CHAPTER 4

INTERRELATED SCIENTIFIC PRINCIPLES: MATTER, ENERGY, AND ENVIRONMENT

Many of the processes that occur in the natural world involve interactions between matter and energy. Fire occurs when the chemical energy in wood is converted to heat and light. Control of fire was a major technological achievement in early human history.

HAPTER OUTLINE

OBJECTIVES

After reading this chapter, you should be able to:

- Understand that science is usually reliable because information is gathered in a manner that requires impartial evaluation and continuous revision.
- Understand that matter is made up of atoms that have a specific subatomic structure of protons, neutrons, and electrons.
- Recognize that each element is made of atoms that have a specific number of protons and electrons and that isotopes of the same element may differ in the number of neutrons present.
- Recognize that atoms may be combined and held together by chemical bonds to produce molecules.
- Understand that rearranging chemical bonds results in chemical reactions and that these reactions are associated with energy changes.
- Recognize that matter may be solid, liquid, or gas, depending on the amount of kinetic energy contained by the molecules.
- Realize that energy can be neither created nor destroyed, but when energy is converted from one form to another, some energy is converted into a less useful form.
- Understand that energy can be of different qualities.

THE NATURE OF SCIENCE

Since environmental science involves the analysis of data, it is useful to understand how scientists gather and evaluate information. It is also important to understand some chemical and physical principles as a background for evaluating environmental issues. An understanding of these scientific principles will also help you to appreciate the ecological concepts in the chapters that follow.

The word *science* creates a variety of images in the mind. Some people feel that it is a powerful word and are threatened by it. Others are baffled by scientific topics and have developed an unrealistic belief that scientists are brilliant individuals who can solve any problem. For example, there are those who believe that the conservation of fossil fuels is unnecessary because scientists will soon "find" a replacement energy source. Similarly, many are convinced that if government really wanted to, it would allocate sufficient funds to allow scientists to find a cure for AIDS. Such images do not accurately portray what science is really like.

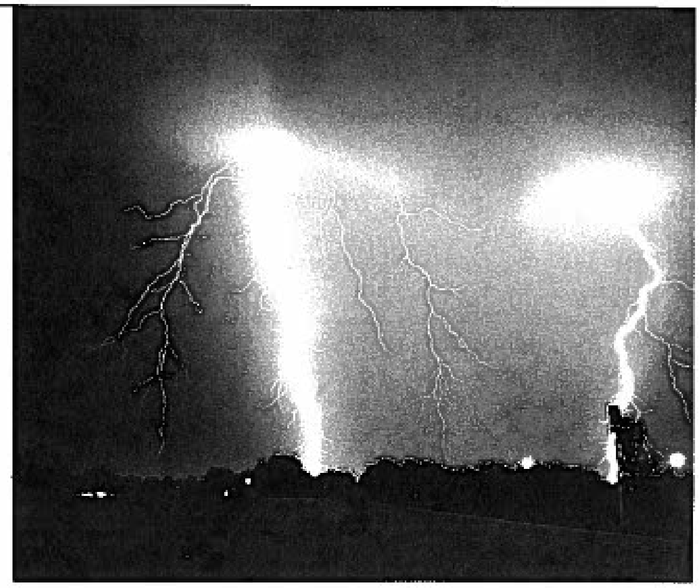
Science is a process used to solve problems or develop an understanding of nature that involves testing possible answers. Science is distinguished from other fields of study by how knowledge is acquired rather than by what is studied. The process has become known as the *scientific method.* The **scientific method** is a way of gaining information (facts) about the world by forming possible solutions to questions, followed by rigorous testing to determine if the proposed solutions are valid.

BASIC ASSUMPTIONS IN SCIENCE

When using the scientific method, scientists make several fundamental assumptions. They presume that:

1. There are specific causes for events observed in the natural world;
2. The causes can be identified;
3. There are general rules or patterns that can be used to describe what happens in nature;
4. An event that occurs repeatedly probably has the same cause each time;
5. What one person perceives can be perceived by others; and
6. The same fundamental rules of nature apply regardless of where and when they occur.

For example, we have all observed lightning associated with thunderstorms. According to the assumptions just stated, we should expect that there is an explanation that would account for all cases of lightning regardless of where or when they occur and that all people could make the same observations. We know from scientific observations and experiments that lightning is caused by a difference in electrical charge, that the behavior of lightning follows general rules that are the same as those seen with static electricity, and that all lightning that has been measured has the same cause wherever and whenever it occurred.



CAUSE-AND-EFFECT RELATIONSHIPS

Scientists distinguish between situations that are merely cor lated (happen together) and those that are correlated and sho **cause-and-effect relationships.** Many events are correlated, b not all correlations show cause-and-effect. When an event occu as a direct result of a previous event, a cause-and-effect relatic ship exists. For example, lightning and thunder are correlated thunder follows lightning—but they also have a cause-and-effe relationship—lightning causes thunder.

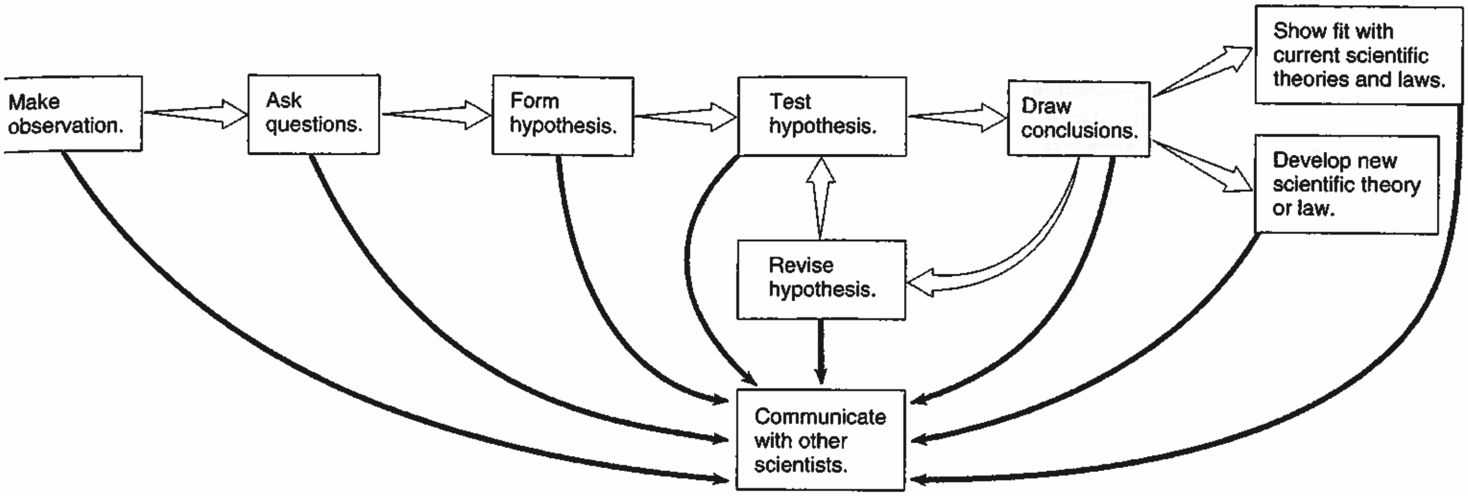
The relationships between autumn and trees dropping th leaves is more difficult to sort out. Because autumn brings colc temperatures, many people assume that the cold temperature caus leaves to turn color and fall. Cold temperatures are correlated w falling leaves. However there is no cause-and-effect relationsh The cause of the change in trees is actually the shortening of da that occurs in the autumn. Experiments have shown that artificia shortening the length of days in a greenhouse will cause trees drop their leaves with no change in temperature. Knowing tha cause-and-effect relationship exists enables us to predict what w happen should that same set of circumstances occur in the future

ELEMENTS OF THE SCIENTIFIC METHOD

The scientific method requires a systematic search for informati and a continual checking and rechecking to see if previous ide are still supported by new information. If the new evidence is r supportive, scientists discard or change their original ide Scientific ideas undergo constant reevaluation, criticism, and mc ification. The scientific method involves several important identi able components, including:

- careful observation,
- asking questions about observed events,
- the construction and testing of hypotheses,
- an openness to new information and ideas, and
- a willingness to submit one's ideas to the scrutiny of others

Underlying all of these activities is constant attention to accura and freedom from bias.



'**IGURE 4.1** **Elements of the Scientific Method** The scientific method consists of several kinds of activities. Observation of a natural phenom-ıon is usually the first step. Observation often leads people to ask questions about the observation they have made or to try to determine why the event oc-ırred. This questioning is typically followed by the construction of a hypothesis that attempts to explain why the phenomenon occurred. The hypothesis is then ȝsted to see if it is supported. Often this involves experimentation. If the hypothesis is not substantiated, it is modified and tested in its new form. It is important all times that others in the scientific community be informed by publishing observations of unusual events, their probable cause, and the results of experiments ǝt test hypotheses. Occasionally, this method of inquiry leads to the development of theories that tie together many bits of information into broad statements ǝt state why things happen in nature and serve to guide future thinking about a specific area of science. Scientific laws are similar broad statements that de-ribe how things happen in nature.

The scientific method is not, however, an inflexible series of ɜps that must be followed in a specific order. Figure 4.1 shows ›w these steps may be linked.

bservation

:ientific inquiry often begins with an observation that an event has :curred. An **observation** occurs when we use our senses (smell, ʒht, hearing, taste, touch) or an extension of our senses (micro-ope, tape recorder, X-ray machine, thermometer) to record an ·ent. Observation is more than a casual awareness. You may hear a und or see an image without really observing it. Do you know ıat music was being played in the shopping mall? You certainly ard it, but if you are unable to tell someone else what it was, you dn't "observe" it. If you had prepared yourself to observe the music ing played, you would be able to identify it. When scientists talk out their observations, they are referring to careful, thoughtful :ognition of an event—not just casual notice. Scientists train them-lves to improve their observational skills, since careful observation important in all parts of the scientific method. (See figure 4.2.)

Because many of the instruments used in scientific investiga-›ns are complicated, we might get the feeling that science is incred-y complex, when in reality these sophisticated tools are being used nply to answer questions that are relatively easy to understand. ›r example, a microscope has several knobs to turn and a specially signed light source. It requires considerable skill to use properly, t it is essentially a fancy magnifying glass that allows small ob-:ts to be seen more clearly. The microscope has enabled scientists answer some relatively fundamental questions such as: Are there ing things in pond water? and Are living things made up of ıaller subunits? Similarly, chemical tests allow us to determine the amounts of specific materials dissolved in water, and a pH meter allows us to determine how acidic or basic a solution is. Both are simple activities, but if we are not familiar with the procedures, we might consider the processes hard to understand.

FIGURE 4.2 **Observation** Careful observation is an important part of the scientific method. This technician is making observations on the characteristics of the soil and recording the results.

Questioning and Exploring

Observations often lead one to ask questions about the observations. Why did this event happen? Will it happen again in the same circumstances? Is it related to something else? Some questions may be simple speculation, but others may inspire you to further investigation. The formation of the questions is not as simple as it might seem because the way the questions are asked will determine how you go about answering them. A question that is too broad or too complex may be impossible to answer; therefore, a great deal of effort is put into asking the question in the right way. In some situations, this can be the most time-consuming part of the scientific method; asking the right question is critical to how you look for answers. For example, you observe that robins eat the berries of many plants but avoid others. You could ask the following questions:

1. Do the robins dislike the flavor of some berries?
2. Will robins eat more of one kind of berry if given a choice between two kinds of berries?

The second question is obviously easier to answer.

Once a decision has been made about what question to ask, scientists *explore other sources of knowledge* to gain more information. Perhaps the question already has been answered by someone else or several possible answers already have been rejected. Knowing what others have already done saves one time. This process usually involves reading appropriate science publications, exploring information on the Internet, or contacting fellow scientists interested in the same field of study. Even if the particular question has not already been answered, scientific literature and other scientists can provide insights that may lead to a solution. After exploring the appropriate literature, a decision is made about whether to continue to explore the question. If the scientist is still intrigued by the question, a formal hypothesis is constructed, and the process of inquiry continues at a different level.

Constructing Hypotheses

A **hypothesis** is a statement that provides a possible answer to a question or an explanation for an observation that can be tested. A good hypothesis must be logical, account for all the relevant information currently available, allow one to predict future events relating to the question being asked, and be testable. Furthermore, if one has the choice of several competing hypotheses, one should use the simplest hypothesis with the fewest assumptions. Just as deciding which questions to ask is often difficult, the formation of a hypothesis requires much critical thought and mental exploration. If the hypothesis is not logical or does not account for all the observed facts in the situation, it must be rejected. If a hypothesis is not testable it is mere speculation.

Testing Hypotheses

Keep in mind that a hypothesis is based on observations and information gained from other knowledgeable sources. It predicts how an event will occur under specific circumstances. Scientists test the predictive ability of a hypothesis to see if the hypothesis is supported or is disproved. If you disprove the hypothesis, it i rejected, and a new hypothesis must be constructed. However, i you cannot disprove a hypothesis, it increases your confidence i the hypothesis, but it does not prove it to be true in all cases an for all time. Science always allows for the questioning of idea and the substitution of new ones that more completely describ what is known at a particular point in time. It could be that an al ternative hypothesis you haven't thought of explains the situatio or that you have not made the appropriate observations to indicat that your hypothesis is wrong.

The test of a hypothesis can take several forms. It may simpl involve the collection of pertinent information that already exist from a variety of sources. For example, if you visited a cemeter and observed from reading the tombstones that an unusually larg number of people of different ages died in the same year, yo could hypothesize that there was an epidemic of disease or a nat ural disaster that caused the deaths. Consulting historical newspa per accounts would be a good way to test this hypothesis.

In other cases, a hypothesis may be tested by simply makin additional observations. For example, if you hypothesized that certain species of bird used cavities in trees as places to buil nests, you could observe many birds of the species and record th kinds of nests they built and where they built them.

Another common method for testing a hypothesis involve devising an experiment. An **experiment** is a re-creation of a event or occurrence in a way that enables a scientist to support o disprove a hypothesis. This can be difficult because a particula event may involve a great many separate happenings called **vari ables.** The best experimental design is a **controlled experiment** i which two groups differ in only one way. For example, tumors o the skin and liver occur in the fish that live in certain rivers *(ob servation).* This raises the question: What causes the tumors Many people feel that the tumors are caused by toxic chemical that have been released into the rivers by industrial plants *(hypoth esis).* However, it is possible that the tumors are caused by a viru by exposure to natural substances in the water, or are the result o genes present in the fish. The following experiment could be con ducted to test the hypothesis that industrial contaminants cause th tumors: Fish could be collected from the river and placed in on of two groups. One group (the control group) would be raised in container through which the normal river water passes. The sec ond group (experimental group) would be raised in an identica container through which water from the industrial facility passe There would need to be large numbers of fish in both groups. Thi kind of experiment is called a controlled experiment. If the fish i the experimental group develop a significantly larger number o tumors than the control group, something in the water from th plant is the probable cause of the tumors. This is particularly tru if the chemicals present in the water are already known to caus tumors. After the data have been evaluated, the results of the ex periment would be published.

The results of a well-designed experiment should be able t support or disprove a hypothesis. However, this does not alway occur. Sometimes the results of an experiment are inconclusive This means that a new experiment must be conducted or tha more information must be collected. Often, it is necessary t ıave large amounts of information before a decision can be nade about the validity of a hypothesis. The public often fails :o appreciate why it is necessary to perform experiments on so nany subjects or to repeat experiments again and again.

The concept of **reproducibility** is important to the scientific nethod. Because it is often not easy for scientists to eliminate un-:onscious bias, independent investigators must be able to repro-luce the experiment to see if they get the same results. To do this, hey must have a complete and accurate written document to work rom. That means the scientists must publish the methods and re-ults of their experiment. This process of publishing one's work or others to examine and criticize is one of the most important teps in the process of scientific discovery. The results of experi-nents are only considered reliable if they are supported by many xperiments and by different investigators.

'he Development of Theories and Laws

Vhen broad consensus exists about an area of science, it is known as theory or law. A **theory** is a widely accepted, plausible generaliza-on about fundamental concepts in science that explains *why* things appen. An example of a scientific theory is the **kinetic molecular heory,** which states that all matter is made up of tiny, moving parti-les. As you can see, this is a very broad statement, and it is the re-ılt of years of observation, questioning, experimentation, and data nalysis. Because we are so confident that the theory explains the na-ıre of matter, we use this concept to explain why materials disperse ı water or air, why materials change from solids to liquids, and why ifferent chemicals can interact during chemical reactions.

Theories and hypotheses are different. A hypothesis provides possible explanation for a specific question; a theory is a broad oncept that shapes how scientists look at the world and how they ame their hypotheses. Because they are broad, unifying state-ıents, there are few theories. However, just because a theory ex-ts does not mean that testing stops. As scientists continue to gain ew information, they may find exceptions to a theory or even in re cases disprove a theory.

It is important to recognize that the word *theory* is often used a much less restrictive sense. Often it is used in ordinary con-ersation to describe a vague idea or a hunch. This is not a theory the scientific sense. So when you see or hear the word *theory,* ou must look at the context to see if the speaker or writer is re-rring to a theory in the scientific sense.

A **scientific law** is a uniform or constant fact of nature that scribes *what* happens in nature. An example of a scientific law the **law of conservation of mass,** which states that matter is ɩt gained or lost during a chemical reaction. While laws describe ıat happens and theories describe why things happen, in a way, ws and theories are similar. They have both been examined peatedly and are regarded as excellent predictors of how nature haves.

ɔmmunication

several points in the discussion of the scientific method the ;nificance of communication has arisen. Communication is central characteristic of the scientific method. Science is conducted openly, under the critical eyes of others who are interested in the same questions. An important part of the communication process involves the publication of articles in scientific journals about one's research, thoughts, and opinions. This communication can occur at any point during the process of scientific discovery.

People may ask questions about unusual observations. They may publish preliminary results of incomplete experiments. They may publish reports that summarize large bodies of material. And they often publish strongly held opinions that may not always be supportable with current data. This provides other scientists with an opportunity to criticize, make suggestions, or agree. (See figure 4.3.) Scientists also talk to one another at conferences and by phone, e-mail, and the Internet. The result is that science is subjected to examination by many minds as it is discovered, discussed, and refined.

FIGURE 4.3 **Communication** One important way in which scientists communicate is through publication in scientific journals.

LIMITATIONS OF SCIENCE

Science is a powerful tool for developing an understanding of the natural world, but it cannot analyze international politics, decide if family-planning programs should be instituted, or evaluate the significance of a beautiful landscape. These tasks are beyond the scope of scientific investigation. This does not mean that scientists cannot comment on such issues. They often do. But they should not be regarded as more knowledgeable on these issues just because they are scientists. Scientists may know more about the scientific aspects of these issues, but they struggle with the same moral and ethical questions that face all people, and their judgments on these matters can be just as biased as anyone else's. Consequently, major differences of opinion often exist among lawmakers, regulatory agencies, special interest groups, and members of scientific organizations about the significance or value of specific scientific information.

It is important to differentiate between the scientific data collected and the opinions scientists have about what the data mean. Scientists form and state opinions that may not always be supported by fact, just as other people do. Equally reputable scientists commonly state opinions that are in direct contradiction. This is especially true in environmental science, where predictions about the future must be based on inadequate or fragmentary data. The issue of climate change (covered in chapter 16) is an example of this.

It is important to recognize that scientific knowledge can be used by different people to support opinions that may not be valid. For example, the following statements are all factual.

1. Many of the kinds of chemicals used in modern agriculture are toxic to humans and other animals.
2. Small amounts of agricultural chemicals have been detected in some agricultural products.
3. Low levels of some toxic materials have been strongly linked to a variety of human illnesses.

This does not mean that *all* foods grown with the use of *any* chemicals are less nutritious or are dangerous to health or that "organically grown" foods are necessarily more nutritious or healthful because they have been grown without agricultural chemicals. The idea that something that is artificial is necessarily bad and something natural is necessarily good is an oversimplification. After all, many plants such as tobacco, poison ivy, and rhubarb leaves naturally contain toxic materials. Furthermore, the use of chemical fertilizers has contributed to the health and well-being of the human population because increased crop yields due to fertilizer use account for about one-third of the food grown in the world, thus reducing malnutrition. However, it is appropriate to question if the use of agricultural chemicals is always necessary or if trace amounts of specific agricultural chemicals in food are dangerous.

PSEUDOSCIENCE

Pseudoscience (*pseudo* = false) is a deceptive practice that uses the appearance or language of science to convince, confuse, or mislead people into thinking that something has scientific validity when it does not. When pseudoscientific claims are closely examined, it is found that they are not supported by unbiased tests.

Often facts are selected to support a particular point of view For example, certain kinds of ionizing radiation are known t cause cancer. Electrical devices and power lines emit electromagnetic radiation. These facts have caused many people to see a lin between exposure to electromagnetic radiation and health, whe there is none. They maintain that living near electric power line causes cancer or other health effects. However, careful scientifi studies, which compared people who lived near power lines wit matched groups of people who did not live near power lines, sho that those who live near power lines have no more health problem than those that do not. Often it is interesting to look at the motivation of those making pseudoscientific claims. Are they sellin something? Are they seeking money for presumed injuries?

THE STRUCTURE OF MATTER

Now that we have an appreciation for the methods of science, it i time to explore some basic information and theories about th structure and function of various kinds of matter. **Matter** is anything that takes up space and has mass. Air, water, trees, cemen and gold are all examples of matter. As stated earlier, the kineti molecular theory is a central theory that describes the structur and activity of matter. This theory states that all matter is made u of tiny objects that are in constant motion. Although differen kinds of matter have different properties, they all are similar in on fundamental way. They are all made up of one or more kinds o smaller subunits called atoms.

ATOMIC STRUCTURE

Atoms are fundamental subunits of matter. There are 92 kinds o atoms found in nature. Each kind forms a specific type of matte known as an **element.** Gold (Au), oxygen (O), and mercury (Hg are examples of elements. All atoms have a central region know as a **nucleus,** which is composed of two kinds of relatively heav particles: positively charged particles called **protons** and uncharged particles called **neutrons.** Surrounding the nucleus of th atom is a cloud of relatively lightweight, fast-moving, negativel charged particles called **electrons.**

The atoms of each element differ from one another in the number of protons, neutrons, and electrons present. For example, a typical mercury atom contains 80 protons and 80 electrons; gold has 7 of each, and oxygen only eight of each. (See figure 4.4.) (Appendix 1 page 451, contains a periodic table of the elements.) All atoms of a element always have the same number of protons and electrons, bu the number of neutrons may vary from one atom to the next.

Atoms of the same element that differ from one another in th number of neutrons they contain are called **isotopes.** For exampl there are three isotopes of the element hydrogen. All hydrogen atom have one proton and one electron, but one isotope of hydrogen ha no neutrons, one has one neutron, and one has two neutrons. Thes isotopes behave the same chemically but have different masses sinc they contain different numbers of neutrons. (See figure 4.5.)

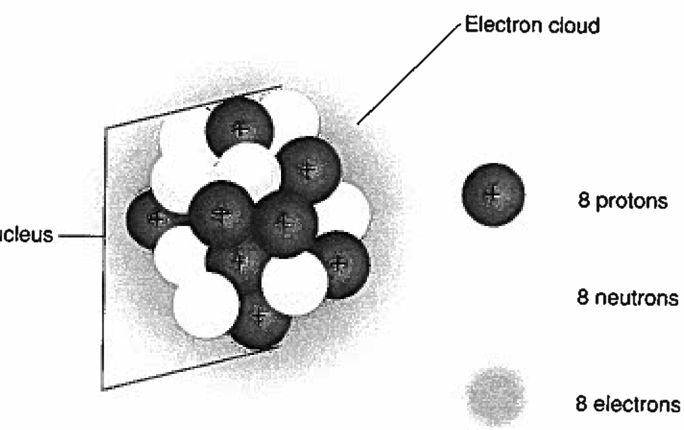
[T]HE MOLECULAR NATURE OF MATTER

[T]he kinetic molecular theory states that all matter is made of tiny par[t]icles that are in constant motion. However, there are several kinds of [t]hese tiny particles. In some instances, atoms act as individual parti[c]les. In other instances, atoms bond to one another chemically to [f]orm stable units called **molecules.** In still other cases, atoms or [m]olecules may gain or lose electrons and thus become electrically [c]harged particles called **ions.** Atoms or molecules that lose electrons [a]re positively charged because they have more protons (+) than elec[tr]ons (−). Those that gain electrons have more electrons (−) than [p]rotons (+) and are negatively charged.

Oppositely charged ions are attracted to one another and may [f]orm stable units similar to molecules; however, they typically [s]plit into their individual ions when dissolved. For example, table [s]alt (NaCl) is composed of sodium ions (Na^+) and chloride ions ([C]l^-). It is a white, crystalline material when dry but separates into [i]ndividual ions when placed in water.

When two or more atoms or ions are bonded chemically, a [n]ew kind of matter called a **compound** is formed. While only [9]2 kinds of atoms are commonly found, there are millions of ways atoms can be combined to form compounds. Water (H_2O), table sugar ($C_6H_{12}O_6$), table salt (NaCl), and methane gas (CH_4) are examples of compounds.

Many other kinds of matter are **mixtures,** variable combinations of atoms, ions, or molecules. Honey is a mixture of several sugars and water; concrete is a mixture of cement, sand, gravel, and reinforcing rods; and air is a mixture of several gases, of which the most common are nitrogen and oxygen. Table 4.1 summarizes the various kinds of matter and the subunits of which they are composed.



[F]IGURE 4.4 Diagrammatic Oxygen Atom Most oxygen [at]oms are composed of a nucleus containing eight positively charged protons [an]d eight neutrons without charges. Eight negatively charged electrons move [in] a cloud around the nucleus.

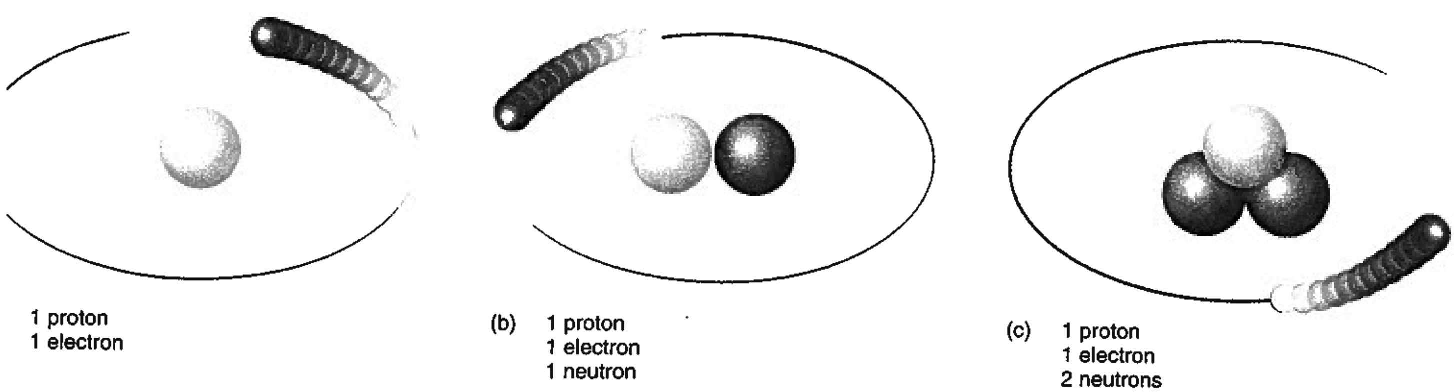
A WORD ABOUT WATER

The temperature of the Earth is such that water can exist in all three phases—solid, liquid, and gas. If we look at Earth from space, it is a blue planet with patches of white. The blue color is caused by the three-quarters of the surface of the Earth covered with water in the oceans. The wisps of white are caused by water droplets in clouds. Water in all its forms determines the weather and climate of regions of the Earth. Earth's surface is shaped by the flow of water and ice. Life on Earth is based on water. Most kinds of organisms live in water and the most common molecule found in living things is water.

Water molecules are polar molecules with positive and negative ends. Since unlike charges attract each other, water molecules tend to stick together. This contributes to several of water's unusual properties. Because water molecules are polar, it takes a great deal of energy to cause water molecules to separate from one another—to go from the liquid form to the water vapor. Thus, the evaporation of water has the ability to cool the surroundings. The polar nature of water molecules also contributes to its ability to dissolve most substances. It is often described as the universal solvent. Almost everything dissolves, to some extent, in water. Many important solutions are formed as a result of water.

ACIDS, BASES, AND PH

Acid and bases are two classes of compounds that are of special interest. Their characteristics are determined by the nature of their chemical bonds. When acids are dissolved in water, hydrogen ions



[FI]GURE 4.5 Isotopes of Hydrogen (a) The most common form of hydrogen is the isotope that has one proton and no neutrons in its nucleus. [T]he isotope deuterium has one proton and one neutron. (c) The isotope tritium has two neutrons and one proton. Each of these isotopes of hydrogen also has [one] electron. Most scientists use the term *hydrogen* in a generic sense—that is, the term is not specific but might refer to any or all of these isotopes.

Going Green

Evaluating Green Claims

Businesses have discovered that there is money to be made by marketing their products as ecologically friendly, Earth friendly, or green. But how do you know when a product is truly green? Most of us do not have the expertise to evaluate highly technical statements about products, so it is useful to have some general guidelines that help separate the charlatans from those that have a sincere interest in marketing a green product. Be a skeptical consumer.

1. Look for statements that are specific. Statements like "contains all natural ingredients," or "biodegradable," or "nontoxic" are not useful unless there is other evidence provided to support the claim. A "natural ingredients" statement should be backed up with a list of the actual ingredients and their sources. A claim of being biodegradable is not a very useful term, since most things will biodegrade if given enough time and the proper microorganisms. However, if there are statements about how quickly materials break down or that they break down in septic systems or sewage treatment plants, you can have more confidence. A claim of being nontoxic is meaningless—nearly everything is toxic in high enough concentrations, even table salt, ethanol, and vinegar.
2. Look for evidence that companies have a general environmental commitment. Do they market in recycled containers? Do they sell concentrated products that can be diluted at home, thus saving energy? Do they sell with a minimum of packaging?
3. Look for statements about the use of recycled materials in the product. Saying a product or container is recyclable is not very useful if there is no easy way to recycle it. Does the business have a program for recycling its products? If a claim is made that the product is made from recycled materials, evaluate the claim. What percent is post-consumer waste? Many products that claim to be made from recycled materials are made from materials salvaged during the manufacturing process.
4. Look for evidence that the claims are highlighting one positive element while ignoring other important issues. A statement that a product contains no chlorine is not useful if the other ingredients are as bad or worse.
5. Look for statements that take credit for things they are legally required to do. "Meets all FDA requirements" and "contains no CFCs" are meaningless statements because it would be illegal to sell the product if it didn't meet FDA requirements and it is illegal to sell products containing CFCs.

TABLE 4.1 Relationships Between the Kinds of Subunits Found in Matter

Category of Matter	Subunits	Characteristics
Subatomic particles	protons	Positively charged Located in nucleus of the atom
	neutrons	Have no charge Located in nucleus of the atom
	electrons	Negatively charged Located outside the nucleus of the atom
Elements	atoms	Atoms of an element are composed of specific arrangements of protons,neutrons, and electrons. Atoms of different elements differ in the number of protons, neutrons, and electrons present.
Compounds	molecules or ions	Compounds are composed of two or more atoms or ions chemically bonded together. Different compounds contain specific atoms or ions in specific proportions.
Mixtures	atoms, molecules, or ions	The molecular particles in mixtures are not chemically bonded to each other. The number of each kind of molecular particle present is variable.

(H^+) are set free. A *hydrogen ion* is positive because it has lost its electron an now has only the positive charge of it proton. Therefore, a hydrogen ion i a proton. An **acid** is any compound tha releases hydrogen ions (protons) in a solution. Some familiar examples of common acids are sulfuric acid (H_2SO_4) i automobile batteries and acetic aci (HCH_2COOH) in vinegar.

A **base** is the opposite of an acid i that it accepts hydrogen ions in solution Many common bases release **hydroxid ions** (OH^-). This ion is composed of a oxygen atom and a hydrogen ato bonded together but with an additiona electron. The hydroxide ion is negativel charged. It is a base because it is able t accept hydrogen ions in solution to for water ($H^+ + OH^- \rightarrow H_2O$). A very stron base often used in oven cleaners i sodium hydroxide (NaOH). Sometime people refer to a base as an alkali an solutions that are basic often are calle alkaline solutions.

The concentration of an acid or base solution is given by a num- er called its **pH.** The pH scale is a measure of hydrogen ion concen- ration. However, the pH scale is different from what you might xpect. First, it is an inverse scale, which means that the lower the H, the greater the number of hydrogen ions present. Second, the cale is logarithmic, which means that a difference between two con- ecutive pHs is really a difference by a factor of 10. For example, a H of 7 indicates that the solution is neutral and has an equal num- er of H^+ ions and OH^- ions, but a pH of 6 means that the solution as 10 times more hydrogen ions than it would at a pH of 7.

As the number of hydrogen ions in the solution increases, the H gets smaller. A number higher than 7 indicates that the solution as more OH^- than H^+. As the number of hydroxide ions in- reases, the pH gets larger. The higher the pH, the more concen- rated the hydroxide ions. (See figure 4.6.)

NORGANIC AND ORGANIC MATTER

norganic and organic matter are usually distinguished from one nother by one fact: Organic matter consists of molecules that con- ain carbon atoms that are usually bonded to form chains or rings. onsequently, organic molecules can be very large. Many different inds of organic compounds exist. Inorganic compounds generally onsist of small molecules and combinations of ions, and relatively ew kinds exist. All living things contain molecules of organic ompounds. They must either be able to manufacture organic ompounds from inorganic compounds or to modify organic com- ounds they obtain from eating organic material. Typically, chem- al bonds in organic molecules contain a large amount of chemical nergy that can be released when the bonds are broken and new in- rganic compounds are produced. Salt, water, metals, sand, and xygen are examples of inorganic matter. Sugars, proteins, and fats e examples of organic compounds that are produced and used by ving things. Natural gas, oil, and coal are all examples of organic ibstances that were originally produced by living things but have een modified by geologic processes.

HEMICAL REACTIONS

hen atoms or ions combine to form compounds, they are held gether by chemical bonds, as in the water molecule in figure 4.7. **hemical bonds** are attractive forces between atoms resulting from e interaction of their electrons. Each chemical bond contains a cer- in amount of energy. When chemical bonds are broken or formed, chemical reaction occurs. During chemical reactions, the amount energy within the chemical bonds changes. If the chemical bonds the new compounds have less chemical energy than the previous mpounds, some of the energy is released, often as heat and light. iese kinds of reactions are called **exothermic reactions.** In other ses, the newly formed chemical bonds contain more energy than as present in the compounds from which they were formed. Such actions are called **endothermic reactions.** For such a reaction to cur, the additional energy must come from an external source.

A common example of an exothermic reaction is the burning of tural gas. The primary ingredient in natural gas is the compound ethane. When methane and oxygen are mixed together and a small iount of energy is used to start the reaction, the chemical bonds the methane and oxygen (reactants) are rearranged to form two different compounds, carbon dioxide and water (products). In this kind of reaction, the products have less energy than the reactants. The leftover energy is released as light and heat. (See figure 4.8.) In every reaction, the amount of energy in the reactants and in the products can be compared and the differences accounted for by energy loss to, or gain from, the surroundings.

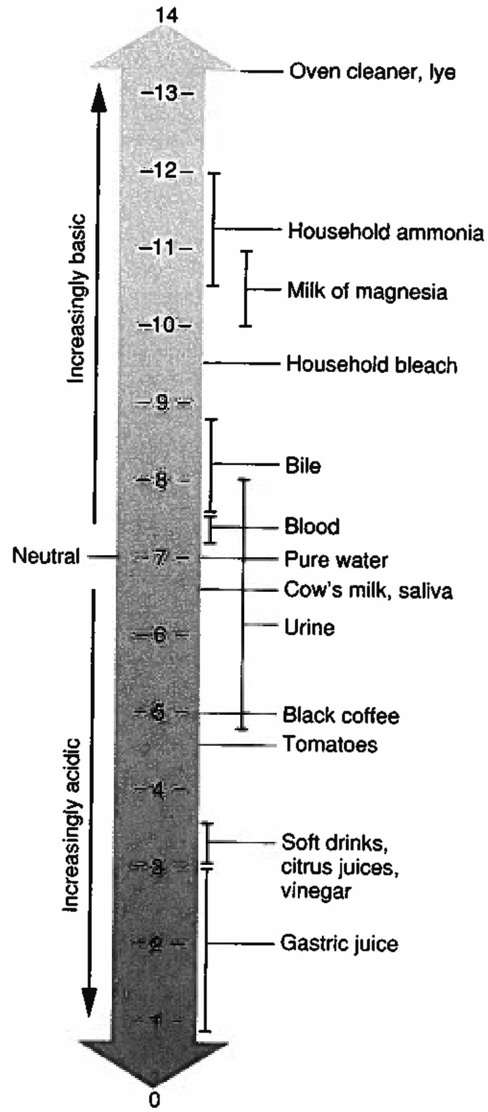


FIGURE 4.6 **The pH Scale** The concentration of hydrogen ions (H^+) is greatest when the pH is lowest. At a pH of 7.0, the concentrations of H^+ and OH^- are equal. We usually say as the pH gets smaller, the solution becomes more acidic. As the pH gets larger, the solution becomes more basic or alkaline.

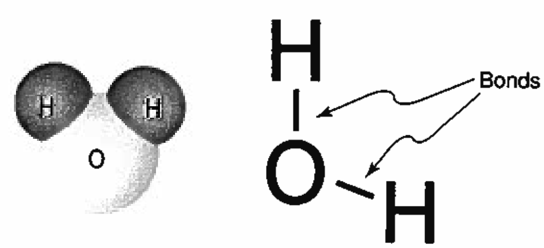


FIGURE 4.7 **Water Molecule** A water molecule consists of an atom of oxygen bonded to two atoms of hydrogen. The molecule is not symmetrical. The hydrogen atoms are not on opposite sides of the oxygen atom.

Water Connections

Applying the Scientific Method—Acid Rain

In the 1970s people in North America began to *observe* that in the northeastern United States and adjacent Canada, certain bodies of water and certain forested areas were changing. Fish were disappearing and trees were dying. They began to ask *questions* about why this was occurring. At the same time people began to make *observations* about the pH of rain and snow. They found that in many places in the Northeast the pH of rain was very low—it was acid. Normal rain has a pH of about 5.7, and measurements of rain indicated that the pH was often much more acid than normal. People began to ask if there was a *cause-and-effect relationship* between the acid precipitation and the decline of forests and certain lakes.

When the pH of the water in many northeastern lakes was measured it was determined that they were acid and that there was probably a *cause-and-effect relationship* between the acid condition of the water in the lakes and the decline of fish. (Although forest decline was a more difficult problem to understand, research eventually established a *cause-and-effect relationship* between forest decline and acid rain.) The next *question* that was asked was, what was the cause of the acidification of the lakes? Since many of the lakes were downwind of industrial centers, people asked the *question* Is the low pH of the rain the result of industrial activities? In particular, what activities might cause the acid rain?

Experimental evidence linking industrial emissions to acid rain came from several kinds of studies. Much of this research took place during the 1980s.

1. Measurements of the emissions from industrial smokestacks revealed that there were a variety of compounds in the emissions that were acidic in nature. In particular, sulfur compounds from the burning of high-sulfur coal provided compounds that formed acids.
2. The rain in areas that were not downwind of industrial settings had a more normal pH.
3. Reducing emissions resulted in less acid rain.

Since this is a complex problem and involves many scientists working on particular aspects of the problem, there was a great deal of *communication* among scientists as these studies were occurring.

Ultimately, most scientists *concluded* that the cause of the acidification of lakes and the decline of forests was acid rain and the cause of the acid rain was industrial emissions. During the 1990s the U.S. Congress passed legislation that led to the reduction of acid emissions from industrial sources. Efforts to reduce emissions of acid-forming substances continue today. However, as sulfur emissions have been reduced the emphasis today is on nitrogen compounds that result from the burning of fuels by industry, automobiles, and homes.

Testing for Acid Rain

Methane + Oxygen ⟶ Carbon dioxide + Water + Heat + Light

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + \text{Heat} + \text{Light}$$

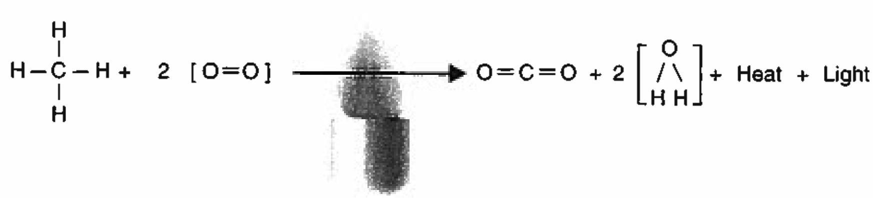


FIGURE 4.8 **A Chemical Reaction** When methane is burned, chemical bonds are rearranged, and the excess chemical bond energy is released as light and heat. The same atoms are present in the reactants as in the products, but they are bonded in different ways, resulting in molecules of new substances.

Even energy-yielding reactions usually need an input of energy to get the reaction started. This initial input of energy is called **activation energy.** In certain cases, the amount of activation energy required to start the reaction can be reduced by the use of a catalyst. A **catalyst** is a substance that alters the rate of a reaction, but the catalyst itself is not consumed or altered in the process. Catalysts are used in catalytic converters, which are attached to automobile exhaust systems. The purpose of the catalytic converter is to bring about more complete burning of the fuel, thus resulting in less air pollution. Most of the materials that are not completely burned by the engine require high temperatures to react further; with the presence of catalysts, these reactions can occur at lower temperatures.

Endothermic reactions require an input of energy in order to occur. For example, nitrogen gas and oxygen gas can be combined to form nitrous oxide ($O_2 + N_2 + \text{heat} \rightarrow 2NO$). Another important endothermic reaction is the process of photosyn-:hesis, which is discussed in the following section.

CHEMICAL REACTIONS IN LIVING THINGS

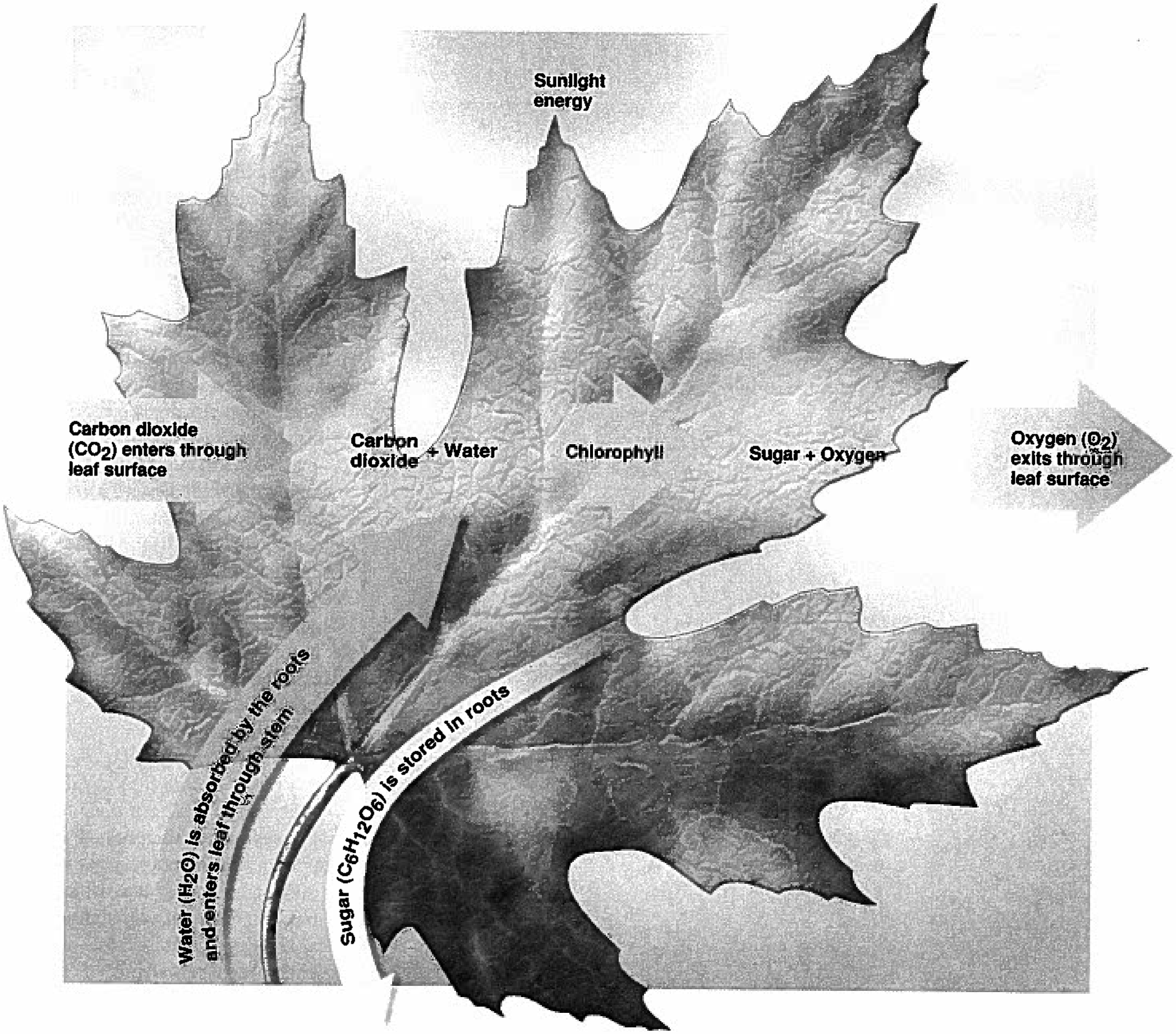
Living things are constructed of cells that are themselves made up of both inorganic and organic matter in very specific arrange-nents. The chemical reactions that occur in living things are regulated by protein molecules called **enzymes** that reduce the ac-ivation energy needed to start the reactions. Enzymes are impor-ant since the high temperatures required to start these reactions without enzymes would destroy living organisms. Many enzymes are arranged in such a way that they cooperate in controlling a chain of reactions, as in photosynthesis and respiration.

Photosynthesis is the process plants use to convert inorganic material into organic matter, with the assistance of light energy. Light energy enables the smaller inorganic molecules (water and carbon dioxide) to be converted into organic sugar molecules. In the process, molecular oxygen is released.

$$6CO_2 + 6H_2O \xrightarrow[\text{in chloroplasts}]{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

$$\text{Carbon dioxide} + \text{Water} \longrightarrow \text{Sugar} + \text{Oxygen}$$

Molecules of the green pigment chlorophyll are found in cellular structures called chloroplasts. Chlorophyll is responsible for trap-ping the sunlight energy needed in the process of photosynthesis. Therefore, photosynthesis takes place in the green portions of the plant, usually the leaves. (See figure 4.9.) The organic molecules



IGURE 4.9 **Photosynthesis** This reaction is an example of one that requires an input of energy (sunlight) to combine low-energy molecules (CO_2 d H_2O) to form sugar ($C_6H_{12}O_6$) with a greater amount of chemical bond energy. Molecular oxygen (O_2) is also produced.

produced as a result of photosynthesis can be used as an energy source by the plants and by organisms that eat the plants.

Respiration involves the use of atmospheric oxygen to break down large, organic molecules (sugars, fats, and proteins) into smaller, inorganic molecules (carbon dioxide and water). This process releases energy the organisms can use.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

$$\text{Sugar} + \text{Oxygen} \longrightarrow \text{Carbon dioxide} + \text{Water} + \text{Energy}$$

(See figure 4.10.) All organisms, including plants, must carry on some form of respiration, since all organisms need a source of energy to maintain life.

Chemistry and the Environment

Chemistry is extremely important in discussions of environmental problems. The chemicals of fertilizer and pesticides are extremely important in food production, but they also present environmental problems. Photochemical smog is a problem created by chemical reactions that take place between pollutants and other components of the atmosphere. Persistent organic chemicals are those that are not broken down by microorganisms and remain in the environment for long periods. Organic molecules in water reduce the amount of oxygen available to animals that need it to stay alive. These and other examples of environmental chemistry will be discussed in later chapters on agriculture, air pollution, and water pollution.

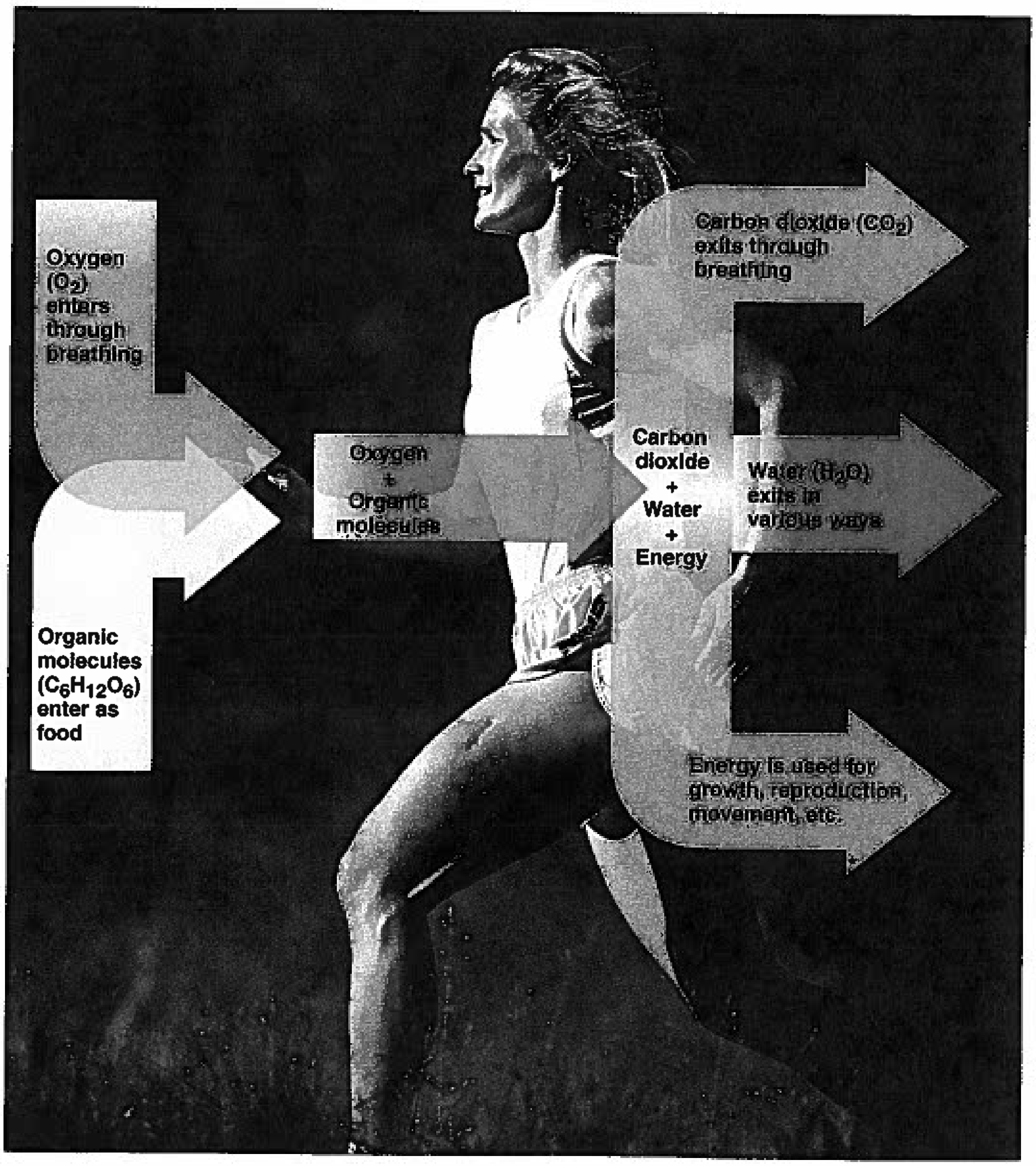


FIGURE 4.10 Respiration Respiration involves the release of energy from organic molecules when they react with oxygen. In addition to providing energy in a usable form, respiration produces carbon dioxide and water.

Energy Principles

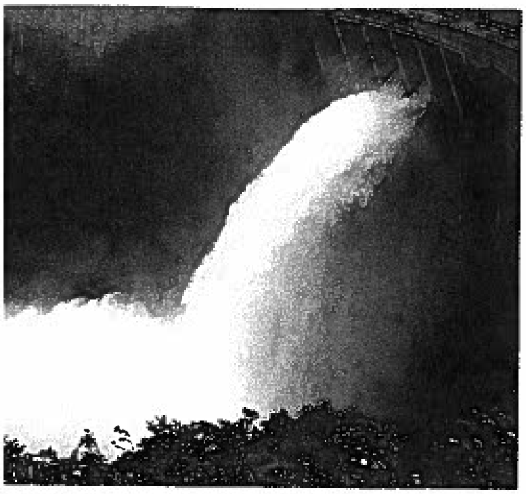
The "Chemical Reactions in Living Things" section started out with a description of matter, yet it used the concept of energy to describe chemical bonds, chemical reactions, and molecular motion. That is because energy and matter are inseparable. It is difficult to describe one without the other. **Energy** is the ability to do work. Work is done when an object is moved over a distance. This occurs even at the molecular level.

Kinds of Energy

There are several kinds of energy. Heat, light, electricity, and chemical energy are common forms. The energy contained by moving objects is called **kinetic energy.** The moving molecules in air have kinetic energy, as does water running downhill or a dog chasing a ball. In contrast, **potential energy** is the energy matter has because of its position. The water behind a dam has potential energy by virtue of its elevated position. (See figure 4.11.) An electron moved to a position farther from the nucleus has increased potential energy due to the increased distance between the electron and the nucleus.

States of Matter

Depending on the amount of energy present, matter can occur in three common states: solid, liquid, or gas. The physical nature of matter changes when a change occurs in the amount of kinetic energy its molecular particles contain, but the chemical nature of matter and the kinds of chemical reactions it will undergo remain the same. For example, water vapor, liquid water, and ice all have the same chemical



'IGURE 4.11 Kinetic and Potential ıergy Kinetic and potential energy are interconvertible. ıe potential energy possessed by the water behind a ım is converted to kinetic energy as the water flows to a wer level.

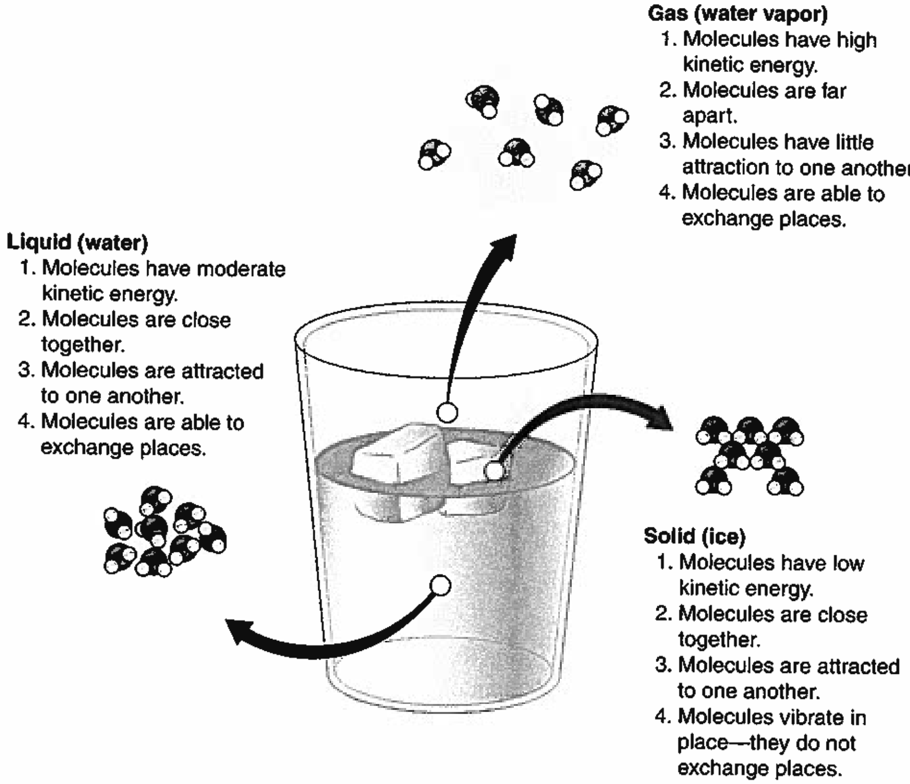


FIGURE 4.12 States of Matter Matter exists in one of three states, depending on the amount of kinetic energy the molecules have. The higher the amount of energy, the greater the distance between molecules and the greater their degree of freedom of movement.

ımposition but differ in the arrangement and ac- ıity of their molecules. The amount of kinetic ıergy molecules have determines how rapidly ey move. (See figure 4.12.) In solids, the molec- ar particles have comparatively little energy, and ey vibrate in place very close to one another. In ıuids, the particles have more energy, are farther art from one another, and will roll, tumble, and ıw over each other. In gases, the molecular particles move very ɔidly and are very far apart. All that is necessary to change the ysical nature of a substance is an energy change. Heat energy must added or removed.

When two forms of matter have different temperatures, heat en- ɜy will flow from the one with the higher temperature to the one th the lower temperature. The temperature of the cooler matter in- ɜases while that of the warmer matter decreases. You experience s whenever you touch a cold or hot object. This is referred to as a **nsible heat** transfer. When heat energy is used to change the state matter from solid to liquid at its melting point or liquid to gas at boiling point, heat is transferred, but the temperature of the mat- does not change. This is called a **latent heat** transfer. You have perienced this effect when water evaporates from your skin. Your dy supplies the heat necessary to convert liquid water to water ɔor. While the temperature of the water does not change, the phys- l state of the water does. The heat that was transferred to the water ısed it to evaporate, and your body cooled. When substances ınge from gas to liquid at the boiling point or liquid to solid at the ezing point, there is a corresponding release of heat energy with- : a change in temperature.

:RST AND SECOND LAWS F THERMODYNAMICS

ergy can exist in several different forms, and it is possible to ıvert one form of energy into another. However, the total ount of energy remains constant.

The **first law of thermodynamics** states that energy can neither be created nor destroyed; it can only be changed from one form into another. From a human perspective, some forms of energy are more useful than others. We tend to make extensive use of electrical energy for a variety of purposes, but there is very little electrical energy present in nature. Therefore, we convert other forms of energy into electrical energy.

The **second law of thermodynamics** states that whenever energy is converted from one form to another, some of the useful energy is lost. The energy that cannot be used to do useful work is called **entropy.** Therefore, another way to state the second law of thermodynamics is to say that when energy is converted from one form to another, entropy increases. An alternative way to look at the idea of entropy is to say that entropy is a measure of disorder and that the amount of disorder (entropy) typically increases when energy conversions take place. Obviously, it is possible to generate greater order in a system (living things are a good example of highly ordered things), but when things become more highly ordered, the disorder of the surroundings must increase. For example, all living things release heat to their surroundings.

It is important to understand that when energy is converted from one form to another, there is no loss to *total* energy, but there is a loss of *useful* energy. For example, gasoline, which contains chemical energy, can be burned in an automobile engine to provide the kinetic energy to turn the wheels. The heat from the burning gasoline is used to move the pistons, which turns the crankshaft and eventually causes the wheels to turn. At each step in the process, some heat energy is lost from the system. During

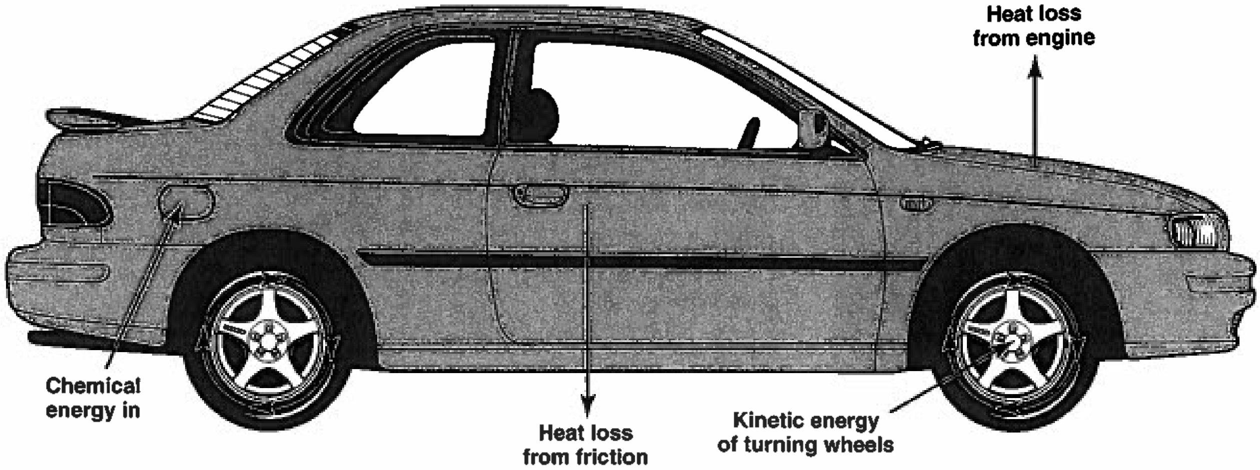


FIGURE 4.13 **Second Law of Thermodynamics** Whenever energy is converted from one form to another, some of the useful energy is lost, usually in the form of heat. The burning of gasoline produces heat, which is lost to the atmosphere. As the kinetic energy of moving engine parts is transferred to the wheels, friction generates some additional heat. All of these steps produce low-quality heat in accordance with the second law of thermodynamics.

combustion, heat is lost from the engine. Friction results in further loss of energy as heat. Therefore, the amount of useful energy (kinetic energy of the wheels turning) is much less than the total amount of chemical energy present in the gasoline that was burned. (See figure 4.13).

Within the universe, energy is being converted from one form to another continuously. Stars are converting nuclear energy into heat and light. Animals are converting the chemical potential energy found in food into kinetic energy that allows them to move. Plants are converting sunlight energy into the chemical bond energy of sugar molecules. In each of these cases, some energy is produced that is not able to do useful work. This is generally in the form of heat lost to the surroundings.

ENVIRONMENTAL IMPLICATIONS OF ENERGY FLOW

If we wish to understand many kinds of environmental problems, we must first understand the nature of energy and energy flow.

ENTROPY INCREASES

The heat produced when energy conversions occur is dissipated throughout the universe. This is a common experience. All machines and living things that manipulate energy release heat. It is also true that organized matter tends to become more disordered unless an external source of energy is available to maintain the ordered arrangement. Houses fall into ruin, automobiles rust, and appliances wear out unless work is done to maintain them. In reality, all of these phenomena involve the loss of heat. The organisms that decompose the wood in our houses release heat. The chemical reaction that causes rust releases heat. Friction, caused by the movement of parts of a machine against each other, generates heat and causes the parts to wear.

Ultimately, orderly arrangements of matter, such as clothing, automobiles, or living organisms, become disordered. There is an increase in entropy. Eventually, nonliving objects wear out and living things die and decompose. This process of becoming more disordered coincides with the constant flow of energy toward a dilute form of heat. This dissipated, low-quality heat has little value to us, since we are unable to use it.

ENERGY QUALITY

It is important to understand that some forms of energy are more useful to us than others. Some forms, such as electrical energy, are of high quality because they can be easily used to perform a variety of useful actions. Other forms, such as the heat in the water of the ocean, are of low quality because we are not able to use them for useful purposes. Although the total *quantity* of heat energy in the ocean is much greater than the total amount of electrical energy in the world, little useful work can be done with the heat energy in the ocean because it is of *low quality*. Therefore, it is not as valuable as other forms of energy that can be used to do work for us.

The reason the heat of the ocean is of little value is related to the small temperature difference between two sources of heat. When two objects differ in temperature, heat will flow from the warmer to the cooler object. The greater the temperature difference, the more useful the work that can be done. For example, fossil-fuel power plants burn fuel to heat water and convert it to steam. High-temperature steam enters the turbine, while cold cooling water condenses the steam as it leaves the turbine. This steep temperature gradient also provides a steep pressure gradient as heat energy flows from the steam to the cold water, which causes a turbine to turn, which generates electricity. Because the average temperature of the ocean is not high, and it is difficult to find another object that has a greatly lower temperature than the ocean, it is difficult to use the huge heat content of the ocean to do useful work for us.

CAMPUS SUSTAINABILITY INITIATIVE

Cooling Off the University of Arizona

ı hot climates, air conditioning makes the hot part of the year bearable. lowever, air conditioning has its costs—both monetary and environmenal. The electricity needed to provide air conditioning costs money and ıe production of that electricity results in carbon emissions.

The University of Arizona's water chilling and ice storing project is reucing the amount of electricity needed to cool the campus, which is both ost effective and environmentally conscious. The system involves the use f water chillers, cooling towers, pumps, and underground pipes that conect to buildings.

Because daytime and nighttime temperatures in Arizona can be rastically different, the university turns the water chillers on during the cooler evening hours to produce ice. The project can produce more than 900 tons of ice per hour. Currently, this process begins at 7:30 P.M. In the morning around 10 A.M., the university turns the chillers off and the ice begins to melt. The cold water is then delivered all over campus to cool buildings. This process moves the bulk of the university's electrical demand for air conditioning from the hot daytime hours to the cooler nighttime hours, which means that less energy is needed to provide air conditioning. The system has been called one of the most energy efficient and environmentally friendly chilled water systems in the world. Annual savings are expected to be about half a million dollars.

It is important to understand that energy that is of low quality ·om our point of view may still have significance to the world in ·hich we live. For example, the distribution of heat energy in the ɔean tends to moderate the temperature of coastal climates, conibutes to weather patterns, and causes ocean currents that are exemely important in many ways. It is also important to recognize that e can sometimes figure new ways to convert low-quality energy to gh-quality energy. For example, it is possible to use the waste heat om power plants to heat cities if the power plants are located in the ties. Scientists have recently made major improvements in wind turnes and photovoltaic cells that allow us to economically convert w-quality light or wind to high-quality electricity.

›iological Systems nd Thermodynamics

·om the point of view of ecological systems, organisms such plants do photosynthesis and are able to convert low-quality ʒht energy to high-quality chemical energy in the organic olecules they produce. Eventually, they will use this stored ıergy for their needs, or it will be used by some other organ-n that has eaten the plant. In accordance with the second law thermodynamics, all organisms, including humans, are in the ocess of converting high-quality energy into low-quality ergy. Waste heat is produced when the chemical-bond energy in food is converted into the energy needed to move, grow, or respond. The process of releasing chemical-bond energy from food by organisms is known as cellular respiration. From an energy point of view, it is comparable to the process of **combustion,** which is the burning of fuel to obtain heat, light, or some other form of useful energy. The efficiency of cellular respiration is relatively high. About 40 percent of the energy contained in food is released in a useful form. The rest is dissipated as low-quality heat.

Pollution and Thermodynamics

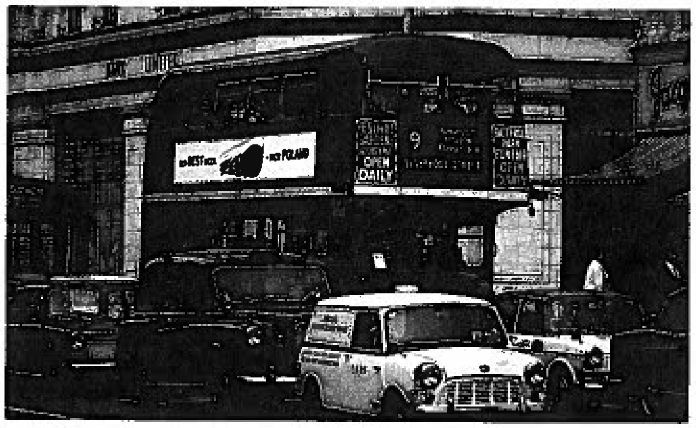
An unfortunate consequence of energy conversion is pollution. The heat lost from most energy conversions is a pollutant. The wear of the brakes used to stop cars results in pollution. The emissions from power plants pollute. All of these are examples of the effect of the second law of thermodynamics. If each person on Earth used less energy, there would be less waste heat and other forms of pollution that result from energy conversion. The amount of energy in the universe is limited. Only a small portion of that energy is of high quality. The use of high-quality energy decreases the amount of useful energy available, as more low-quality heat is generated. All life and all activities are subject to these important physical principles described by the first and second laws of thermodynamics.

ISSUES & ANALYSIS

Diesel Engine Trade-offs

In the United States nearly all automobiles have gasoline engines. Only about 1 percent have diesel engines. In Europe more than 50 percent of new automobiles sold have diesel engines. Automobile diesel engines are much more efficient than gasoline engines. They have an efficiency of 35 to 42 percent compared to gasoline engines with an efficiency of 25 to 30 percent. This means that they go much farther on a liter of fuel than do equivalent gasoline engines. Furthermore diesel engines last longer than gasoline engines.

Since gasoline engines are less efficient than diesel engines, gasoline engines produce 20 to 40 percent more carbon dioxide than diesel engines for the same distance driven. Increased carbon dioxide is known to cause a warming of the Earth's atmosphere. One of the reasons for the popularity of diesel engines in Europe is concern about the effect of carbon dioxide on global climate.



Current diesel engines produce more particulate matter and nitrogen oxides than do gasoline engines. However, current air quality guidelines for particulate matter and nitrogen oxides in Europe are more stringent than those in the United States. The World Health Organization has estimated that thousands of people die each year because of particulate air pollution. Changes are being made in fuels, engine design, and pollution control devices that reduce the amount of particulate matter and nitrogen oxides produced.

- Should U.S. automakers switch to diesel engines as the Europeans have?
- Is global climate change an important reason to use diesel engines?
- Should problems with particulate emissions prevent the development of diesel engines for passenger vehicles?

SUMMARY

Science is a method of gathering and organizing information. It involves observation, asking questions, exploring alternative sources of information, hypothesis formation, the testing of hypotheses, and publication of the results for others to evaluate. A hypothesis is a logical prediction about how things work that must account for all the known information and be testable. The process of science attempts to be careful, unbiased, and reliable in the way information is collected and evaluated. This often involves conducting experiments to test the validity of a hypothesis. If a hypothesis is continually supported by the addition of new facts, it may be incorporated into a theory. A theory is a broadly written, widely accepted generalization that ties together large bodies of information and explains why things happen. Similarly, a law is a broad statement that describes what happens in nature.

The fundamental unit of matter is the atom, which is made up of protons and neutrons in the nucleus surrounded by a cloud of moving electrons. The number of protons for any one type of atom is constant, but the number of neutrons in different atoms of the same type of atom may vary. The number of electrons is equal to the number of protons. Protons have a positive charge, neutrons lack a charge, and electrons have a negative charge.

Molecules are units made of a combination of two or more atoms bonded to one another. Chemical bonds are physical attractions between atoms resulting from the interaction of their electrons. When chemical bonds are broken or formed, a chemical reaction occurs, and the amount of energy within the chemical bonds is changed. Chemical reactions require activation energy to get the reaction started.

Matter that is composed of only one kind of atom is known as an element. Matter that is composed of small units containing different kinds of atoms bonded in specific ratios is known as a compound. An atom or molecule that has gained or lost electrons so that it has an electric charge is known as an ion.

Matter can occur in three states: solid, liquid, and gas. These three differ in the amount of energy the molecular units contain and the distance between the units. Kinetic energy is the energy contained by moving objects. Potential energy is the energy an object has because of its position.

The first law of thermodynamics states that the amount of energy in the universe is constant, that energy can neither be created nor destroyed. The second law of thermodynamics states that when energy is converted from one form to another, some of the useful energy is lost (entropy increases). Some forms of energy are more useful than others. The quality of the energy determines how much useful work can be accomplished by expending the energy. Low-temperature heat sources are of poor quality, since they cannot be used to do useful work.

THINKING GREEN

1. Replace household chemicals with those that are more environmentally friendly.
2. Find out when the next household hazardous waste cleanup is in your community and get rid of unwanted hazardous materials.
3. Read the labels on your household cleaning products.
4. Use baking soda as a substitute for toothpaste.
5. Reduce your consumption of electricity by 10 percent.

WHAT'S YOUR TAKE?

he following chart gives the typical light output per watt of electricity ;ed for various kinds of lighting devices:

Kind of Light	Light Output per Watt of Electricity Used
100-watt incandescent lightbulb	About 17 lumens/watt
White LED	About 17 lumens/watt
Compact fluorescent bulb	About 50 lumens/watt
Standard 40-watt fluorescent tube	About 60 lumens/watt
T8 fluorescent with electronic Ballast (32 watt)	About 90 lumens/watt

Compact fluorescent bulbs can be screwed into standard light fixtures. They cost about 10 times more than an incandescent lightbulb but last about 10 times longer.

Based on this information, should you replace incandescent lightbulbs with compact fluorescents? Develop an argument supporting your position.

REVIEW QUESTIONS

1. How do scientific disciplines differ from nonscientific disciplines?
2. What is a hypothesis? Why is it an important part of the way scientists think?
3. Why are events that happen only once difficult to analyze from a scientific point of view?
4. What is the scientific method, and what processes does it involve?
5. How are the second law of thermodynamics and pollution related?
6. Diagram an atom of oxygen and label its parts.
7. What happens to atoms during a chemical reaction?
8. State the first and second laws of thermodynamics.
9. How do solids, liquids, and gases differ from one another at the molecular level?
10. List five kinds of energy.
11. Are all kinds of energy equal in their capacity to bring about changes? Why or why not?

CRITICAL THINKING QUESTIONS

1. You observe that a high percentage of frogs, which are especially sensitive to environmental poisons, in small ponds in your agricultural region have birth defects. Suspecting agricultural chemicals present in runoff to be the culprit, state the hypothesis in your own words. Next, devise an experiment that might help you support or reject your hypothesis.
2. Given the experiment you proposed in Critical Thinking Question 1, imagine some results that would support that hypothesis. Now imagine you are a different scientist, one who is very skeptical of the initial hypothesis. How convincing do you find these data? What other possible explanations (hypotheses) might there be to explain the results? Devise a different experiment to test this new hypothesis.
3. Increasingly, environmental issues such as global climate change are moving to the forefront of world concern. What role should science play in public policy decisions? How should we decide between competing scientific explanations about an environmental concern such as global climate change? What might be some of the criteria for deciding what is "good science" and what is "bad science"?
4. How important are the first and second laws of thermodynamics to explaining environmental issues? Using the concepts in these laws of thermodynamics, try to explain a particular environmental issue. How does an understanding of thermodynamics change your conceptual framework regarding this issue?

5. The text points out that incandescent lightbulbs are only 5–10 percent efficient at using energy to accomplish their task, while new, initially more expensive, compact fluorescent lighting uses significantly less electricity to provide the same quantity of light. Examine the contextual framework of those who advocate for new lighting methods and the contextual framework of those who continue to design and build using the old methods. What are the major differences in perspective? What could you suggest be done to help bring these different perspectives closer together?
6. Some scientists argue that living organisms constantly battle against the principles of the second law of thermodynamics using the principles of the first law of thermodynamics. What might they mean by this? Do you think this is accurate? What might be some of the implications of this for living organisms?