1.1 Chemistry

Connecting to Your World

The *Galileo* spacecraft was placed in orbit around Jupiter to collect data about the planet and its moons. Instruments aboard *Galileo* analyzed the atmosphere of the moon Io. They found large amounts of sulfur and sulfur dioxide. These chemicals are usually released when volcanoes erupt on Earth. So the presence of these chemicals verified that the volcanoes on Io's surface are active. Chemistry helped scientists to study the geology of a distant object in the solar system. In this section, you will learn about chemistry in general and ways you can use your knowledge of chemistry.

Guide for Reading

Key Concepts

- Why is the scope of chemistry so vast?
- What are five traditional areas of study in chemistry?
- How are pure and applied chemistry related?
- What are three general reasons to study chemistry?

Vocabulary

matter
chemistry
organic chemistry
inorganic chemistry
biochemistry
analytical chemistry
physical chemistry
pure chemistry
applied chemistry
technology

Reading Strategy

Relating Text and Visuals As you read, look closely at Figure 1.2. Explain how this illustration helps you to understand the traditional areas of study in chemistry.

What Is Chemistry?

In autumn thousands of visitors travel to New England to view vivid colors like those in Figure 1.1. These colors appear as the trees approach the winter months when growth no longer takes place. The bright pigments are produced by a complex chemical process, which depends on changes in temperature and hours of daylight. The color pigments in leaves are an example of matter. Matter is the general term for all the things that can be described as materials, or "stuff." **Matter** is anything that has mass and occupies space. You don't have to be able to see something for it to qualify as matter. The air you breathe is an example of "invisible" matter.

Chemistry is the study of the composition of matter and the changes that matter undergoes. **Because living and nonliving things are made of matter, chemistry affects all aspects of life and most natural events.** Chemistry can explain how some creatures survive deep in the ocean where there is no light, or why some foods taste sweet and some taste bitter. It can even explain why there are different shampoos for dry or oily hair.

Figure 1.1 Chemical changes that occur in leaves can cause brilliant displays of color.

Areas of Study

Because the scope of chemistry is vast, chemists tend to focus on one area. **Five traditional areas of study are organic chemistry, inorganic chemistry, biochemistry, analytical chemistry, and physical chemistry.**

Most of the chemicals found in organisms contain carbon. Organic chemistry was originally defined as the study of these carbon-based chemicals. Today, with a few exceptions, **organic chemistry** is defined as the study of all chemicals containing carbon. By contrast, **inorganic chemistry** is the study of chemicals that, in general, do not contain carbon. Inorganic chemicals are found mainly in non-living things, such as rocks. The study of processes that take place in organisms is **biochemistry.** These processes include muscle contraction and digestion. **Analytical chemistry** is the area of study that focuses on the composition of matter. A task that would fall into this area of chemistry is measuring the level of lead in drinking water. **Physical chemistry** is the area that deals with the mechanism, the rate, and the energy transfer that occurs when matter undergoes a change.

The boundaries between the five areas are not firm. A chemist is likely to be working in more than one area of chemistry at any given time. For example, an organic chemist uses analytical chemistry to determine the composition of an organic chemical. Figure 1.2 shows how research in these areas of study can be used to keep humans healthy.

Figure 1.2 Chemists study structures and processes in the human body. **Inferring** ***Does a bone contain mainly organic or inorganic chemicals?***

Pure and Applied Chemistry

Some chemists enjoy doing research on fundamental aspects of chemistry. This type of research is sometimes called pure chemistry. **Pure chemistry** is the pursuit of chemical knowledge for its own sake. The chemist doesn't expect that there will be any immediate practical use for the knowledge. Most chemists do research that is designed to answer a specific question. **Applied chemistry** is research that is directed toward a practical goal or application. In practice, pure chemistry and applied chemistry are often linked. **Pure research can lead directly to an application, but an application can exist before research is done to explain how it works.** Nylon and aspirin provide examples of these two approaches.

Nylon For years, chemists didn't fully understand the structure of materials such as cotton and silk. Hermann Staudinger, a German chemist, proposed that these materials contained small units joined together like links in a chain. In the early 1930s, Wallace Carothers did experiments to test Staudinger's proposal. His results supported the proposal. During his research Carothers produced some materials that don't exist in nature. One of these materials, nylon, can be drawn into long, thin, silk-like fibers, as shown in Figure 1.3. Because the supply of natural silk was limited, a team of scientists and engineers were eager to apply Carother's research to the commercial production of nylon. By 1939, they had perfected a large-scale method for making nylon fibers.

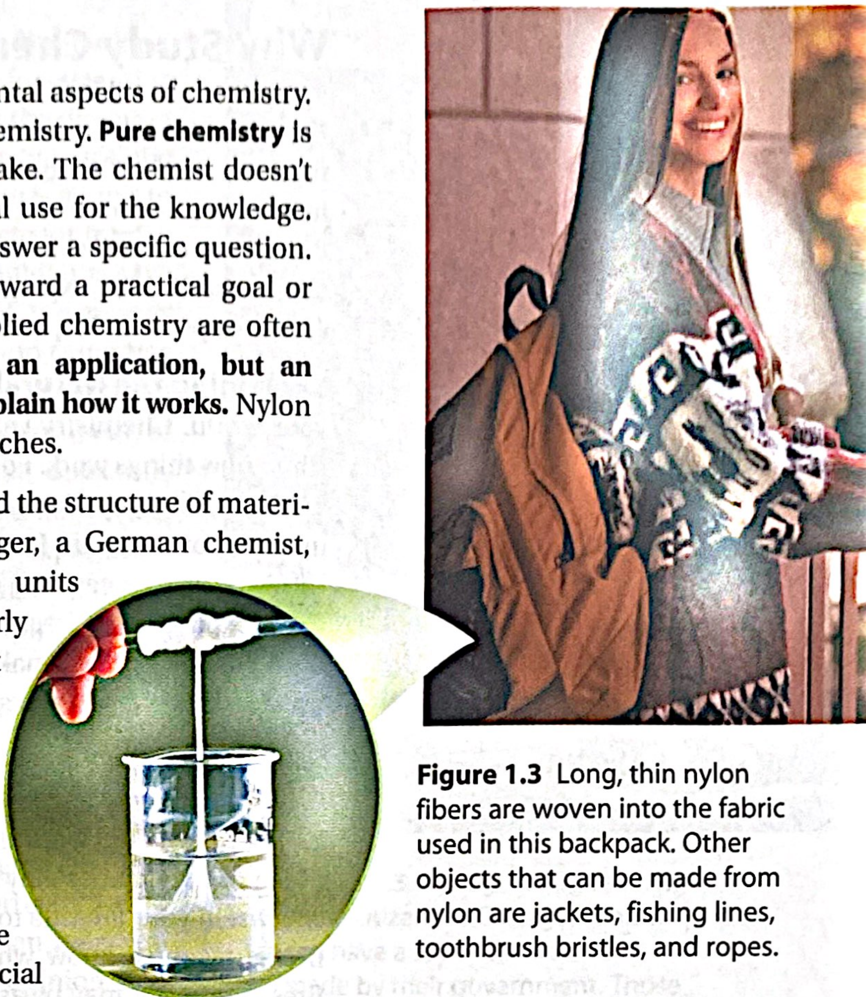

Figure 1.3 Long, thin nylon fibers are woven into the fabric used in this backpack. Other objects that can be made from nylon are jackets, fishing lines, toothbrush bristles, and ropes.

Aspirin Long before researchers figured out how aspirin works, people used it to relieve pain. By 1950, some doctors began to recommend a low daily dose of aspirin for patients who were at risk for a heart attack. Many heart attacks occur when blood clots block the flow of blood through arteries in the heart. Some researchers suspected that aspirin could keep blood clots from forming. In 1971, it was discovered that aspirin can block the production of a group of chemicals that cause pain. These same chemicals are also involved in the formation of blood clots.

Technology The development of nylon and the use of aspirin to prevent heart attacks belong to a system of applied science called technology. **Technology** is the means by which a society provides its members with those things needed and desired. Technology allows humans to do some things more quickly or with less effort. It allows people to do things that would be impossible without technology, such as traveling to the moon. In any technology, scientific knowledge is used in ways that can benefit or harm people and the environment. Debates about how to use scientific knowledge are usually debates about the risks and benefits of technology.

Checkpoint ***Which material found in nature does nylon resemble?***

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1.2 Chemistry Far and Wide

Guide for Reading

Key Concepts

- What impact do chemists have on materials, energy, medicine, agriculture, the environment, and the study of the universe?

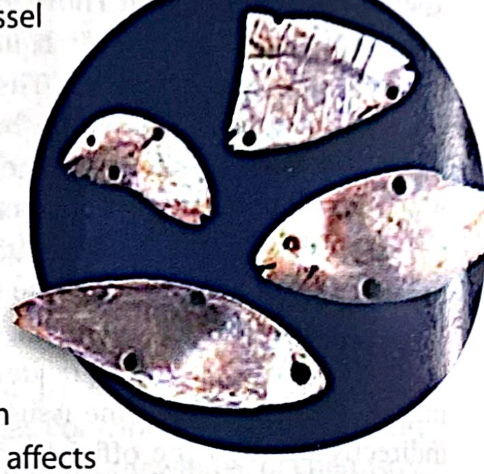
Vocabulary

macroscopic
microscopic
biotechnology
pollutant

Reading Strategy

Monitoring Your Understanding After you read this section, identify something you learned that is important to your life and explain why it is important to you.

Connecting to Your World The first tools were objects such as a stone with a sharp edge. In time, people learned to reshape these objects to produce better tools. Native Americans in what is now Illinois drilled holes in mussel shells and carved lines onto the shells to make them look like small fish. The shells were likely used as lures for ice fishing. People also began to produce materials that did not exist in nature. By weaving plant fibers together, they made cloth, which is softer and dries more quickly than animal skins. Chemistry plays a key role in the production of new materials. In this section, you will learn how chemistry affects many aspects of modern life.



Materials

The search for new materials continues. **Chemists design materials to fit specific needs.** Often they find inspiration in nature. In 1948, while hiking through the woods of his native Switzerland, George de Mestral took a close look at the pesky burrs that stuck to his clothing. When he looked at the burrs under magnification, he saw that each burr was covered with many tiny hooks that could latch on to tiny loops in the woven cloth of his clothing. George had a weaver make two cloth tapes. On the surface of one tape were hooks, and on the surface of the other tape were loops that the hooks could fit into, as shown in Figure 1.6. In 1955 George patented the design for his hook-and-loop tapes. These tapes are used as fasteners for items such as shoes and gloves.

This story illustrates two different ways of looking at the world—the macroscopic view and the microscopic view. The burrs that George de Mestral used as a model for his tapes are small compared to many objects in nature. However, they were large enough for George to see. Burrs belong to the **macroscopic** world, the world of objects that are large enough to see with the unaided eye. George needed more than his own vision to see the hooks on a burr. The hooks belong to the **microscopic** world, or the world of objects that can be seen only under magnification.

Figure 1.6 This is a magnified view of hook-and-loop tape. Color was added to the photo to highlight the structures. **Classifying** ***Does the photograph show a macroscopic or a microscopic view of the tape? Explain.***

Energy

Energy is necessary to meet the needs of a modern society. It is used to heat buildings, manufacture goods, and process foods. It is used to transport people and goods between locations. With population growth and more industrialization around the globe, the demands for energy continue to increase. There are two ways to meet the demand for energy—conserve energy resources and produce more energy. **Chemists play an essential role in finding ways to conserve energy, produce energy, and store energy.**

Conservation One of the easiest ways to conserve energy is through the use of insulation. Much of the energy consumed is used to keep houses warm and freezers cold. Insulation acts as a barrier to heat flow from the inside to the outside of a house or from the outside to the inside of a freezer. The foam used in drink cups provides excellent insulation because it contains pockets of trapped air. One of the most exciting modern insulation materials devised by chemists is SEAgel, which is a foam made from seaweed. SEAgel is very lightweight. In fact, SEAgel is so light that it can float on soap bubbles, as shown in Figure 1.7.

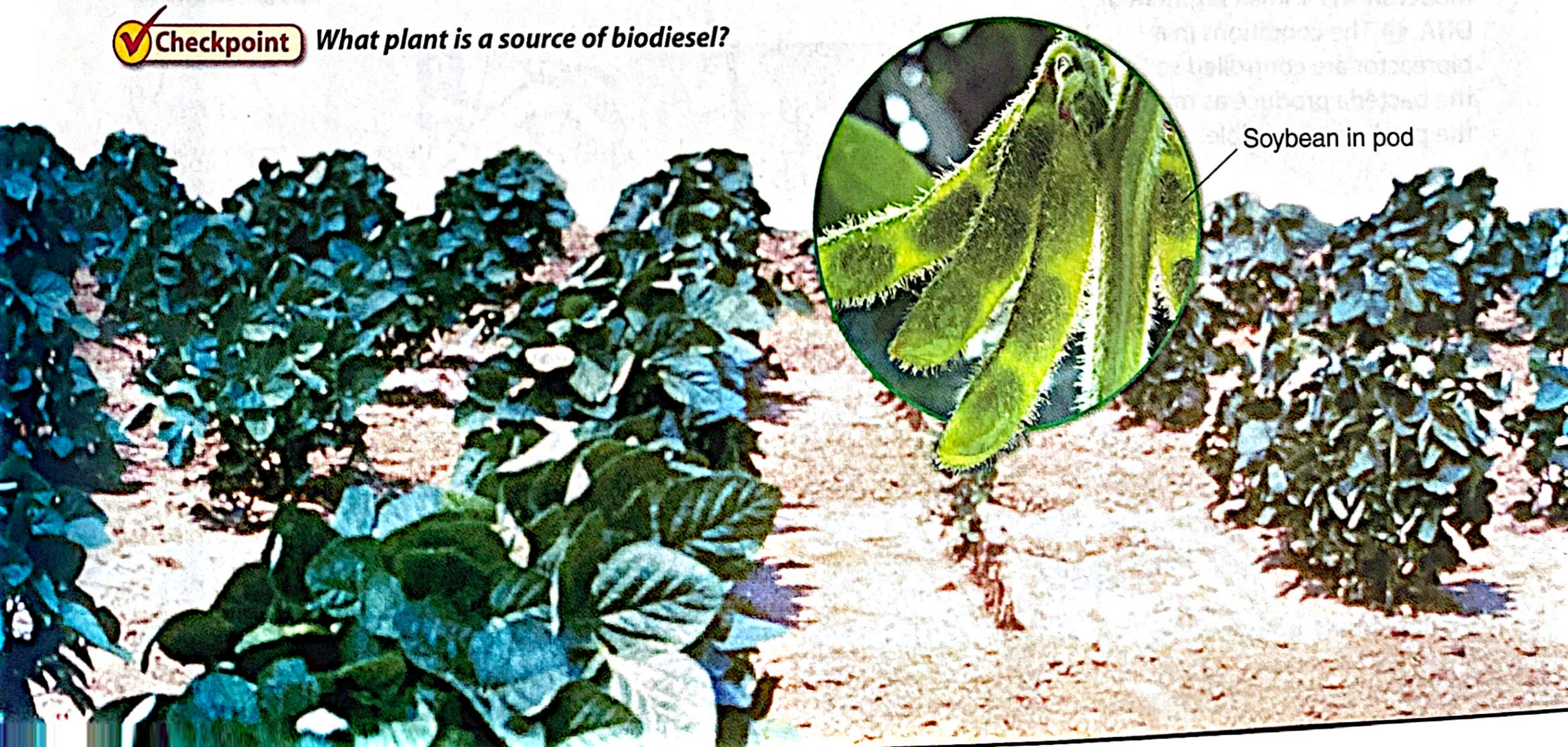
Figure 1.7 This insulation is light enough to float on soap bubbles yet is very effective at preventing heat transfer.

Production The burning of coal, petroleum, and natural gas is a major source of energy. These materials are called fossil fuels because they formed from the remains of ancient plants and animals. Scientists are always looking for new sources of energy because the supply of fossil fuels is limited. One intriguing possibility is fuels obtained from plants. Oil from the soybeans shown in Figure 1.8 is used to make biodiesel. Regular diesel fuel is a petroleum product that produces an irritating black exhaust when it burns. When biodiesel burns, the exhaust smells like French fries!

Storage Batteries are devices that use chemicals to store energy that will be released as electric current when the batteries are used. Batteries vary in size, power, and hours of useful operation. For some applications, it is important to have batteries that can be recharged rather than thrown away. One application that benefits from rechargeable batteries is cordless tools. These tools were first developed for NASA. Astronauts in the Apollo program needed a way to drill beneath the Moon's surface to collect samples. Other devices that use rechargeable batteries are digital cameras, wireless phones, and laptop computers.

Checkpoint ***What plant is a source of biodiesel?***

Figure 1.8 Oil from soybeans can be used in a substitute for regular diesel fuel.
Predicting ***The supply of diesel fuel is limited. Is the supply of soybeans limited?***



Medicine and Biotechnology

No field has benefited more from advances in chemistry than medicine. **Chemistry supplies the medicines, materials, and technology that doctors use to treat their patients.** Work in the field of medicine is often done by biochemists. Their overall goal is to understand the structure of matter found in the human body and the chemical changes that occur in cells. To accomplish their goal, they work with biologists and doctors.

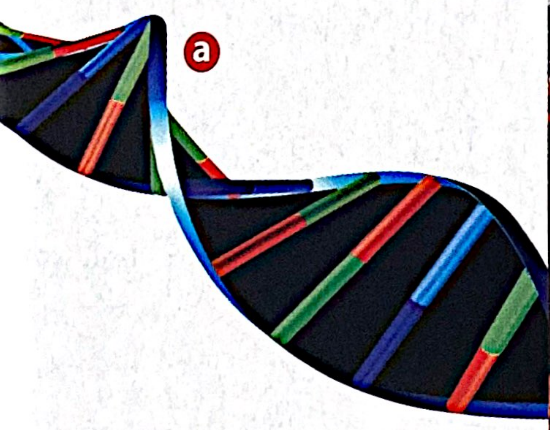
Medicines There are over 2000 prescription drugs. They are designed to treat various conditions including infections, high blood pressure, and depression. Other drugs, such as aspirin and antacids, can be sold without a prescription. Many drugs are effective because they interact in a specific way with chemicals in cells. Knowledge of the structure and function of these target chemicals helps a chemist design safe and effective drugs.

Materials Chemistry can supply materials to repair or replace body parts. Diseased arteries can be replaced with plastic tubes. Artificial hips and knees made from metals and plastics can replace worn-out joints and allow people to walk again without pain. Burn patients may benefit from a plastic "skin" that can heal itself when the plastic cracks. Chemicals that repair the damage are released from tiny capsules in the plastic.

Biotechnology Figure 1.9a shows a model of a small piece of DNA. Segments of DNA called genes store the information that controls changes that take place in cells. From 1990 to 2003, scientists worldwide worked on the Human Genome Project. They identified the genes that comprise human DNA—about 30,000. They determined the sequence of the genes in DNA. Some tools these scientists developed are used in biotechnology.

Biotechnology applies science to the production of biological products or processes. It uses techniques that can alter the DNA in living organisms. It may depend on the transfer of genes from one organism to another. When genes from humans are inserted into bacteria, the bacteria act as factories. They produce chemicals of importance to humans, such as insulin, which is used to treat some types of diabetes. Production takes place in large versions of the bioreactors in Figure 1.9b. In the future, scientists expect to use gene therapy to treat some diseases. A gene that is not working properly would be replaced with one that will work properly.

Figure 1.9 The discovery of the structure of DNA led to the development of biotechnology. (a) This computer graphics model shows a small segment of DNA. (b) The conditions in a bioreactor are controlled so that the bacteria produce as much of the product as possible.



Agriculture

The world's population is increasing, but the amount of land available to grow food is decreasing. Land that was once used for agriculture is now used for homes and industries. So it is important to ensure that land used for agriculture is as productive as possible. **Chemists help to develop more productive crops and safer, more effective ways to protect crops.**

Productivity One way to track productivity is to measure the amount of edible food that is grown on a given unit of land. Some factors that decrease productivity are poor soil quality, lack of water, weeds, plant diseases, and pests that eat crops. Chemists can help with many of these problems. They test soil to see if it contains the right chemicals to grow a particular crop and recommend ways to improve the soil. They use biotechnology to develop plants that are more likely to survive a drought or insect attack.

Chemists can also help to conserve water. In many regions, water is not an abundant resource. Finding reliable ways to determine when a crop needs water is important. The jellyfish in Figure 1.10 has a gene that causes it to glow. If that gene is inserted into a potato plant, the plant glows when it needs to be watered. These altered plants would be removed from the field before the rest of the crop was harvested.

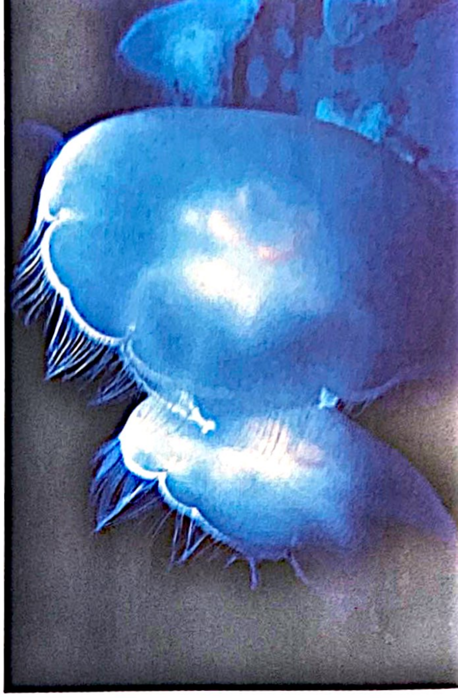


Figure 1.10 If genes from this jellyfish *(Aequaria victoria)* are transferred to a potato plant, the plant glows when it needs to be watered. **Predicting** ***How does the modified plant help a farmer to conserve water?***

Crop Protection For years, farmers have used chemicals to attack insect pests. In the past, these chemicals were nonspecific; that is, a chemical designed to kill a pest could also kill useful insects. Today, the trend is toward chemicals that are designed to treat specific problems. These chemicals are often similar to the chemicals that plants produce for protection.

Chemists sometimes use chemicals produced by insects to fight insect pests. Female insects may produce chemicals that attract male insects. This type of chemical has proved effective in combating pinworms. The worms leave holes and black blotches when they tunnel into tomatoes. Pinworms mate when they are in the moth stage of development. The plastic tube wrapped around the stem of the tomato plant in Figure 1.11 contains the chemical that a female pinworm moth emits to attract male moths. When the chemical is released from these tubes, it interferes with the mating process so that fewer pinworms are produced.

Checkpoint ***What jellyfish gene did scientists transfer to a potato?***

Figure 1.11 In the plastic tube wrapped around the tomato stem, there is a chemical that attracts male pinworm moths. This process reduces the rate of mating between female and male moths, and the number of pinworms produced.

Figure 1.12 This poster was used to warn people about the danger to children from lead-based paint.

The Environment

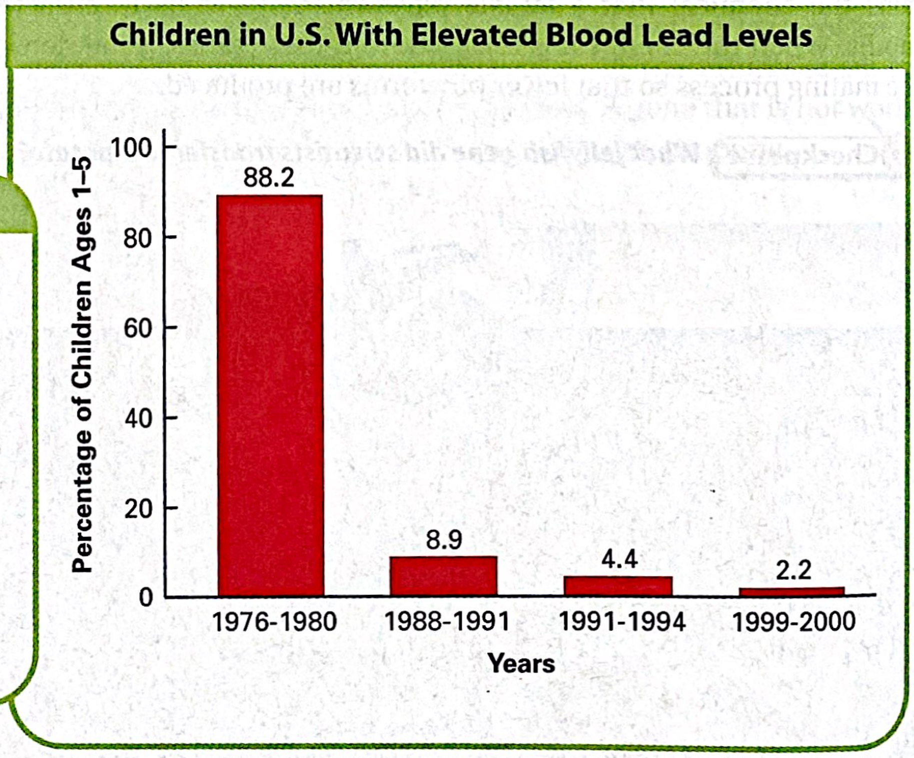
One unintended consequence of new technologies is the production of pollutants. A **pollutant** is a material found in air, water, or soil that is harmful to humans or other organisms. **Chemists help to identify pollutants and prevent pollution.**

Identify Pollutants Lead is a pollutant with a long history. The Romans used lead pipes for plumbing and stored their wine in lead-glazed vessels. Brain damage from lead poisoning may have caused Roman rulers to make bad decisions, which led to the fall of the Roman Empire. Until the mid-1900s, lead was used in many products, including paints and gasoline. A study done in 1971 showed that the level of lead that is harmful to humans is much lower than had been thought, especially for children. Low levels of lead in the blood can permanently damage the nervous system of a growing child. This damage causes many problems, including a reduced ability to learn.

Prevent Pollution The use of lead paint in houses was banned in 1978. Using lead in gasoline and in public water supply systems was banned in 1986. Today, the major source of lead in children is lead-based paint in about 39 million homes built before 1978. When children play with flakes of peeling paint or touch surfaces covered with paint dust, they can transfer the paint to their mouths with their fingers. The strategies used to prevent lead poisoning include testing children's blood for lead, regulation of home sales to families with young children, and public awareness campaigns with posters like the one in Figure 1.12. The graph in Figure 1.13 shows the results of these efforts.

Checkpoint *When was the use of lead paint in houses banned?*

Figure 1.13 This graph shows data on children in the United States with higher than acceptable levels of lead in their blood.



INTERPRETING GRAPHS

a. Analyzing Data What percent of children had elevated lead levels in the 1970s?
b. Calculating If a percentage point equals 200,000 children, how many children had elevated lead levels in 2000?
c. Drawing Conclusions Explain the dramatic drop in the percentage of children affected by lead poisoning between 1980 and 1988.

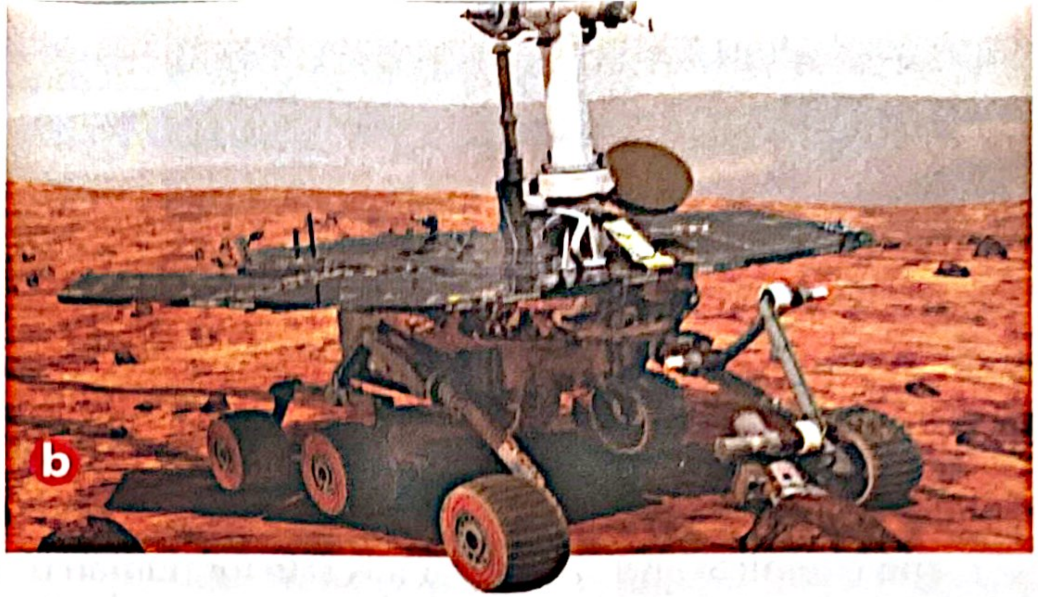


Figure 1.14 With help from NASA, chemists study matter from other bodies in the solar system. (a) Apollo astronauts brought rocks from the moon back to Earth. (b) This artist's drawing shows the robotic vehicle *Opportunity* on the surface of Mars.

The Universe

Scientists assume that the methods used to study Earth can be applied to other objects in the universe. **To study the universe, chemists gather data from afar and analyze matter that is brought back to Earth.**

In the early 1800s, scientists began to study the composition of stars by analyzing the light they transmitted to Earth. In 1868, Pierre Janssen discovered a gas on the sun's surface that was not known on Earth. Norman Lockyer named the gas helium from the Greek word *helios,* meaning "sun." In 1895, William Ramsay discovered helium on Earth.

Because the moon and the planets do not emit light, scientists must use other methods to gather data about these objects. They depend on matter brought back to Earth by astronauts or on probes that can analyze matter in space. Chemists have analyzed more than 850 pounds of moon rocks that were brought back to Earth. The large rock in Figure 1.14a is similar to rocks formed by volcanoes on Earth, suggesting that vast oceans of molten lava once covered the moon's surface. Figure 1.14b is a drawing of the robotic vehicle *Opportunity.* The vehicle was designed to determine the chemical composition of rocks and soil on Mars. Data collected at the vehicle's landing site indicated that the site was once drenched with water.