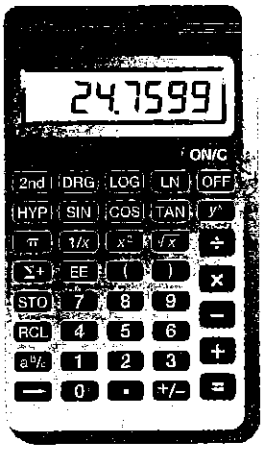
The measurements have different uncertainties (perhaps because they were made on different balances). The measurement with the largest uncertainty, ± 1 gram, is the mass of the clothing. Since the total mass cannot be known more accurately than the least accurate measurement in the sum, the total is rounded off to the nearest whole gram. (Notice that a decimal point was included with the total to show that the final zero in this measurement is a significant digit.)

When a calculation is performed in several steps, extra digits are carried in the intermediate results. Only the final answer is rounded to the proper number of significant digits.

To round off a number, look at the digit following the first digit to be rounded. If the digit is less than 5, round down. If the digit is 5 or more, round up.

SAMPLE PROBLEM 4

Perform the following calculation, then round off the answer to the proper number of significant digits: 6.15 m × 4.026 m = ?



STRATEGY	SOLUTION
1. Analyze	You are asked to multiply two numbers and to round off the answer to the correct number of significant digits.
2. Plan	Since the numbers are awkward, an electronic calculator would be a useful tool. You can then follow the rules for using significant digits in calculations to round off the answer. Be sure to include the units in your calculation as well as in your answer.
3. Solve	Using a calculator, multiply the two numbers: $6.15\ \text{m} \times 4.026\ \text{m} = 24.7599\ \text{m}^2$ This is the answer given by the calculator. You must now round off this answer to the correct number of significant digits: $24.7599\ \text{m}^2 = 24.8\ \text{m}^2$
4. Evaluate	According to the rules for significant digits, only three significant digits can be shown in the final answer. The digit to be rounded was the 7. The number was correctly rounded up to 8.

PRACTICE PROBLEMS

7. Perform the following calculations and round the answers to the proper number of significant digits.

(a)
$$\begin{array}{r} 165.86\ \text{g} \\ 4.0911\ \text{g} \\ 27.32\ \text{g} \\ +140.\ \text{g} \\ \hline \end{array}$$
(Answer: 337 g)

(b)
$$\begin{array}{r} 150\ \text{mL} \\ 76.9\ \text{mL} \\ 209\ \text{mL} \\ +0.036\ \text{mL} \\ \hline \end{array}$$
(Answer: 440 mL)

(c) $\dfrac{12.7\ \text{km}}{3.0} =$ *(Answer: 4.2 km)*

8. Perform the following calculations and round the answers to the proper number of significant digits.

(a) $\dfrac{35.6\ \text{L} + 2.4\ \text{L}}{4.803} =$ *(Answer: 7.91 L)*

(b) $2.542\ \text{m} \times (16.408\ \text{m} - 3.88\ \text{m}) =$ *(Answer: 31.85 m^2)*

Scientific Notation

INTEGRATING BIOLOGY

Do you know that bacteria inhabit your digestive system? Do you know what one type of bacteria is called?

In science it is common to work with very large and very small numbers. For example, a drop of water contains approximately 1,700,000,000,000,000,000,000 molecules (or particles) of water. On the other hand, a single *E. coli* bacterium in your digestive tract is only about 0.000 002 meter long. To make numbers such as these easier to work with, they can be written in scientific notation.

When a number is written in scientific notation, it is separated into two parts. The first part is a number between 1 and 10. The second part is a power of ten.

For example, the number 0.00225 written in scientific notation is 2.25×10^{-3}. The first part, 2.25, is found from the original number by inspection. This part contains only the significant digits of the original number, which can be identified using the Atlantic-Pacific rule. The second part is a power of ten written in exponential form, that is, in the form of 10^n, where n is called the exponent. Let's find out more about exponents.

EXPONENTS Suppose you were going to write the number 1000 in exponential form. To do this, ask yourself: How many times must 10 be multiplied by itself to make 1000? After a bit of trial and error, you might come up with the following equation:

$$1000 = 10 \times 10 \times 10 \qquad \textbf{(Eq. 4)}$$

In other words, 10 multiplied by itself three times makes 1000. In exponential form this would be written as:

$$1000 = 10 \times 10 \times 10 = 10^3 \qquad \textbf{(Eq. 5)}$$

Figure 1–25 *Rod-shaped* E. coli *bacteria are normal inhabitants of the human intestine. Because they are so tiny, an instrument known as a scanning electron microscope must be used to observe these bacteria. Each water droplet contains billions of water molecules. How do scientists express very small or very large numbers?*

The exponent, $n = 3$, shows how many times ten is multiplied by itself.

Very large and very small numbers can be written in a compact way using exponents. The number 1,000,000 (one million), for example, is the same as 10 multiplied by itself six times:

$$1{,}000{,}000 = \underset{①}{10} \times \underset{②}{10} \times \underset{③}{10} \times \underset{④}{10} \times \underset{⑤}{10} \times \underset{⑥}{10} = 10^6 \quad \textbf{(Eq. 6)}$$

You can easily prove this to yourself with a pocket calculator.

Writing very small numbers (numbers less than one) involves the use of reciprocals. For example, 0.01 (one hundredth) is written in exponential form as

$$0.01 = \frac{1}{100} = \frac{1}{10 \times 10} = \frac{1}{10^2} = 10^{-2} \quad \textbf{(Eq. 7)}$$

Notice that in this case, the exponent, $n = -2$, is a negative number.

CONVERTING NUMBERS TO SCIENTIFIC NOTATION To write numbers in scientific notation, the proper exponent can be found by counting how many times the decimal point must be moved to bring it to its final position so that the number is between 1 and 10.

$$0.\underset{①}{0}\underset{②}{0}\underset{③}{2}25 \rightarrow 2.25 \times 10^{-3} \quad \textbf{(Eq. 8)}$$

When the decimal point is moved to the right, the exponent is written as a negative number. Since it moves three times to the right in this case, the exponent is -3.

To express numbers greater than one in scientific notation, the exponent is positive. For instance, a horse might have a mass of 707 kilograms. This measurement written in scientific notation is 7.07×10^2 kilograms. The decimal point must be moved twice to the left, so the exponent is 2.

$$7\,0\,7 \rightarrow 7.07 \times 10^2 \qquad \textbf{(Eq. 9)}$$
$$\text{②①} \text{ (decimal point implied)}$$

SAMPLE PROBLEM 5

A single tiny drop of water may contain approximately 1,700,000,000,000,000,000,000 molecules (or particles) of water. Express this number in scientific notation.

STRATEGY	SOLUTION
1. Analyze	You are given a very large number that must be rewritten in scientific notation. A number in scientific notation has two parts: The first part is between 1 and 10 and contains the significant digits of the measurement. The second part is a power of ten written in exponential form.
2. Plan	You can find the first part of the number by inspection and by applying the Atlantic-Pacific rule. To find the second part of the number, count the number of places you must move the decimal point to determine the exponent.
3. Solve	The first part will be 1.7. The decimal point must be moved to the left 21 times to put it in its final position, so the exponent will be 21. The final answer is $1{,}700{,}000{,}000{,}000{,}000{,}000{,}000 = 1.7 \times 10^{21}$
4. Evaluate	The number 1,700,000,000,000,000,000,000 has only two significant digits, so the first part of the answer should have two significant digits as well. The number is greater than 1, so the exponent should be positive. The number is very large, so you would expect the exponent to be large as well. Thus, 1.7×10^{21} is a reasonable answer.

Practice Problems

9. Write the following numbers in scientific notation:
   (a) 32,700 *(Answer: 3.27×10^4)*
   (b) 1,024,000 *(Answer: 1.024×10^6)*
   (c) 0.004 710 0 *(Answer: 4.7100×10^{-3})*
   (d) 0.000 000 003 901 *(Answer: 3.901×10^{-9})*

10. Are the following numbers written correctly in scientific notation? If any of the numbers are wrong, rewrite the number correctly:
   (a) $0.000\,341\,2 = 3.412 \times 10^{-3}$ *(Answer: 3.412×10^{-4})*
   (b) $475{,}500{,}000 = 4.75 \times 10^8$ *(Answer: 4.755×10^8)*
   (c) $0.000\,056\,0 = 5.6 \times 10^{-5}$ *(Answer: 5.60×10^{-5})*
   (d) $18{,}060{,}000 = 18.06 \times 10^6$ *(Answer: 1.806×10^7)*

Percents and Percent Error

In your study of chemistry, many of your results will be expressed as a percent. A fraction can be written as a percent by converting it to a decimal and then multiplying the decimal by 100 percent. For example, if 900 million kilograms of plastic soft drink bottles are produced each year and 180 million kilograms of them are recycled, the percentage of plastic soft drink bottles that are recycled is

$$\frac{180 \text{ million kilograms}}{900 \text{ million kilograms}} = 0.2 \times 100\% = 20\% \qquad \textbf{(Eq. 10)}$$

An example of the way percents are used in chemistry is the **percent error.** A measurement can be compared with its accepted value by calculating its percent error. The percent error is found from the following formula:

$$\text{percent error} = \frac{\text{measured value} - \text{accepted value}}{\text{accepted value}} \times 100 \text{ percent} \qquad \textbf{(Eq. 11)}$$

This formula first takes the difference between the measured value and the accepted value. This difference is then divided by the accepted value. The result is then multiplied by 100 percent to give a percent.

A percent error can be either positive or negative. If the measured value is greater than the accepted value, the difference (measured value − accepted value) will be positive and the percent error will be positive. If the measured value is less than the accepted value, the difference will be negative and the percent error will be negative.

Chemistry in Action

You and Your World

Recycling Plastics

The following data represent the amount of each type of plastic produced in the United States and the amount recycled.

Group 1 (PET)	872 million kilograms produced 207 million kilograms recycled
Group 2 (HDPE)	3978 million kilograms produced 200 million kilograms recycled
Group 3 (PVC)	3884 million kilograms produced 9 million kilograms recycled
Group 4 (LDPE)	5080 million kilograms produced 34 million kilograms recycled
Group 5 (PP)	3384 million kilograms produced 100 million kilograms recycled
Group 6 (PS)	2203 million kilograms produced 17 million kilograms recycled

You might want to calculate the percentages yourself. As you can see, we are still a long way from 100 percent recycling.

Visit our Web site at **http://www.phschool.com** to support your study of chemistry.

CHEMISTRY IN

ACTION

CONSUMER TIP

Brand A vs. Brand B

Using ratios, you can find differences in cost between similar products, allowing you to buy the things you need and save money at the same time. For example, suppose a bottle of chocolate syrup (Brand A) costs $2.50 for 10 ounces, but Brand B costs $2.75 for 12 ounces. Which brand is cheaper by the ounce?

$$\text{Brand A} = \frac{\$2.50}{10.\ \text{oz}} = \$0.25 \text{ per ounce}$$

$$\text{Brand B} = \frac{\$2.75}{12\ \text{oz.}} = \$0.23 \text{ per ounce}$$

Brand B is 2 cents cheaper per ounce: A small difference, perhaps, but over a lifetime of eating chocolate sundaes the pennies would add up!

Ratios

Another common method of expressing results in chemistry is by the use of ratios. You are probably already familiar with ratios in your daily life. Riding in a car, for example, you have a sense of how fast you are going by observing how long it takes for the scenery to go by. In your mind you are forming a ratio, a kind of fraction. This ratio, called the speed, has a length or distance measurement in the numerator and a time measurement in the denominator:

$$\text{speed} = \frac{\text{distance}}{\text{time}} \qquad \textbf{(Eq. 12)}$$

The length measurement may be the distance between any two convenient objects, like streetlights, and the time measurement may be your heartbeat. With practice, your sense of speed can become very accurate and precise.

A ratio that is frequently used in chemistry is density. Density is a concept that is useful in many aspects of life. Like speed, density is a ratio because it is found by dividing one quantity by another quantity. A density is often a ratio of one measurement divided by a measurement of length, area, or volume. Have you ever heard the term population density? In a city with a high population density, many people live in each square kilometer

Figure 1–26 *Five people are standing on a square 2.0 m × 2.0 m in area. What is the population density?*

of the city. The population density is calculated by dividing the population of the city by its total area:

$$\text{population density} = \frac{\text{population}}{\text{area}} \qquad \textbf{(Eq. 13)}$$

Population density has units of people/km^2, which can be read as "people per square kilometer" or "the number of people in one square kilometer." Are you familiar with any cities that have a high population density?

In chemistry, **density** is one of the important properties of matter. Density is equal to the mass of a substance per unit volume. **The density of an object is calculated by dividing the mass of the object by its volume.**

$$\text{density} = \frac{\text{mass}}{\text{volume}} \qquad \text{(Eq. 14)}$$

Typically, density is expressed in units of g/cm^3, which can be read as "grams per cubic centimeter" or "the number of grams in one cubic centimeter." If a metal block has a mass of 75 grams and a volume of 22 cubic centimeters, the density of the block is

$$\text{density} = \frac{75\ \text{g}}{22\ \text{cm}^3} \qquad \textbf{(Eq. 15)}$$
$$= 3.4\ \text{g/cm}^3$$

This result means that each cubic centimeter of the block has a mass of 3.4 grams.

The densities of some common substances are shown in the table in Figure 1–27. The density of a substance determines whether that substance will float or sink in a liquid such as water.

The concept of density has many useful applications. For example, almost 50 different kinds of plastics are in use today. To help in recycling, the plastics industry has introduced a coding system based on density. All plastic products are imprinted with a number from 1 to 6 inside the three arrows of the recycling symbol. Each number represents a different type of plastic, based on density and ease of recycling.

USING DENSITIES IN CALCULATIONS Knowing the volume occupied by an object and its density, you can calculate the mass of the object. In the same way, knowing the mass of an object and its density, you can calculate the volume it occupies. To make these calculations, the definition of density must be rearranged using algebra, as the next Sample Problem will demonstrate.

Density of Some Common Substances

Substance	Density (g/cm^3)
air	0.0013*
ice	0.917
water	1.00
aluminum	2.70
iron	7.86
gold	19.3

* at 0°C and 1 atm pressure

Figure 1–27 *The densities of some common substances are listed in the table. What is the density of iron?*

Figure 1–28 *The liquids and solids in the beaker have different densities. If you did not know their individual densities, how could you determine the relative density of each substance?*

Exploration

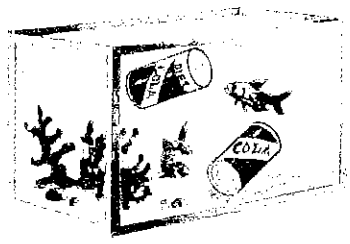
Floating and Sinking

1. Study the drawing below. The liquid is water.

- Why does one can of soda float while the other can sinks?

2. Repeat this experiment yourself using a can of diet soda and a can of regular soda.

- Do the ingredients used in soft drinks affect their density? Write a brief essay describing your observations.



SAMPLE PROBLEM 6

Using the information in the table in Figure 1–27 and the definition of density, calculate the mass of 200. cm^3 of air.

STRATEGY	SOLUTION
1. Analyze	You are asked to calculate the mass of a given volume of air. You can solve this problem by substituting the known values in the equation for density.
2. Plan	According to the table, the density of air is 0.0013 g/cm^3. Organizing all the information into a list is helpful: density = 0.0013 g/cm^3 volume = 200. cm^3 mass = unknown The definition of density is given in Equation 14: $\text{density} = \frac{\text{mass}}{\text{volume}}$ The only unknown quantity in this equation is the mass. Using algebra, you can rearrange the definition of density to solve for the mass: mass = volume × density
3. Solve	Since you know the volume and the density, you now have everything you need to calculate the mass. mass = 200. cm^3 × 0.0013 g/cm^3 = 0.26 g
4. Evaluate	The answer is expressed in the correct unit (grams) for mass. Since each cubic centimeter of air has a very small mass (as shown by the density), it makes sense that 200. cm^3 would also have a small mass. Thus, your answer is reasonable.

PRACTICE PROBLEMS

11. Using the definition of density and the information in the table in Figure 1–27, find the mass of a 35-cm^3 sample of aluminum. *(Answer: 95 g)*

12. Using the definition of density and the information in the table in Figure 1–27, calculate the volume occupied by 160. g of iron. *(Answer: 20.4 cm^3)*

Problem Solving Chemistry at Work

Hold Your Breath!

Raychelle loved visiting the community swimming pool with her older sister Tonya. This summer, Tonya had promised to teach Raychelle how to swim.

"Before you can swim," Tonya said, "you first have to learn how to float."

Tonya demonstrated how easy it was to float on the surface of the water: She just put her head back, spread her arms to the side, and let her feet rise from the bottom of the pool. Then it was Raychelle's turn. As Tonya stood behind her and held her shoulders, Raychelle tried to imitate what Tonya had done. It worked! Her feet bobbed to the surface and she was floating.

"Tonya, I'm floating!" she exclaimed.

Just then, Tonya let go of her shoulders and Raychelle started to sink. Quickly, Tonya grabbed her and gave her a hint: She told Raychelle to take a deep breath and hold her lungs fully inflated. This time, when Tonya let go, Raychelle continued to float. When she finally exhaled, however, she again began to sink rapidly.

Forming a Hypothesis

1. Can you suggest a hypothesis to explain Raychelle's experience?
2. How could you test your hypothesis?

As you noticed in the last Sample Problem, the cubic centimeter (cm^3) units disappeared in the final answer. This "disappearance," or cancellation, of the units was no accident. The final answer is a mass, which has units of grams, not cubic centimeters. Learning how to cancel unwanted units in a calculation is very important for solving chemistry problems. In the next section, we will explain this problem-solving strategy in detail.

1–6 Section Review

1. What are significant digits?
2. Describe how the Atlantic-Pacific rule can be used to help find the significant digits in a measurement.
3. How can you calculate the density of an object?
4. **Critical Thinking—Applying concepts** The accepted value for the boiling point of water is 100.0°C at sea level. When students in San Diego, California, measured this value, their result was 98.5°C. What is the percent error? Is it positive or negative? Why?

Guide for Reading

- What is dimensional analysis?
- What are the four steps you should follow in solving a chemistry problem?

1–7 Problem Solving

Solving a chemistry problem is like taking a trip. Where are you? Where are you going? How are you going to get there? Like any journey, solving a chemistry problem is much easier and more enjoyable if you plan ahead and keep your destination in mind. In this section, we will discuss problem-solving techniques that can help you chart a smooth course through your chemistry homework.

Dimensional Analysis

Many chemistry problems involve converting measurements from one unit to another. Another name for the unit of a measurement is dimension. **The technique of converting between units is called dimensional analysis.**

It is easiest to explain **dimensional analysis** with an example. Suppose the people responsible for the oil leak we described at the beginning of the chapter told Joanie that 250 gallons of oil entered the swamp. To use this measurement in her scientific work, Joanie must convert 250 gallons to metric units. The liter is a metric unit of volume, so Joanie's problem is this: How many liters are in 250 gallons? You can use dimensional analysis to answer this question.

UNIT EQUALITIES A unit equality is the starting point for solving the problem. A **unit equality** is an equation that shows how different units are related. Some unit equalities are given in the table in Figure 1–29. Reading from the table, the unit

Unit Equalities

Metric to Metric*

1000 m = 1 km	1 cm = 0.01 m	1 L = 1000 cm^3
1 m = 100 cm	1 mm = 0.001 m	1 mL = 1 cm^3
1 m = 1000 mm	1 μm = 1×10^{-6} m	
1 m = 1×10^{6} μm	1 nm = 1×10^{-9} m	
1 m = 1×10^{9} nm	1 pm = 1×10^{-12} m	
1 m = 1×10^{12} pm		

English to Metric	Miscellaneous
1 in. = 2.54 cm	1 ft = 12 in.
1 gal = 3.785 L	1 mi = 5280 ft
1 cal = 4.184 J	1 min = 60 s
1 atm = 101,325 Pa	1 hr = 60 min
	1 atm = 760 mm Hg

*These unit equalities follow from the definitions of the metric prefixes in Figure 1–17 on page 20 and they apply to other metric units as well, for example, 1000. g = 1 kg.

Figure 1–29 *Some unit equalities used in dimensional analysis are listed in the table. What is the unit equality that relates liters and cubic centimeters?*

equality showing the relationship between gallons and liters is

$$1 \text{ gal} = 3.785 \text{ L} \qquad \textbf{(Eq. 16)}$$

In other words, 1 gallon is a little less than 4 liters.

CONVERSION FACTORS The next step in solving the problem is to write **conversion factors** from the unit equality. A conversion factor is an equation that is always equal to 1. Two conversion factors can be written from one unit equality. Starting with Equation 16, the first conversion factor is created by dividing both sides of the equation by 1 gallon:

$$\frac{1 \text{ gal}}{1 \text{ gal}} = \frac{3.785 \text{ L}}{1 \text{ gal}}$$

$$1 = \frac{3.785 \text{ L}}{1 \text{ gal}} \qquad \textbf{(Eq. 17)}$$

The second conversion factor is created by dividing both sides of Equation 16 by 3.785 liters:

$$\frac{1 \text{ gal}}{3.785 \text{ L}} = \frac{3.785 \text{ L}}{3.785 \text{ L}}$$

$$\frac{1 \text{ gal}}{3.785 \text{ L}} = 1 \qquad \textbf{(Eq. 18)}$$

One of these conversion factors will convert gallons to liters and the other will convert liters to gallons. The question now is this: Which one should you use?

USING CONVERSION FACTORS Conversion factors work in the following way. It is customary in algebra to use a symbol for the unknown quantity in a problem. In this case, the unknown is the number of liters. An appropriate symbol for the unknown is V, for volume, but you could pick any symbol that suited you. The unknown will go on one side of the equal sign. On the other side is the information you were given (250 gallons) and one of the conversion factors:

$$V = 250 \cancel{\text{gal}} \times \frac{3.785 \text{ L}}{1 \cancel{\text{gal}}}$$

$$V = 946 \text{ L} \qquad \textbf{(Eq. 19)}$$

So you have found that 250 gallons is equal to 946 liters.

CANCELLATION OF UNITS Notice that the gallon unit canceled from Equation 19, leaving just the liter unit on the right side of the equal sign. This cancellation must happen because your answer must be expressed in the correct units for the quantity you are trying to find, in this case, volume. If the units do not cancel correctly, the calculation was probably set up wrong.

To make the cancellation, the correct conversion factor must be used. In setting up Equation 19, you chose the conversion

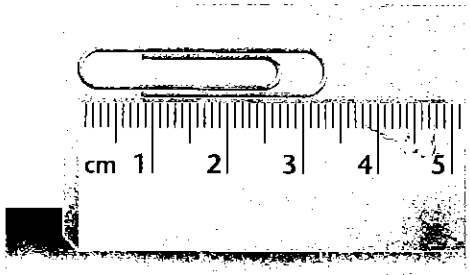


Figure 1–30 *The length of a paper clip is a little over 3 centimeters. How would you convert this measurement to meters? To millimeters?*

factor with the gallon unit on the bottom of the fraction bar. That way the gallon unit cancels from the equation.

Choosing the correct conversion factor requires looking carefully at the units involved in the problem. Studying the units and deciding which conversion factor to use are essential parts of performing a dimensional analysis.

Dimensional Analysis Applied to Unit Conversions

You can quickly and easily make conversions among English units and metric units by following these steps:

- Write down the unit equality for the units you need to convert.
- Write down the conversion factors corresponding to the unit equality.
- Use a symbol to represent the unknown quantity in the problem. Put this symbol on the left side of the equal sign.
- Write the given information on the right side of the equal sign and multiply by one of the conversion factors. Choose the correct conversion factor by performing a dimensional analysis. Units should cancel to give the desired unit. Units that are the same in the given measurement and below the fraction bar cancel from the equation.
- When the conversion is finished, the unit on the right side of the equal sign should be the unit you are converting to.

SAMPLE PROBLEM 7

How many inches are in 250. centimeters?

STRATEGY	SOLUTION
1. Analyze	This is a unit conversion problem, which you can solve by dimensional analysis. You can use the symbol d to represent the unknown number of inches. The unit equality you need is given in Figure 1–29: 1 in. = 2.54 cm. The two conversion factors you can write from this equality are $\frac{1\text{ in.}}{2.54\text{ cm}}$ and $\frac{2.54\text{ cm}}{1\text{ in.}}$
2. Plan	Choose the correct conversion factor by performing a dimensional analysis. Because you want centimeter units to cancel, use the conversion factor with centimeter units in the denominator. You are now ready to solve the problem.

3. Solve

$$d = 250.\ \text{cm} \times \frac{1\ \text{in.}}{2.54\ \text{cm}}$$

$$d = 98.4\ \text{in.}$$

4. Evaluate To evaluate the answer, you should look at both the number and the unit. The centimeter unit canceled from the equation as required, leaving only units of inches. And since 1 in. has a length of about 2.5 cm, 250 cm should have a length of about 100 in. Thus, your answer is expressed in the correct units and has a reasonable value.

PRACTICE PROBLEMS

13. How many gallons are in 39 L? *(Answer: 10. gal)*

14. How many centimeters are in 16 in.? *(Answer: 41 cm)*

Lengthy Conversions

Sometimes several conversion factors are needed to complete a unit conversion. In such cases, the conversion could be performed in a series of separate steps. But it is usually more efficient to combine the steps, as the following example will illustrate.

How many seconds are in 5.0 hours? Checking the table in Figure 1–29, you will see that there is no unit equality that connects seconds and hours directly. However, there is a definition that relates hours and minutes, and another that relates minutes and seconds. Thus, you could perform the conversion from hours to seconds in two steps. But you can also solve the problem by combining the separate steps into one longer step.

First, list the definitions, as follows:

$$1\ \text{hr} = 60\ \text{min}$$

$$1\ \text{min} = 60\ \text{s}$$

Next, list the conversion factors you can use:

$$\frac{1\ \text{hr}}{60\ \text{min}} \quad \text{and} \quad \frac{60\ \text{min}}{1\ \text{hr}}$$

$$\frac{1\ \text{min}}{60\ \text{s}} \quad \text{and} \quad \frac{60\ \text{s}}{1\ \text{min}}$$

Use t as the variable to represent the number of seconds in 5.0 hours. Setting up the equation gives:

$$t = 5.0\ \text{hr} \times \frac{60\ \text{min}}{1\ \text{hr}} \times \frac{60\ \text{s}}{1\ \text{min}}$$

$$t = 18{,}000\ \text{s} \qquad \textbf{(Eq. 20)}$$

Notice that the equation contains two conversion factors instead of just one. The first conversion factor changes hours to minutes. The second conversion factor changes minutes to seconds. The conversion factors were chosen by dimensional analysis so that the unwanted units, hours and minutes, would cancel.

SAMPLE PROBLEM 8

How many feet are in 86 centimeters?

STRATEGY	SOLUTION
1. Analyze	You are asked to convert centimeters to feet. There is no unit equality between centimeters and feet in Figure 1–29. However, there is an equality between centimeters and inches, and another between inches and feet.
2. Plan	Here are the unit equalities you will need: $$1 \text{ in.} = 2.54 \text{ cm}$$ $$1 \text{ ft} = 12 \text{ in.}$$ The conversion factors you can use are $$\frac{1 \text{ in.}}{2.54 \text{ cm}} \text{ and } \frac{2.54 \text{ cm}}{1 \text{ in.}}$$ $$\frac{1 \text{ ft}}{12 \text{ in.}} \text{ and } \frac{12 \text{ in.}}{1 \text{ ft}}$$ Choose the correct conversion factors by dimensional analysis. The symbol d can be used for the unknown quantity.
3. Solve	$$d = 86 \cancel{\text{cm}} \times \frac{1 \cancel{\text{in.}}}{2.54 \cancel{\text{cm}}} \times \frac{1 \text{ ft}}{12 \cancel{\text{in.}}}$$ $$d = 2.8 \text{ ft}$$
4. Evaluate	The unwanted units canceled from the equation as required, leaving only units of feet on both sides of the equal sign. Since 1 meter, or 100 cm, is about the same length as 1 yard (or 3 ft), it makes sense that 86 cm should be a little less than 3 ft.

PRACTICE PROBLEMS

15. How many cubic centimeters are in 2.3 gal? *(Answer: 8700 cm^3)*

16. How many meters are in 3.5 mi? *(Answer: 5600 m)*

Figure 1–31 *Suppose you were asked to convert seconds to kilograms. Could you do it? Why or why not?*

Impossible Conversions

Suppose you were asked, "How many seconds are in a kilogram?" Would you be able to answer this question? We hope your answer is a resounding "No!" This is a meaningless question and an impossible conversion to make because the units correspond to different quantities—the second is a unit of time, whereas the kilogram is a unit of mass. When you begin a unit conversion, first ask yourself: Do the units correspond to the same quantity? No one, not even the best chemist, can change apples to oranges! If the units in the problem do not correspond to the same quantity, it is impossible, no matter how hard you might try, to convert the units.

A Four-Step Problem-Solving Strategy

The Sample Problems we have worked out in this chapter have followed a four-step format. We recommend that you follow this same strategy, as outlined below, when working on your own problems.

1. **Analyze** Read the entire problem carefully. Identify the unknown quantity in the problem and choose a symbol to represent it. Organize the given information into a table or list. Sketch a picture or a diagram to help clarify the problem.
2. **Plan** Is the problem similar to any you have seen before? Review earlier problems for clues to connecting the unknown to the given information. Write down any equations that link the unknown and the given

information together. Make a plan for solving the problem. For example, you may have to rearrange an equation to isolate the unknown, as you saw in Sample Problem 6. Make an estimate of the answer. Ask yourself, What would be a reasonable answer in this case?

3. **Solve** Perform the mathematical steps outlined in your plan. Check units and significant digits.
4. **Evaluate** Ask yourself, Does the answer make sense? Compare the answer (numerical value and units) with your estimate.

Graphing

When an experiment generates many measurements, it can be difficult to see patterns in all the information. A graph can help clarify these patterns. Let's see how a graph can help by examining an example.

Suppose a balloon is filled with air and attached to the bottom of a large container of water. If the water temperature is changed, by heating or by adding ice, the volume of the air in the balloon also changes. The data in the table in Figure 1–32 were obtained by measuring the volume of the balloon at several temperatures. Is there a pattern in these measurements?

A graph of this information immediately reveals the answer. Yes! The volume of the air changes in a regular way when the temperature changes. This straight-line pattern is not obvious from the list of data in the table.

HOW TO DRAW A SCIENTIFIC GRAPH Scientific graphs show the relationship between two experimental variables. One variable is called the independent variable. The independent variable is the one that the scientist changes in the experiment. In the balloon experiment, the independent variable is the temperature. The independent variable is plotted on the horizontal,

Measurements of the Volume of a Sample Gas at Various Temperatures

Trial	Temperature (°C)	Volume (mL)
1	25	101.3
2	30.	102.2
3	35	103.4
4	40.	105.0
5	45	106.7
6	50.	108.4
7	55	110.0
8	60.	111.5
9	65	112.9
10	70.	114.2

Figure 1–32 *The data table shows how the volume of air in a balloon changes as the temperature changes. Is it easy for you to see a pattern in these data?*

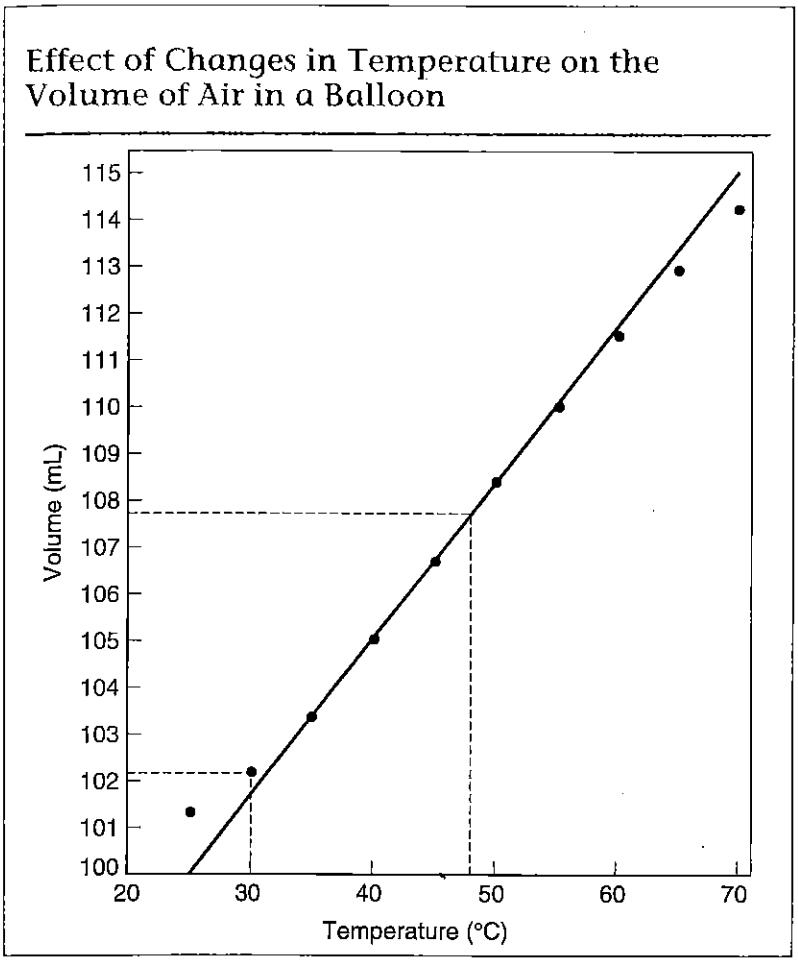


Figure 1–33 *The pattern in the data becomes much clearer when the data are plotted on a graph. Which is the independent variable in this graph? The dependent variable?*

or x, axis of the graph. The second variable, called the dependent variable, is plotted on the vertical, or y, axis of the graph. The dependent variable responds to changes in the independent variable. The volume is the dependent variable in the balloon experiment. Here is a list of steps to follow in drawing a scientific graph. Refer to the graph in Figure 1–33 as you read these steps:

- Label each axis of the graph with the name of the variable and the units of the measurement. As shown in the graph, a simple numbering scheme is used for each axis, because it makes it easier for you to see relationships immediately.
- Convert each pair of measurements into a point on the graph. Mark the point by a clean dot. The second pair of measurements in the data table, for example, is plotted on the graph by locating 30°C on the horizontal axis and 102.2 mL on the vertical axis. The locations are projected onto the graph, as shown by the dotted lines, and the place where the lines intersect is marked with a dot as the data point.
- Connect the data points with a "best fit" line.
- Give the graph a suitable title when it is complete. The title of the graph in Figure 1–33 is "Effect of Changes in Temperature on the Volume of Air in a Balloon."

SPOTTING TRENDS IN A GRAPH A graph tells a "story" by showing a trend in the experimental data. After plotting all the measurements in the data table, a straight-line pattern is

To draw a best-fit line, do not merely connect the data points. For data that display a linear pattern, use a ruler to draw a line that best accommodates all the data points. Because of uncertainty and errors in measurement, some of the data points will be above the best-fit line, while others will be below it. To obtain the slope of this line, calculate $\Delta y/\Delta x$.

clearly seen in the graph. Not all of the data points fall exactly on the line, but the trend is obvious. Drawing a line through the data points highlights the pattern.

A trend is different from the data that it is based on. A trend is an interpretation of the data. And like all interpretations, it may or may not be correct. It is possible for a graph to appear to follow a certain trend, but on further investigation you may find a different trend or even no trend at all.

In addition to straight lines (or linear trends), curves and other complicated trends are also found in science. A trend, whatever its shape, can be used to make predictions. Looking at the graph in Figure 1–33, you can easily predict the volume of the balloon at temperatures other than the ones actually measured. The Sample Problem that follows illustrates this idea.

SAMPLE PROBLEM 9

Using Figure 1–33 as a guide, what volume do you predict the balloon would have at 48°C?

STRATEGY	SOLUTION
1. **Analyze**	You are asked to find the volume of the balloon at a given temperature using the graph in Figure 1–33.
2. **Plan**	The straight line drawn through the data points in the graph includes a point corresponding to 48°C and the unknown volume. Reading this volume from the graph will give you the answer to the problem.
3. **Solve**	The procedure for reading the graph is illustrated in Figure 1–33. Following this procedure, you find that the volume of the balloon at 48°C is 107.7 mL.
4. **Evaluate**	According to the data table, the volume of the balloon at 45°C is 106.7 mL and at 50°C is 108.4 mL. Your answer is between these values, which is reasonable.

PRACTICE PROBLEMS

17. What volume would the balloon have at 57°C? *(Answer: 110.7 mL)*

18. Does the straight line in Figure 1–33 correctly predict the volume of the balloon at all temperatures? Within what range of temperatures does the line give accurate predictions for the volume of the balloon? *(Answer: No. The line is most accurate within a temperature range of 35°C to 60°C.)*