1.3 Thinking Like a Scientist

Guide for Reading

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

Vocabulary

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

Reading Strategy

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

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

Alchemy

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

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

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

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

An Experimental Approach to Science

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

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

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

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

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

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

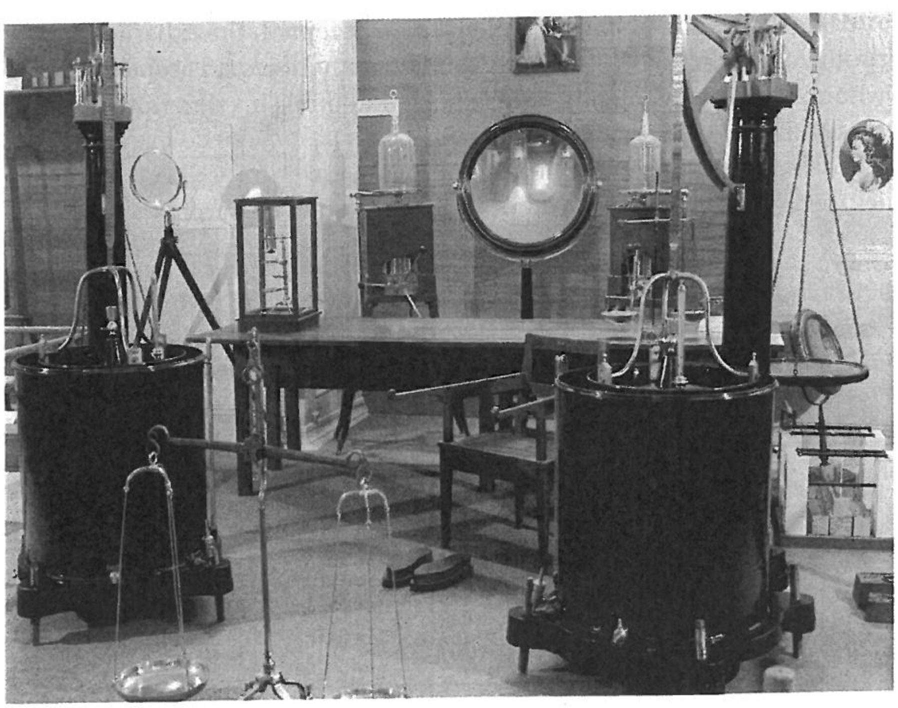


Figure 1.17 This reconstruction of Lavoisier's laboratory is in a museum in Paris, France.
Interpreting Photographs ***What objects do you recognize that are similar to objects that you use in the laboratory?***

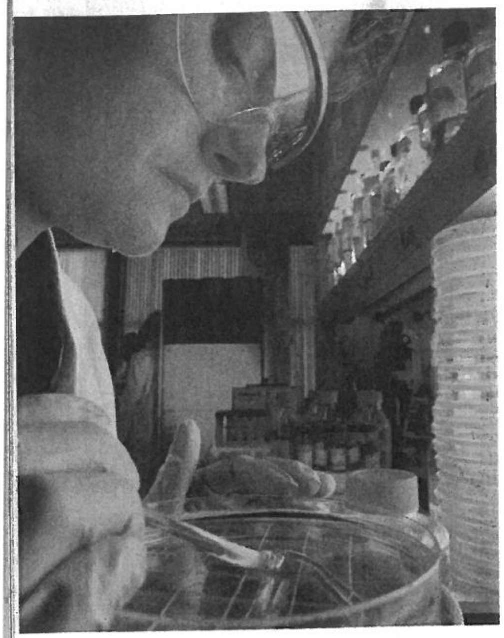


Figure 1.18 Observation is an essential step in the scientific method.

The Scientific Method

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

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

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

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

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

Word *Origins*

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

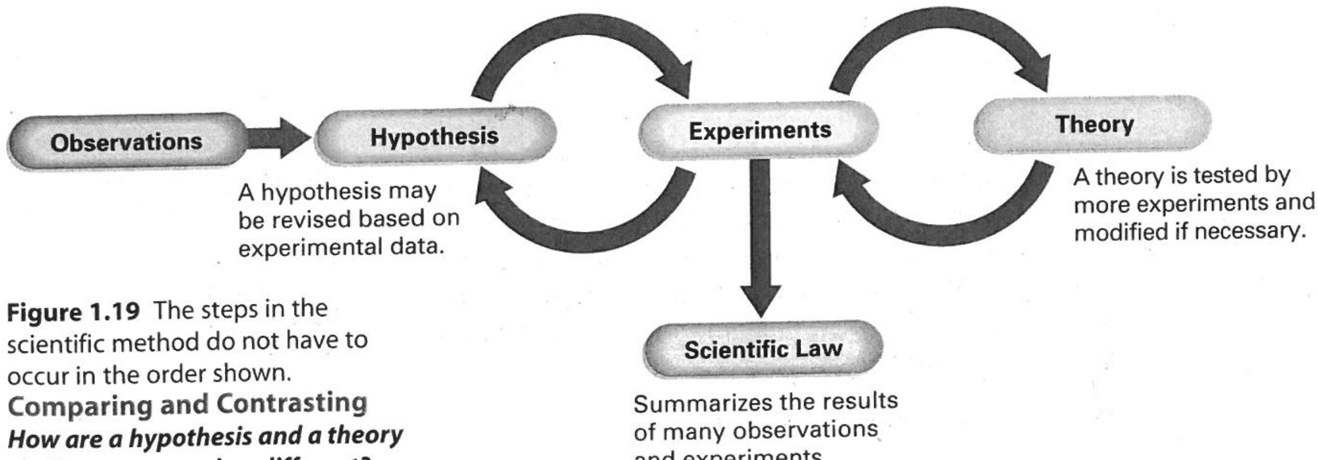
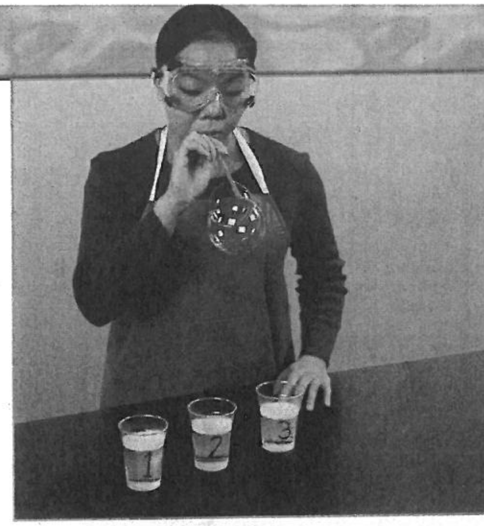


Figure 1.19 The steps in the scientific method do not have to occur in the order shown.
Comparing and Contrasting
How are a hypothesis and a theory similar? How are they different?

Quick LAB

Bubbles!



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

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

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

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

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

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

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

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

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

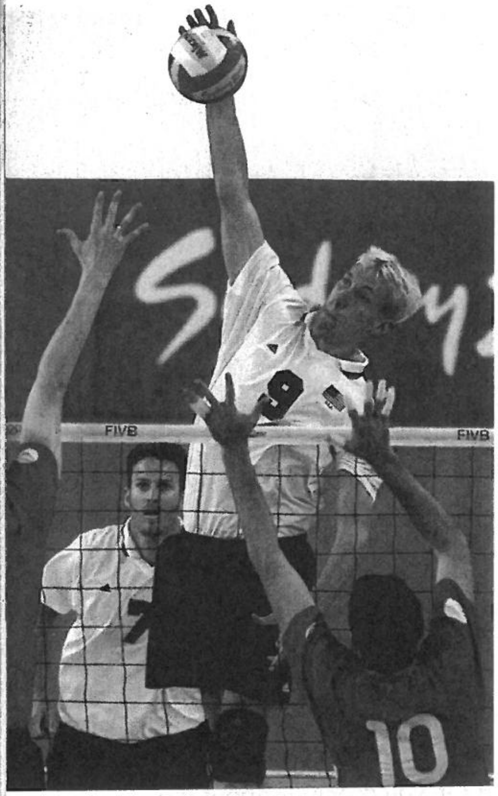


Figure 1.20 For a volleyball team to win, the players must collaborate, or work together.

Collaboration and Communication

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

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

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

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

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

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

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

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

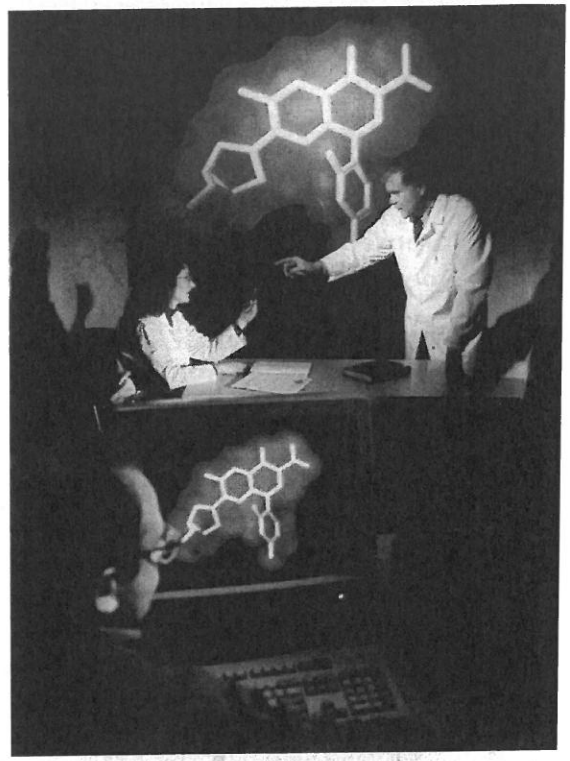


Figure 1.22 Communication between scientists can occur face to face. These chemists are using the model projected on the screen to discuss the merits of a new medicine.

1.3 Section Assessment

16. **Key Concept** What did alchemists contribute to the development of chemistry?
17. **Key Concept** How did Lavoisier revolutionize the science of chemistry?
18. **Key Concept** Name three steps in the scientific method.
19. **Key Concept** Explain why collaboration and communication are important in science.
20. How did Lavoisier's wife help him to communicate the results of his experiments?
21. Why should a hypothesis be developed before experiments take place?
22. Why is it important for scientists to publish a description of their procedures along with the results of their experiments?
23. What is the difference between a theory and a scientific law?
24. What process takes place before an article is published in a scientific journal?
25. In Chapter 2, you will learn that matter is neither created nor destroyed in any chemical change. Is this statement a theory or a law? Explain your answer.

Connecting Concepts

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

Interactive Textbook

Assessment 1.3 Test yourself on the concepts in Section 1.3.

with **ChemASAP**

1.4 Problem Solving in Chemistry

Guide for Reading

Key Concepts

- What is a general approach to solving a problem?
- What are the three steps for solving numeric problems?
- What are the two steps for solving conceptual problems?

Reading Strategy

Identifying Main Idea/Details Under the heading Solving Numeric Problems, there are three main ideas presented as subheads. As you read, list two details that support each main idea.

Connecting to Your World Shape-sorter toys fascinate young children. Typically, the children try placing a shape in different holes until they find the right one. They may try to place an incorrect shape in the same hole over and over again. An older child has enough experience to place the correct shape in each hole on the first try. The trial-and-error approach used by young children is one method of problem solving, but it is usually not the best one. In this section, you will learn effective ways to solve problems in chemistry.

Skills Used in Solving Problems

Problem solving is a skill you use all the time. You are in a supermarket. Do you buy a name brand or the store brand of peanut butter? Do you buy the 1-liter bottle or the 2-liter bottle of a carbonated beverage? Do you choose the express line if there are five customers ahead of you or the non-express line with a single shopper who has lots of items?

When you solve a problem you may have a data table, a graph, or another type of visual to refer to. The shopper in Figure 1.23 is reading the label on a can while trying to decide whether to buy the item. She may need to avoid certain ingredients because of a food allergy. Or she may want to know the amount of Calories per serving.

The skills you use to solve a word problem in chemistry are not that different from those you use while shopping or cooking or planning a party. **Effective problem solving always involves developing a plan and then implementing that plan.**

Figure 1.23 A shopper must make many decisions. Some of those decisions are based on data, like the information on a food label.

Solving Numeric Problems

Because measurement is such an important part of chemistry, most word problems in chemistry require some math. The techniques used in this book to solve numeric problems are conveniently organized into a three-step, problem-solving approach. This approach has been shown to be very helpful and effective. So we recommend that you follow this approach when working on numeric problems in this textbook. **The steps for solving a numeric word problem are analyze, calculate, and evaluate.** Figure 1.24 summarizes the three-step process and Sample Problem 1.1 shows how the steps work in a problem.

1 Analyze To solve a word problem, you must first determine where you are starting from (identify what is known) and where you are going (identify the unknown). What is known may be a measurement. Or it may be an equation that shows a relationship between measurements. If you expect the answer (the unknown) to be a number, you need to determine what units the answer should have before you do any calculations.

After you identify the known and the unknown, you need to make a plan for getting from the known to the unknown. Planning is at the heart of successful problem solving. As part of planning, you might draw a diagram that helps you visualize a relationship between the known and the unknown. You might need to use a table or graph to identify data or to identify a relationship between a known quantity and the unknown. You may need to select an equation that you can use to calculate the unknown.

2 Calculate If you make an effective plan, doing the calculations is usually the easiest part of the process. For some problems, you will have to convert a measurement from one unit to another. Or you may need to rearrange an equation before you can solve for an unknown. However, you will be taught these math skills as needed. There will also be reminders throughout the textbook to use the Math Handbook in Appendix C.

3 Evaluate After you calculate an answer, you should evaluate it. Is the answer reasonable? Does it make sense? If not, reread the word problem. Did you copy the data correctly? Did you choose the right equations? It helps to round off the numbers and make an estimate of the answer. If the answer is much larger or much smaller than your estimate, check your calculations.

Check that your answer has the correct unit and the correct number of significant figures. You may need to use scientific notation in your answer. You will study significant figures and scientific notation in Chapter 3.

Checkpoint ***How can making an estimate help you evaluate an answer?***

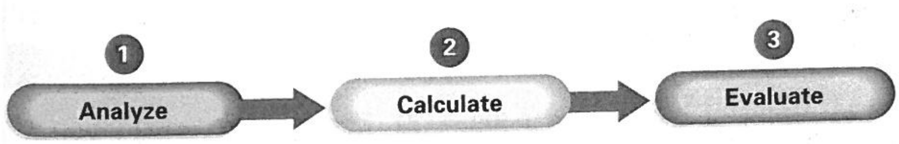
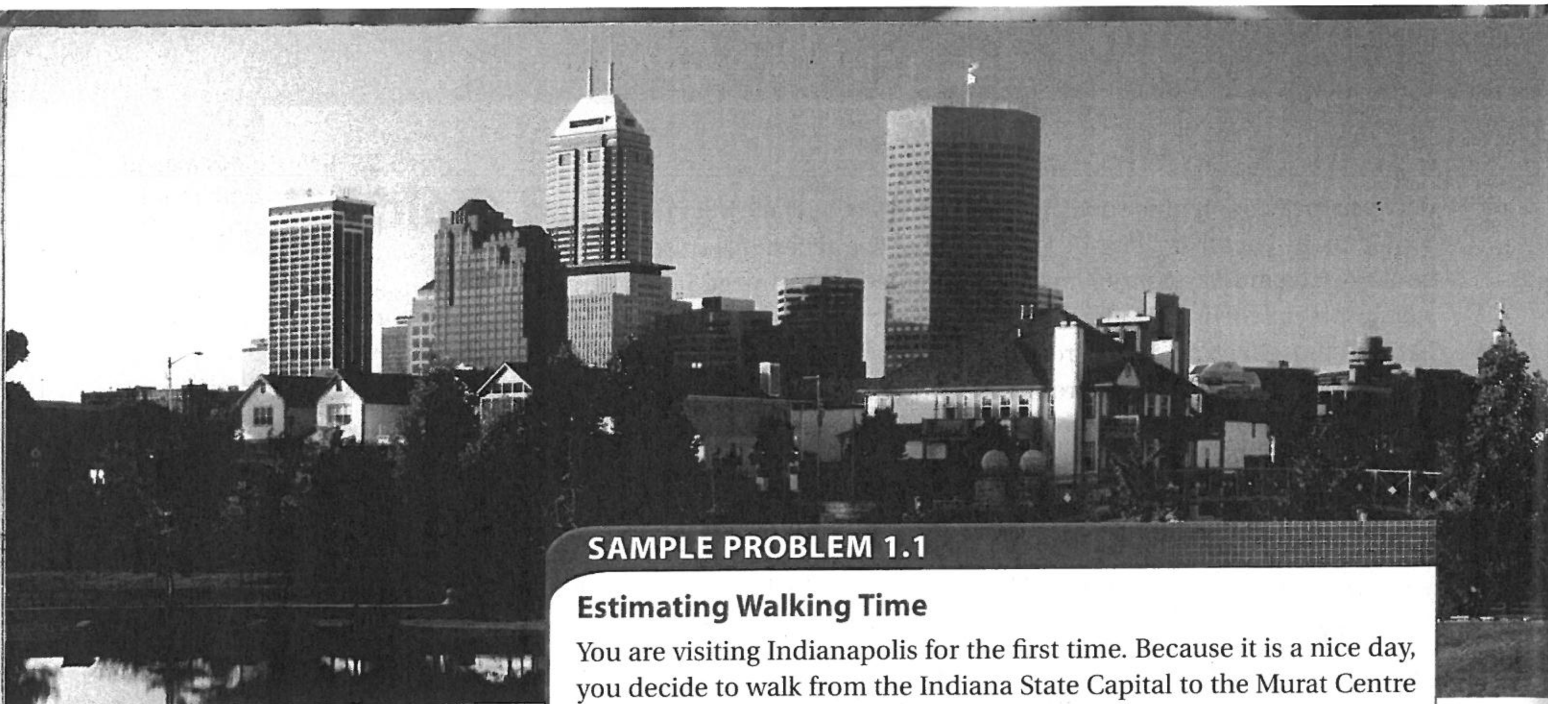


Figure 1.24 This flowchart summarizes the steps for solving a numeric problem. **Predicting** ***In which step do you make a plan for getting from what is known to what is unknown?***



This view of Indianapolis, Indiana, shows part of the historic central canal in White River State Park.

SAMPLE PROBLEM 1.1

Estimating Walking Time

You are visiting Indianapolis for the first time. Because it is a nice day, you decide to walk from the Indiana State Capital to the Murat Centre for an afternoon performance. According to the map in Figure 1.25, the shortest route from the capital to the theater is 8 blocks. How many minutes will the trip take if you can walk one mile in 20 minutes? Assume that 10 short city blocks equals one mile.

1 Analyze ***List the knowns and the unknown.***

Knowns

- distance to be traveled = 8 blocks
- walking speed = 1 mile/20 minutes
- 1 mile = 10 blocks

Unknown

- time of trip = ? minutes

This problem is an example of what is typically called a conversion problem. In a conversion problem, one unit of measure (in this case, blocks) must be expressed in a different unit (in this case, minutes).

Divide the distance to be traveled (in blocks) by the number of blocks in one mile to get the distance of the trip in miles. Then multiply the number of miles by the time it takes to walk one mile.

2 Calculate ***Solve for the unknown***

$$8\ \cancel{\text{block}} \times \frac{1\ \text{mile}}{10\ \cancel{\text{blocks}}} = 0.8\ \text{mile}$$

$$0.8\ \cancel{\text{mile}} \times \frac{20\ \text{minutes}}{1\ \cancel{\text{mile}}} = 16\ \text{minutes}$$

3 Evaluate ***Does the result make sense?***

The answer seems reasonable, 16 minutes to walk 8 short blocks. The answer has the correct unit. The relationships used are correct.

Practice Problems

26. Using the information in the sample problem, how many short blocks can be walked in 48 minutes?

27. There is an ice cream shop 6 blocks north of your hotel. How many minutes will it take to walk there and back?

Interactive Textbook

Problem-Solving 1.27
Solve Problem 27 with the help of an interactive guided tutorial.

with ChemASAP

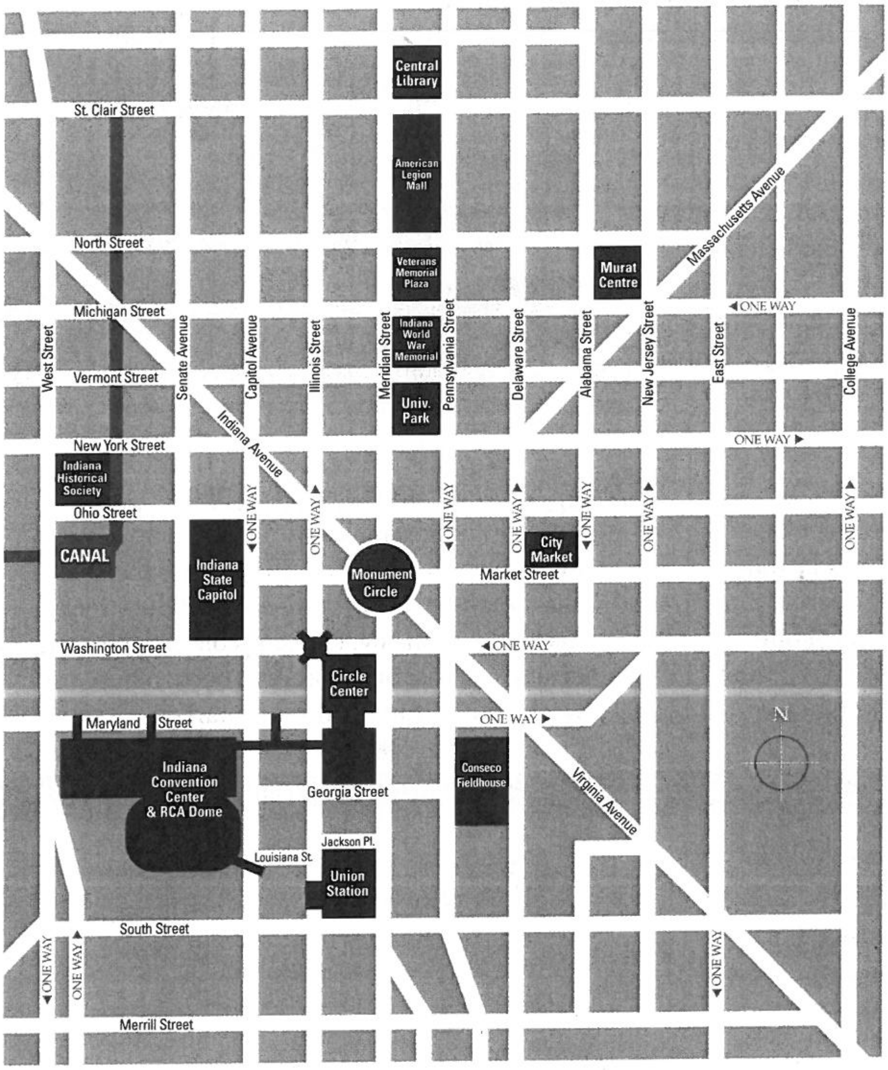


Figure 1.25 Refer to this map of Indianapolis, Indiana, while you do Sample Problem 1.1.
Interpreting Diagrams
In the section of downtown bounded by north, east, south, and west streets, the main streets and avenues are named for states. What are the five exceptions to this pattern?

Solving Conceptual Problems

Not every word problem in chemistry requires calculations. Some problems ask you to apply the concepts you are studying to a new situation. In this text, these nonnumeric problems are labeled conceptual problems. To solve a conceptual problem, you still need to identify what is known and what is unknown. Most importantly, you still need to make a plan for getting from the known to the unknown. But if your answer is not a number, you do not need to check the units, make an estimate, or check your calculations.

The three-step problem-solving approach is modified for conceptual problems. **The steps for solving a conceptual problem are analyze and solve.** Figure 1.26 summarizes the process, and Conceptual Problem 1.1 on the next page shows how the steps work in an actual problem.

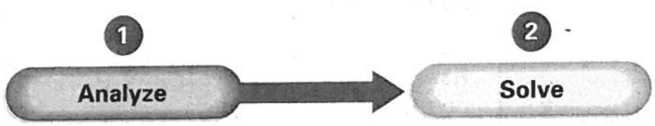
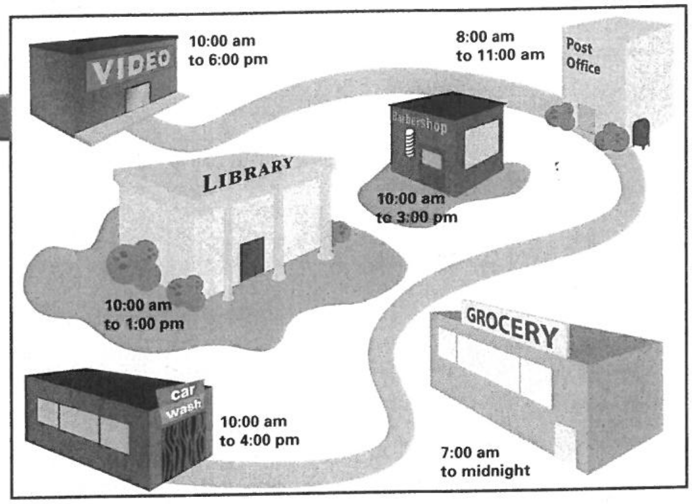


Figure 1.26 This flowchart shows the two steps used for solving a conceptual problem.
Comparing and Contrasting
With a conceptual problem, why is the second step solve rather than calculate?

CONCEPTUAL PROBLEM 1.1



Running Errands

Manny has to run 6 errands between 10 and 5 on Saturday. He must get a haircut, wash his car, buy stamps, rent a video, return a library book, and buy some groceries. Assume that each errand will take 30 minutes and that Manny will do only one errand per hour. Manny will stop for a lunch break between 12 and 1. Use the information in the drawing to figure out a way for Manny to accomplish all 6 tasks.

1 Analyze ***Identify the relevant concepts.***

Each place that Manny needs to visit is open for a limited number of hours on Saturday. Manny must do his errands between 10 and 12, and between 1 and 5. At a rate of one errand per hour, Manny must do 2 errands before lunch and 4 errands after lunch.

2 Solve ***Apply concepts to this situation.***

The post office and library are open only in the morning. The barbershop and the car wash close earlier than the video store. The supermarket is open late. One possible order for the errands is post office, library, barbershop, car wash, video store, and supermarket.

Practice Problems

28. Describe two alternative orders in which Manny could complete his errands.

29. What if Manny had 7 errands instead of 6? What would he need to do to adjust for the extra errand?

Interactive Textbook

Problem-Solving 1.29 Solve Problem 29 with the help of an interactive guided tutorial.

with **ChemASAP**

1.4 Section Assessment

30. **Key Concept** What are the two general steps in successful problem solving?

31. **Key Concept** List the three steps for solving numeric problems.

32. **Key Concept** List the two steps for solving conceptual problems.

33. Read the conversion problem and then answer the questions. "There are 3600 seconds in an hour. How many seconds are there in one day?"

- **a.** Identify the known and the unknown.
- **b.** What relationship between the known and unknown do you need to solve the problem?
- **c.** Calculate the answer to the problem.
- **d.** Evaluate your answer and explain why your answer makes sense.

Writing Activity

Compare and Contrast Paragraph Write a paragraph comparing the processes for solving numeric problems and conceptual problems. How are the processes similar? In what way are they different?

Interactive Textbook

Assessment 1.4 Test yourself on the concepts in Section 1.4.

with **ChemASAP**

CHAPTER 1

Assessment

Reviewing Content

1.1 Chemistry

34. Explain why air is classified as matter.

35. The Japanese characters for chemistry literally mean "change study." Why are these appropriate characters to represent chemistry?

36. Describe the main difference between inorganic chemistry and organic chemistry.

37. Was Wallace Carothers doing pure chemistry or applied chemistry when he discovered nylon? Explain your answer.

38. Explain how chemists were able to connect the ability of aspirin to relieve pain to its ability to reduce the risk of a heart attack.

39. Why would a firefighter or a reporter need to understand chemistry?

1.2 Chemistry Far and Wide

40. George de Mestral used burrs as a model for his hook-and-loop tapes. Using burrs as an example, explain the difference between a macroscopic and a microscopic view of matter.

41. How does the use of insulation help to conserve energy?

42. What is the overall goal of scientists who work with biotechnology?

43. Describe two ways that biotechnology can be used to treat diseases.

44. How can testing soil help to increase the productivity of farmland?

45. What is a pollutant?

46. Why is it important that young children not be exposed to lead-based paint?

47. How can scientists study the composition of distant stars?

1.3 Thinking Like a Scientist

48. What did the scientists who founded the Royal Society of London share with Lavoisier?

49. What is the most powerful tool that any scientist can have?

50. What is the purpose of an experiment?

51. Which of the following is not a part of the scientific method?

a. hypothesis **b.** experiment
c. guess **d.** theory

52. How do a manipulated variable and a responding variable differ?

53. You perform an experiment and get unexpected results. According to the scientific method, what should you do next?

54. Explain how the results of many experiments can lead to both a scientific law and a theory.

55. List two general reasons why scientists are likely to collaborate.

1.4 Problem Solving in Chemistry

56. Identify the statements that correctly describe good problem solvers.

a. Read a problem only once.
b. Check their work.
c. Look up missing facts.
d. Look for relationships among the data.

57. What do effective problem-solving strategies have in common?

58. In which step of the three-step problem-solving approach for numeric problems is a problem-solving strategy developed?

59. On the average, a baseball team wins two out of every three games it plays. How many games will this team lose in a 162-game season?

60. If your heart beats at an average rate of 72 times per minute, how many times will your heart beat in an hour? In a day?

61. How many days would it take you to count a million pennies if you could count one penny each second?