Science, Matter, Energy, and Systems
Science is built up of facts, as a house is built of stones; but an accumulation of facts is no more a science than a heap of stones is a house.

HENRI POUSCARÉ

Key Questions

2-1 What do scientists do?
2-2 What is matter and what happens when it undergoes change?
2-3 What is energy and what happens when it undergoes change?
2-4 What are systems and how do they respond to change?
CORE CASE STUDY

How Do Scientists Learn about Nature? Experimenting with a Forest

Suppose a logging company plans to cut down all of the trees on a hillside behind your house. You are very concerned and want to know about the possible harmful environmental effects of this action.

One way to learn about such effects is to conduct a controlled experiment, just as environmental scientists do. They begin by identifying key variables, such as water loss and soil nutrient content, that might change after the trees are cut down. Then, they set up two groups. One is the experimental group, in which a chosen variable is changed in a known way. The other is the control group, in which the chosen variable is not changed. They then compare the results from the two groups.

In 1963, botanist F. Herbert Bormann, forest ecologist Gene Likens, and their colleagues began carrying out such a controlled experiment. Their goal was to compare the loss of water and soil nutrients from an area of uncut forest (the control site) with one that had been stripped of its trees (the experimental site).

They built V-shaped concrete dams across the creeks at the bottoms of several forested valleys in the Hubbard Brook Experimental Forest in New Hampshire (Figure 2-1). The dams were designed so that all surface water leaving each forested valley had to flow across a dam, where scientists could measure its volume and dissolved nutrient content.

First, the researchers measured the amounts of water and dissolved soil nutrients flowing from an undisturbed forested area in one of the valleys (the control site, Figure 2-1, left). These measurements showed that an undisturbed mature forest is very efficient at storing water and retaining chemical nutrients in its soils.

Next, they set up an experimental forest area in a nearby valley (Figure 2-1, right). One winter, they cut down all the trees and shrubs in that valley, left them where they fell, and sprayed the area with herbicides to prevent the regrowth of vegetation. Then, for 3 years, they compared outflow of water and nutrients in this experimental site with those in the control site.

The scientists found that, with no plants to help absorb and retain water, the amount of water flowing out of the deforested valley increased by 30–40%. As this excess water ran rapidly over the ground, it eroded soil and carried dissolved nutrients out of the topsoil in the deforested site. Overall, the loss of key soil nutrients from the experimental forest was 6–8 times that in the nearby uncut control forest.

In this chapter, you will learn more about how scientists study nature and about the matter and energy that make up the world within and around us. You will also learn about three scientific laws, or rules of nature, that govern the changes that matter and energy undergo. And you will learn the important difference between a scientific hypothesis and a scientific theory.

Figure 2-1 This controlled field experiment measured the loss of water and soil nutrients from a forest due to deforestation. The forested valley (left) was the control site; the cutover valley (right) was the experimental site.
## What Do Scientists Do?

**Concept 2-1**
Scientists collect data and develop hypotheses, theories, models, and laws about how nature works.

### Science Is a Search for Order in Nature

*Science* is an attempt to discover how nature works and to use that knowledge to describe what is likely to happen in nature. It is based on the assumption that events in the physical world follow orderly cause-and-effect patterns that can be understood through careful observation, measurements, experimentation, and modeling. Figure 2-2 summarizes the scientific process.

There is nothing mysterious about this scientific process. You use it all the time in making decisions. As the famous physicist Albert Einstein put it, “The whole of science is nothing more than a refinement of everyday thinking.”

### Scientists Use Observations, Experiments, and Models to Answer Questions about How Nature Works

Here is a more formal outline of the steps scientists often take in trying to understand the natural world, although they do not always follow the steps in the order listed. The outline is based on the scientific experiment carried out by Bormann and Likens (*Core Case Study*), which illustrates the nature of the scientific process shown in Figure 2-2.

1. **Identify a problem.** Bormann and Likens identified the loss of water and soil nutrients from cutover forests as a problem worth studying.
2. **Find out what is known about the problem.** They searched the scientific literature to find out what scientists knew about both the retention and the loss of water and soil nutrients in forests.
3. **Ask a question to investigate.** The scientists asked, “How does clearing forested land affect its ability to store water and retain soil nutrients?”
4. **Perform an experiment and collect and analyze data to answer the question.** To collect data—information needed to answer their questions—scientists often perform experiments and make observations and measurements, as Bormann and Likens did (Figure 2-1). (Sometimes, they simply observe and measure natural phenomena to collect data without doing an experiment.)
5. **Propose a hypothesis to explain the data.** Scientists suggest a scientific hypothesis—a possible and testable answer to a scientific question or explanation of what scientists observe in nature. Bormann and Likens came up with the following hypothesis to explain their data: *When a forest is cleared of its vegetation and exposed to rain and melting snow, it retains less water and loses large quantities of soil nutrients.*

6. **Use the hypothesis to make projections that can be tested.** Scientists make projections about what should happen if their hypothesis is correct and then run experiments to test the projections. Bormann and Likens projected...
that if their hypothesis was valid for nitrogen, then a cleared forest should also lose other soil nutrients such as phosphorus over a similar time period and under similar weather conditions.

- **Test the projections with further experiments or observations.** To test their projection, Bormann and Likens repeated their controlled experiment and measured the phosphorus content of the soil. Another way to test projections is to use a **model**, an approximate representation or simulation of a system.

- **Accept or revise the hypothesis.** After Bormann and Likens confirmed that the soil in a cleared forest also loses phosphorus, they measured losses of other soil nutrients, which further supported their hypothesis. The research of other scientists also supported the hypothesis. A well-tested and widely accepted scientific hypothesis or a group of related hypotheses is called a **scientific theory**. The research by Bormann and Likens and other scientists led to a widely accepted scientific theory that trees and other plants hold soil in place and help it to retain water and nutrients needed by the plants for their growth.

### Scientists Are Curious and Skeptical, and They Demand Evidence

Four important features of the scientific process are **curiosity, skepticism, reproducibility**, and **peer review**. Good scientists are extremely curious about how nature works, and they are keen observers of what is happening in nature (see Individuals Matter 2.1). Scientists tend to be highly skeptical of new data and hypotheses. They say, “Show me your evidence and explain the reasoning behind the scientific ideas or hypotheses that you propose to explain your data.” Any evidence that scientists gather should also be reproducible. In other words, other scientists should be able to get the same results if they run the same experiments.

Science is a community effort, and an important part of the scientific process is **peer review**. It involves scientists openly publishing details of the methods they used, the results of their experiments, and the reasoning behind their hypotheses for other scientists working in the same field (their peers) to evaluate.

For example, Bormann and Likens (Core Case Study) submitted the results of their forest experiments to a respected scientific journal. Before publishing this report, the journal’s editors asked other soil and forest experts to review it. Other scientists have repeated the measurements of soil content in undisturbed and cleared forests of the same type and also in different types of forests, and their results have also been subjected to peer review. In addition, computer models of forest systems have been used to evaluate this problem, with the results also subjected to peer review.

Scientific knowledge advances in this self-correcting way, with scientists continually questioning the measurements and data produced by their peers. They also collect new data and sometimes come up with new and better hypotheses (Science Focus 2.1).

### Critical Thinking and Creativity Are Important in Science

Scientists use logical reasoning and critical thinking skills (p. xxiv) to learn about the natural world. Thinking critically involves four important steps:

1. Be skeptical about everything you read or hear.
2. Look at the evidence and evaluate it and any related information, along with inputs and opinions from a variety of reliable sources.
3. Be open to many viewpoints and evaluate each one before coming to a conclusion.
4. Identify and evaluate your personal assumptions, biases, and beliefs. As the American psychologist and philosopher William James observed, “A great many people think they are thinking when they are merely rearranging their prejudices.”

Logic and critical thinking are very important tools in science, but imagination, creativity, and intuition are just as vital. According to physicist Albert Einstein, “There is no completely logical way to a new scientific idea.”

### Scientific Theories and Laws Are the Most Important and Certain Results of Science

The real goal of scientists is to develop theories and laws, based on facts and data that explain how the natural world works, as illustrated in the quotation that opens this chapter. We should never take a scientific theory lightly. It has been tested widely, is supported by extensive evidence, and is accepted as being a useful explanation of some phenomenon by most scientists in a particular field or related fields of study.

Because of this rigorous testing process, scientific theories are rarely overturned unless new evidence discredits them or scientists come up with better explanations. So when you hear someone say, “Oh, that’s just a theory,” you will know that he or she does not have a clear understanding of what a scientific theory is. In sports terms, developing a widely accepted scientific theory is roughly equivalent to winning a gold medal in the Olympics.

Another important and reliable outcome of science is a **scientific law**, or **law of nature**—a well-tested and widely accepted description of what we find happening repeatedly and in the same way in nature. An example is the **law of gravity**. After making many thousands of observations and measurements of objects falling from different heights, scientists developed the following scientific law: all objects fall to the earth’s surface at predictable speeds.

We can break a society’s law, for example, by driving faster than the speed limit. But we cannot break a
Jane Goodall: Chimpanzee Researcher and Protector

Jane Goodall is a primatologist and environmental educator with a PhD from Cambridge University. She is also a National Geographic Explorer-in-Residence Emeritus. At age 26, she began a 50-year career of studying chimpanzee social and family life in the Gombe Stream Game Reserve in the African country of Tanzania. She is shown above with one of the chimpanzees she studied. By carefully observing the chimps while living with them, she discovered that chimps have more complex social interactions than had previously been known. For example, she found that they can use tools, eat meat as well as vegetation, and carry on extended fights with one another.

One of her major scientific discoveries was that chimpanzees have tool-making skills. She observed some chimpanzees modifying twigs or blades of grass and then poking them into termite mounds. When the termites latched on to these primitive tools, the chimpanzees pulled them out and ate the termites. Goodall has also observed that chimps can learn simple sign language, do simple arithmetic, play computer games, develop relationships, and worry about and protect one another.

In 1977, she established the Jane Goodall Institute, a nonprofit organization that works to preserve great ape populations and their habitats. Her research encouraged the Tanzanian government to convert the game preserve into the Gombe Stream National Park, which her institute now supports.

Goodall has been a strong advocate for animal rights and has led campaigns against sport hunting, keeping animals in zoos, and using them for medical research. In 1991 she started Roots and Shoots, an environmental education program for youth that is active in more than 100 countries. She has received many awards and prizes for her scientific contributions and conservation efforts. She has also written 23 books for adults and children and produced 14 films about the lives and importance of chimpanzees.

In 2011, the movie Jane's Journey was made about her life's work. Now in her late 70s, Goodall still spends nearly 300 days a year traveling and educating people throughout the world about chimpanzees and the need to protect the environment. She says, "I can't slow down... If we're not raising new generations to be better stewards of the environment, what's the point?"

Background photo: namaste/Shutterstock
For years, the story of Easter Island has been used in textbooks as an example of how humans can seriously degrade their own life-support system and as a warning about what we are doing to our life-support system.

What happened on this small island in the South Pacific is a story about environmental degradation and the demise of an ancient civilization of Polynesians living there. Years ago, scientists studied the island and its remains, including more than 300 huge statues (Figure 2-A). They hypothesized that over time, the Polynesians began living unsustainably as their population grew, and they used the island's forest and soil resources faster than they could be renewed. They further hypothesized that when the forests were depleted, there was no firewood for cooking or keeping warm and no wood for building large canoes in order to leave the island. They also hypothesized that, with the forest cover gone, soils eroded, crop yields plummeted, famine struck, the population dwindled, and the civilization collapsed.

In 2006, anthropologist Terry L. Hunt evaluated the accuracy of past measurements and other evidence and carried out new research to reevaluate the hypothesis about what happened on Easter Island. He used his data to formulate an alternative hypothesis to try to explain the human tragedy on Easter Island, and he came to some new conclusions. First, the Polynesians arrived on the island about 800 years ago, not 2,900 years ago, as had been thought. Second, their population size probably never exceeded 3,000, contrary to the earlier estimate of up to 15,000.

Third, the Polynesians did use the island's trees and other vegetation in an unsustainable manner, and visitors reported that by 1722, most of the island's trees were gone. However, one question not answered by this earlier hypothesis was, why did the trees never grow back? Recent evidence and Hunt's new hypothesis suggest that rats (which either came along with the original settlers as stowaways or were brought along as a source of protein for the long voyage) played a key role in the island's permanent deforestation. Over the years, the rats multiplied rapidly into the millions and devoured the seeds that would have regenerated the forests. According to this new hypothesis, the rats played a key role in the fall of the civilization on Easter Island.

This story is an excellent example of how science works. The gathering of new scientific data and the reevaluation of older data led to a revised hypothesis that challenged earlier thinking about the decline of civilization on Easter Island. As a result, the tragedy may not be as clear an example of human-caused ecological collapse as was once thought.

Note that the original Easter Island story was a scientific hypothesis, not a widely tested and accepted scientific theory. And Hunt's research presents another scientific hypothesis based on new data. Further research may convert Hunt's hypothesis to the status of a scientific theory, or more research may lead to other insights into what happened on this island. This is how science works.

Critical Thinking

Does the new doubt about the original Easter Island hypothesis mean that we should not be concerned about using resources unsustainably on the island in space that we call Earth? Explain.

The Results of Science Can Be Tentative, Reliable, or Unreliable

Sometimes, preliminary scientific results that capture news headlines have not been widely tested and accepted by peer review. They are not yet considered reliable, and can be thought of as tentative science or frontier science. Some of these results and hypotheses will be validated and classified as reliable and some will be discredited and classified as unreliable. At the frontier stage, it is normal for scientists to disagree about the meaning and accuracy of data and the validity of hypotheses and results. This is how scientific knowledge advances.

By contrast, reliable science consists of data, hypotheses, models, theories, and laws that are widely accepted by all or most of the scientists who are considered experts in the field under study. The results of reliable science are based on the self-correcting process of testing, open peer review, and debate. New evidence and
better hypotheses may discredit or alter widely accepted scientific theories, although this is rare. But until that happens, those theories are considered to be the results of reliable science.

Scientific hypotheses and results that are presented as reliable without having undergone the rigor of widespread peer review, or that have been discarded as a result of peer review, are considered to be unreliable science. Here are some critical thinking questions you can use to uncover unreliable science:

- Was the experiment well designed? Did it involve a control group? (Core Case Study)
- Does the proposed hypothesis explain the data?
- Are there no other, more reasonable explanations of the data?
- Are the investigators unbiased in their interpretations of the results? Did their funding come from unbiased sources?
- Have the data and conclusions been subjected to peer review?
- Are the conclusions of the research widely accepted by other experts in this field?

If “yes” is the answer to each of these questions, then you can classify the results as reliable science. Otherwise, the results may represent tentative science that needs further testing and evaluation, or you can classify them as unreliable science.

Science Has Some Limitations

Environmental science and science in general have four important limitations. First, scientists cannot prove or disprove anything absolutely, because there is always some degree of uncertainty in scientific measurements, observations, and models. Instead, scientists try to establish that a particular scientific theory or law has a very high probability or certainty (at least 90%) of being useful for understanding some aspect of the natural world.

Many scientists do not use the word proof because it implies “absolute proof” to people who don’t understand how science works. For example, most scientists will rarely say something like, “Cigarettes cause lung cancer.” Rather, they might say, “Overwhelming evidence from thousands of studies indicates that people who smoke regularly for many years have a greatly increased chance of developing lung cancer.”

**CONSIDER THIS . . .**

THINKING ABOUT Scientific Proof

Does the fact that science can never prove anything absolutely mean that its results are not valid or useful? Explain.

A second limitation of science is that scientists are human and thus are not totally free of bias about their own results and hypotheses. However, the high standard of evidence required through peer review helps to uncover or greatly reduce personal bias and expose occasional cheating by scientists who falsify their results.

A third limitation—especially important to environmental science—is that many systems in the natural world involve a huge number of variables with complex interactions. This makes it difficult, too costly, and too time-consuming to test one variable at a time in controlled experiments such as the one described in the Core Case Study that opens this chapter. To try to deal with this problem, scientists develop mathematical models that can take into account the interactions of many variables. Running such models on high-speed computers can sometimes overcome the limitations of testing each variable individually, saving both time and money. In addition, scientists can use computer models to simulate global experiments on phenomena such as climate change that cannot be done in a controlled physical experiment.

A fourth limitation of science involves the use of statistical tools. For example, there is no way to measure accurately how many metric tons of soil are eroded annually worldwide. Instead, scientists use statistical sampling and other mathematical methods to estimate such numbers. However, such results should not be dismissed as “only estimates” because they can indicate important trends.

Despite these limitations, science is the most useful way that we have of learning about how nature works and projecting how it might behave in the future. But we still know too little about how the earth works, about its present state of environmental health, and about the current and future environmental impacts of our activities.

### 2-2 What Is Matter and What Happens When It Undergoes Change?

**CONCEPT 2-2A**

Matter consists of elements and compounds, which in turn are made up of atoms, ions, or molecules.

**CONCEPT 2-2B**

Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).

Matter Consists of Elements and Compounds

To begin our study of environmental science, we look at matter—the stuff that makes up life and its environment. Matter is anything that has mass and takes up space. It can exist in three physical states—solid, liquid, and gas—and two chemical forms—elements and compounds.
An element is a fundamental type of matter that has a unique set of properties and cannot be broken down into simpler substances by chemical means. For example, the elements gold (Figure 2-3, left) and mercury (Figure 2-3, right) cannot be broken down chemically into any other substance. Chemists arrange the known elements on the basis of their chemical behavior in what is called the Periodic Table of Elements (see Figure 1, p. S12, Supplement 4).

Some matter is composed of one element, such as mercury or gold (Figure 2-3). And some elements such as hydrogen (H), nitrogen (N), oxygen (O), and chlorine (Cl) are found in nature as combinations of two of their atoms represented by the chemical formulas H₂, N₂, O₂, and Cl₂. However, most matter consists of compounds, combinations of two or more different elements held together in fixed proportions. For example, water is a compound made of the elements hydrogen and oxygen that have chemically combined with one another. (See Supplement 4, p. S12, for an expanded discussion of basic chemistry.)

To simplify things, chemists represent each element by a one- or two-letter symbol. Table 2-1 lists the elements and their symbols that you need to know to understand the material in this book.

### Table 2-1 Chemical Elements Used in This Book

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<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Element</th>
<th>Symbol</th>
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</thead>
<tbody>
<tr>
<td>arsenic</td>
<td>As</td>
<td>lead</td>
<td>Pb</td>
</tr>
<tr>
<td>bromine</td>
<td>Br</td>
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<td>Li</td>
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<td>phosphorus</td>
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<td>Cl</td>
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</tr>
<tr>
<td>fluorine</td>
<td>F</td>
<td>sulfur</td>
<td>S</td>
</tr>
<tr>
<td>gold</td>
<td>Au</td>
<td>uranium</td>
<td>U</td>
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Atoms, Molecules, and Ions Are the Building Blocks of Matter

The most basic building block of matter is an atom, the smallest unit of matter into which an element can be divided and still have its distinctive chemical properties. The idea that all elements are made up of atoms is called the atomic theory and it is the most widely accepted scientific theory in chemistry.

Atoms are incredibly small. For example, more than 3 million hydrogen atoms could sit side by side on the period at the end of this sentence. If you could view atoms with a supermicroscope, you would find that each different type of atom contains a certain number of three types of subatomic particles: neutrons (n) with no electrical charge; protons (p), each with a positive electrical charge (+); and electrons (e), each with a negative electrical charge (−).

Each atom has an extremely small center called the nucleus, which contains one or more protons and, in most cases, one or more neutrons. Outside of the nucleus we find one or more electrons in rapid motion (Figure 2-4). We cannot determine the exact locations of the electrons. Instead, scientists can estimate the probability that they will be found at various locations outside the nucleus in certain spatial patterns that are called electron probability clouds. This is somewhat like saying that there are a number of bees flying around inside a cloud. We do not know their exact locations, but the cloud represents an area in which there is a high probability of finding them.

Each atom in its basic form has equal numbers of positively charged protons and negatively charged electrons. Because these electrical charges cancel one another, an atom in its basic form has no net electrical charge.

Each element has a unique atomic number equal to the number of protons in the nucleus of its atom. Carbon (C), with 6 protons in its nucleus, has an atomic number of 6, whereas uranium (U), a much larger atom, has 92 protons in its nucleus and thus an atomic number of 92.

Because electrons have so little mass compared to protons and neutrons, most of an atom's mass is concentrated in its nucleus. The mass of an atom is described by its mass number, the total number of neutrons and protons in its
nucleus. For example, a carbon atom with 6 protons and 6 neutrons in its nucleus has a mass number of 12, and a uranium atom with 92 protons and 143 neutrons in its nucleus has a mass number of 235 (92 + 143 = 235).

Each atom of a particular element has the same number of protons in its nucleus. But the nuclei of atoms of a particular element can vary in the number of neutrons they contain and, therefore, in their mass numbers. The forms of an element having the same atomic number but different mass numbers are called isotopes of that element. Scientists identify isotopes by attaching their mass numbers to the name or symbol of the element. For example, the three most common isotopes of carbon are carbon-12 (with six protons and six neutrons), carbon-13 (with six protons and seven neutrons), and carbon-14 (with six protons and eight neutrons). Carbon-12 makes up about 98.9% of all naturally occurring carbon.

A second building block of matter is a molecule, a combination of two or more atoms of the same or different elements held together by forces called chemical bonds. Molecules are the basic building blocks of many compounds (see Figure 3, p. S14, in Supplement 4 for examples). An example of a molecule is that of water, or H₂O, which consists of two atoms of hydrogen and one atom of oxygen held together by chemical bonds. Another example is methane, or CH₄ (the major component of natural gas), which consists of four atoms of hydrogen and one atom of carbon.

A third building block of some types of matter is an ion—an atom or a group of atoms with one or more net positive or negative electrical charges. Like atoms, ions are made up of protons, neutrons, and electrons. (See p. S13 in Supplement 4 for details on how ions form.) Chemists use a superscript after the symbol of an ion to indicate how many positive or negative electrical charges it has, as shown in Table 2-2.

The nitrate ion \(\text{NO}_3^-\) is a nutrient essential for plant growth. Figure 2-5 shows measurements of the loss of nitrate ions from the deforested area (Figure 2-1, right) in the controlled experiment run by Bormann and Likens (Core Case Study). Numerous chemical analyses of the water flowing through the dam at the cleared forest site showed an average 60-fold rise in the concentration of \(\text{NO}_3^-\) compared to water running off the forested site. After a few years, however, vegetation began growing back in the cleared valley and nitrate levels in its runoff returned to normal levels.

Ions are also important for measuring a substance’s acidity in a water solution, a chemical characteristic that helps determine how a substance dissolved in water will interact with and affect its environment. The acidity of a water solution is based on the comparative amounts of hydrogen ions \(\text{H}^+\) and hydroxide ions \(\text{OH}^-\) contained in a particular volume of the solution. Scientists use pH as

<table>
<thead>
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<th>Table 2-2 Chemical Ions Used in This Book</th>
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<tr>
<td>Positive Ion</td>
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<tr>
<td>hydrogen ion</td>
</tr>
<tr>
<td>sodium ion</td>
</tr>
<tr>
<td>calcium ion</td>
</tr>
<tr>
<td>aluminum ion</td>
</tr>
<tr>
<td>ammonium ion</td>
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</table>

| Negative Ion | Symbol | Components |
| chlorion | Cl⁻ | One chlorine atom, one negative charge |
| hydroxide ion | OH⁻ | One oxygen atom, one hydrogen atom, one negative charge |
| nitrate ion | NO₃⁻ | One nitrogen atom, three oxygen atoms, one negative charge |
| carbonate ion | CO₃²⁻ | One carbon atom, three oxygen atoms, two negative charges |
| sulfate ion | SO₄²⁻ | One sulfur atom, four oxygen atoms, two negative charges |
| phosphate ion | PO₄³⁻ | One phosphorus atom, four oxygen atoms, three negative charges |

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![Figure 2-5](image_url) This graph shows the loss of nitrate ions \(\text{NO}_3^-\) from a deforested watershed in the Hubbard Brook Experimental Forest (Core Case Study).

(Based on data from F.H. Bormann and Gene Likens.)

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a measure of acidity. Pure water (not tap water or rainwater) has an equal number of $H^+$ and $OH^-$ ions. It is called a neutral solution and has a pH of 7. An acidic solution has more hydrogen ions than hydroxide ions and has a pH less than 7. A basic solution has more hydroxide ions than hydrogen ions and has a pH greater than 7. (See Figure 4, p. S15, in Supplement 4 for more details.)

Chemists use a chemical formula to show the number of each type of atom or ion in a compound. This shorthand contains the symbol for each element present (Table 2-1) and uses subscripts to show the number of atoms or ions of each element in the compound’s basic structural unit. Examples of compounds and their formulas encountered in this book are sodium chloride (NaCl) and water (H$_2$O, read as “H-two-O”). Sodium chloride is an ionic compound with a three-dimensional array of sodium ions (Na$^+$) and chloride ions (Cl$^-$) (Figure 2-6). These and other compounds important to our study of environmental science are listed in Table 2-3.

You might want to mark these pages containing Tables 2-1, 2-2, and 2-3, because they show the key elements, ions, and compounds used in this book. Think of them as lists of some main chemical characters in the story of matter that makes up the natural world.

### Organic Compounds Are the Chemicals of Life

Plastics (Figure 2-7), table sugar, vitamins, aspirin, penicillin, and most of the chemicals in your body are called organic compounds, because they contain at least two carbon atoms combined with atoms of one or more other elements. All other compounds are called inorganic compounds. One exception, methane (CH$_4$), has only one carbon atom but is considered an organic compound.

The millions of known organic (carbon-based) compounds include the following:

- **Hydrocarbons**: compounds of carbon and hydrogen atoms. One example is methane (CH$_4$), the main component of natural gas and the simplest organic compound. Another is octane (C$_8$H$_{18}$), a major component of gasoline.
- **Chlorinated hydrocarbons**: compounds of carbon, hydrogen, and chlorine atoms. An example is the insecticide DDT (C$_6$H$_4$Cl$_2$).
- **Simple carbohydrates (simple sugars)**: certain types of compounds of carbon, hydrogen, and oxygen atoms. An example is glucose (C$_6$H$_{12}$O$_6$), which most plants and animals break down in their cells to obtain energy. (For more details, see Figure 5, p. S16, in Supplement 4.)

Larger and more complex organic compounds, essential to life, are composed of macromolecules. Some of these molecules are called polymers, formed when a number of simple organic molecules (monomers) are linked together by chemical bonds—somewhat like rail cars linked in a freight train. The three major types of organic polymers are

- complex carbohydrates such as cellulose and starch, which consist of two or more monomers of simple sugars such as glucose (see Figure 5, p. S16, in Supplement 4), important sources of energy in the food we eat;
- proteins formed by monomers called amino acids (see Figure 6, p. S16, in Supplement 4), important for building certain tissues in our-bodies; and
- nucleic acids (DNA and RNA) formed by monomers called nucleotides (see Figures 7 and 8, pp. S16 and S17, in Supplement 4), and key chemicals in the reproductive processes of many organisms.

Lipids, which include fats and waxes, are not made of monomers but are a fourth type of macromolecule essential for life (see Figure 9, p. S17, in Supplement 4).
Matter Comes to Life through Cells, Genes, and Chromosomes

All organisms are composed of one or more cells—the fundamental structural and functional units of life. They are minute compartments covered with a thin membrane, and within them, the processes of life occur. The idea that all living things are composed of cells is called the cell theory and it is the most widely accepted scientific theory in biology.

Above, we mentioned nucleotides in DNA (see Figures 7 and 8, pp. S16 and S17, in Supplement 4). Within some DNA molecules are certain sequences of nucleotides called genes. Each of these distinct pieces of DNA contains instructions, or codes, called genetic information, for making specific proteins. Each of these coded units of genetic information leads to a specific trait, or characteristic, passed on from parents to offspring during reproduction in an animal or plant.

In turn, thousands of genes make up a single chromosome, a double helix DNA molecule (see Figure 8, p. S17, in Supplement 4) wrapped around some proteins. Genetic information coded in your chromosomal DNA is what makes you different from an oak leaf, an alligator, or a mosquito, and from your parents. The relationships of genetic material to cells are depicted in Figure 2-8.

Matter Undergoes Physical, Chemical, and Nuclear Changes

When a sample of matter undergoes a physical change, there is no change in its chemical composition. A piece of aluminum foil cut into small pieces is still aluminum foil. When solid water (ice) melts and when liquid water boils, the resulting liquid water and water vapor are still made up of H₂O molecules.

When a chemical change, or chemical reaction, takes place, there is a change in the chemical composition of the substances involved. Chemists use a chemical equation (and a process called balancing the equation, see p. S17 in Supplement 4) to show how chemicals are rearranged in a chemical reaction. For example, coal is made up almost entirely of the element carbon (C). When coal is burned completely in a power plant, the solid carbon in the coal combines with oxygen gas (O₂) from the atmosphere to form the gaseous compound carbon dioxide (CO₂). Chemists use the following shorthand chemical equation to represent this chemical reaction:

\[
\text{Reactant(s)} \rightarrow \text{Product(s)}
\]

\[
\text{Carbon } + \text{ Oxygen } \rightarrow \text{ Carbon dioxide } + \text{ Energy}
\]

\[
\text{C } + \text{ O}_2 \rightarrow \text{ CO}_2 + \text{ Energy}
\]

\[
\text{Black solid } \rightarrow \text{ Colorless gas } + \text{ Colorless gas} + \text{Energy}
\]
In addition to physical and chemical changes, matter can undergo three types of **nuclear change**, or change in the nuclei of its atoms (Figure 2-9). **Radioactive decay** occurs when the nuclei of unstable isotopes spontaneously emit fast-moving chunks of matter (alpha particles or beta particles), high-energy radiation (gamma rays), or both at a fixed rate (Figure 2-9, top). **Nuclear fission** occurs when the nuclei of certain isotopes with large mass numbers (such as uranium-235) are split apart into lighter nuclei when struck by a neutron and release energy. Each fission releases neutrons, which can cause more nuclei to fission. This cascade of fissions can result in a chain reaction that releases an enormous amount of energy in a short time (Figure 2-9, middle). **Nuclear fusion** occurs when two nuclei of lighter atoms, such as hydrogen, are forced together at extremely high temperatures until they fuse to form a heavier nucleus and release a tremendous amount of energy (Figure 2-9, bottom).

**We Cannot Create or Destroy Atoms: The Law of Conservation of Matter**

We can change elements and compounds from one physical or chemical form to another, but we cannot create or destroy any of the atoms involved in any physical or chemical change. All we can do is rearrange the atoms, ions, or molecules into different spatial patterns (physical changes) or chemical combinations (chemical changes). These facts, based on many thousands of measurements, describe a scientific law known as the **law of conservation of matter**: Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (Concept 2-2B).

**CONSIDER THIS...**

**CONNECTIONS Waste and the Law of Conservation of Matter**

The law of conservation of matter means we can never really throw anything away because the atoms in any form of matter cannot be destroyed as it undergoes physical or chemical changes. Stuff that we put out in the trash may be buried in a sanitary landfill, but we have not really thrown it away because the atoms in this waste material will always be around in one form or another. We can burn trash, but we then end up with ash that must be put somewhere, and with gases emitted by the burning that can pollute the air. We can reuse or recycle some materials and chemicals, but the law of conservation of matter means we will always face the problem of what to do with some quantity of the wastes and pollutants we produce because their atoms cannot be destroyed.
2-3 What Is Energy and What Happens When It Undergoes Change?

**CONCEPT 2-3A**
Whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (first law of thermodynamics).

**CONCEPT 2-3B**
Whenever energy is converted from one form to another in a physical or chemical change, we end up with lower-quality or less-useable energy than we started with (second law of thermodynamics).

**Energy Comes in Many Forms**

Suppose you find this book on the floor and you pick it up and put it on your desktop. To do this you have to use a certain amount of muscular force or work to move the book from one place to another. In scientific terms, work is done when any object is moved a certain distance (work = force × distance). Also, whenever you touch a hot object such as a stove, heat flows from the stove to your finger. Both of these examples involve energy: the capacity to do work or to transfer heat.

There are two major types of energy: moving energy (called kinetic energy) and stored energy (called potential energy). Matter in motion has kinetic energy, or energy associated with motion. Examples are flowing water, a car speeding down the highway, electricity (electrons flowing through a wire or other conducting material), and wind (a mass of moving air that we can use to produce electricity, as shown in Figure 2-10).

Another form of kinetic energy is heat, or thermal energy, the total kinetic energy of all moving atoms, ions, or molecules in an object, a body of water, or the atmosphere. If the atoms, ions, or molecules in a sample of matter move faster, it will become warmer. When two objects at different temperatures come in contact with one another, heat flows from the warmer object to the cooler object. You learned this the first time you touched a hot stove.

In another form of kinetic energy, called electromagnetic radiation, energy travels in the form of a wave as a result of changes in electrical and magnetic fields. There are many different forms of electromagnetic radiation (Figure 2-11), each having a different wavelength (the distance between successive peaks or troughs in the wave) and energy content. Forms of electromagnetic radiation with short wavelengths, such as gamma rays, X-rays, and ultraviolet (UV) radiation, have more energy than do forms with longer wavelengths, such as visible light and

![Figure 2-10](image)

*Figure 2-10* Kinetic energy, created by the gaseous molecules in a mass of moving air, turns the blades of the wind turbine. The turbine then converts this kinetic energy to electrical energy, which is another form of kinetic energy.

**Animated Figure 2-11** The electromagnetic spectrum consists of a range of electromagnetic waves, which differ in wavelength (the distance between successive peaks or troughs) and energy content. © Cengage Learning
infrared (IR) radiation. Visible light makes up most of the spectrum of electromagnetic radiation emitted by the sun.

The other major type of energy is **potential energy**, which is stored and potentially available for use. Examples of this type of energy include a rock held in your hand, the water in a reservoir behind a dam, and the chemical energy stored in the carbon atoms of coal or in molecules of food that you eat.

We can change potential energy to kinetic energy. If you hold this book in your hand, it has potential energy. However, if you drop it on your foot, the book’s potential energy changes to kinetic energy. When a car engine burns gasoline, the potential energy stored in the chemical bonds of the gasoline molecules changes into kinetic energy that propels the car, and into heat that flows into the environment. When water in a reservoir flows through channels in a dam (Figure 2-12), its potential energy becomes kinetic energy that we can use to spin turbines in the dam to produce electricity—another form of kinetic energy.

### Renewable and Nonrenewable Energy

Scientists divide energy resources into two major categories: renewable energy and nonrenewable energy. **Renewable energy** is energy gained from resources that are replenished by natural processes in a relatively short time. Examples are solar energy, available somewhere on the earth all of the time, firewood from trees, wind, moving water, and heat that comes from the earth’s interior (geothermal energy).

**Nonrenewable energy** is energy from resources that can be depleted and are not replenished by natural processes within a human time scale. Examples are energy produced by the burning of oil, coal, and natural gas, and nuclear energy released when the nuclei of atoms of uranium fuel are split apart.

About 99% of the energy that we use to survive—the energy that keeps us warm and supports the plants that we and other organisms eat—comes from the sun at no cost to us. This is in keeping with the solar energy **principle of sustainability** (see Figure 1-2, p. 6 or back cover). Without this essentially inexhaustible solar energy, the earth would be frozen and life as we know it would not exist.

This direct input of solar energy produces several other indirect forms of renewable solar energy. Examples are **wind** (Figure 2-10), **hydropower** (falling and flowing water, Figure 2-12), and **biomass** (solar energy converted to chemical energy and stored in the tissues of trees and other plants) that can be burned to provide heat.

**Commercial energy**—energy that is sold in the marketplace—makes up the remaining 1% of the energy we use to supplement the earth’s direct input of solar energy. About 87% of the commercial energy used in the world and 87% of that used in the United States come from burning nonrenewable **fossil fuels**, or oil, coal, and natural gas (Figure 2-13). They are called fossil fuels because they were formed over millions of years as layers of the decaying remains of ancient plants and animals were exposed to intense heat and pressure within the earth’s crust.

### Some Types of Energy Are More Useful Than Others

**Energy quality** is a measure of the capacity of a type of energy to do useful work. **High-quality energy** is concentrated energy that has a high capacity to do useful work. Examples are very high-temperature heat, concentrated sunlight, high-speed wind, and the energy released when we burn gasoline or coal.
By contrast, **low-quality energy** is energy that is so dispersed that it has little capacity to do useful work. For example, the enormous number of moving molecules in the atmosphere or in an ocean together have such low-quality energy and such a low temperature that we cannot use them to move things or to heat things to high temperatures.

**Energy Changes Are Governed by Two Scientific Laws**

After observing and measuring energy being changed from one form to another in millions of physical and chemical changes, scientists have summarized their results in the **first law of thermodynamics**, also known as the **law of conservation of energy**. According to this scientific law, whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (Concept 2.3A).

This scientific law tells us that no matter how hard we try or how clever we are, we cannot get more energy out of a physical or chemical change than we put in. This is one of nature's basic rules that we cannot violate.

Because the first law of thermodynamics states that energy cannot be created or destroyed, but only converted from one form to another, you may be tempted to think we will never have to worry about running out of energy. Yet if you fill a car's tank with gasoline and drive around or run your computer battery down, something has been lost. What is it? The answer is **energy quality**, the amount of energy available for performing useful work.

Thousands of experiments have shown that whenever energy is converted from one form to another in a physical or chemical change, we end up with lower-quality or less usable energy than we started with (Concept 2.3B). This is a statement of the **second law of thermodynamics**. The resulting low-quality energy usually takes the form of heat that flows into the environment. In the environment, the random motion of air or water molecules further disperses this heat, decreasing its temperature to the point where its energy quality is too low to do much useful work.

In other words, **when energy is changed from one form to another, it always goes from a more useful form to a less useful form**. No one has ever found a violation of this fundamental scientific law.

**CONSIDER THIS . . .**

**CONNECTIONS Can We Recycle or Reuse Energy?**

We can recycle and reuse various forms of matter such as paper and aluminum. However, because of the second law of thermodynamics, we can never recycle or reuse high-quality energy to perform useful work. Once the concentrated, high-quality energy in a serving of food, a full tank of gasoline, or a chunk of uranium nuclear fuel is released, it is degraded to low-quality heat and dispersed into the environment.

Scientists estimate that about 84% of the energy used in the United States is either unavoidably wasted because of the second law of thermodynamics (41%) or unnecessarily wasted (43%). Thus, thermodynamics teaches us an important lesson: the cheapest and quickest way to get more energy is to stop wasting almost half the energy we use. One way to do this is to improve our
energy efficiency, which means getting more work out of the energy we use.

For example, only 5% of the electrical energy used by most incandescent lightbulbs (Figure 2-14, left) produces light, while the other 95% ends up as low-quality waste heat in the environment. There are much more efficient alternatives (Figure 2-14, center and right). We could also use more energy-efficient motor vehicle engines, power plants, and appliances, as we discuss in Chapter 16.

2-4 What Are Systems and How Do They Respond to Change?

**CONCEPT 2-4**

Systems have inputs, flows, and outputs of matter and energy, and feedback can affect their behavior.

**Systems Respond to Change through Feedback Loops**

A system is a set of components that function and interact in some regular way. The human body, a river, an economy, and the earth are all systems.

Most systems have the following key components: **inputs** of matter and energy from the environment, **flows** or **throughputs** of matter and energy within the system, and **outputs** of matter and energy to the environment (Figure 2-15) (Concept 2-4).

A system can become unsustainable if the throughputs of matter and energy resources exceed the abilities of the system’s environment to provide the required resource inputs and to absorb or dilute the system’s outputs of matter and energy. One of the most powerful tools used by environmental scientists to study how the components of systems interact is computer modeling (Science Focus 2.2).

When people ask you for feedback, they are usually seeking your response to something they said or did. They might feed your response back into their mental processes to help them decide whether and how to change what they are saying or doing.

Similarly, most systems are affected in one way or another by **feedback**, any process that increases (positive feedback) or decreases (negative feedback) a change to a system (Concept 2-4). Such a process, called a **feedback loop**, occurs when an output of matter, energy, or information is fed back into the system as an input and leads to changes in that system. Note that, unlike the human brain, most systems do not consciously decide how to respond to feedback. Nevertheless, feedback can affect the behavior of systems.

A **positive feedback loop** causes a system to change further in the same direction (Figure 2-16). In the Hubbard Brook experiments, for example (Core Case Study), researchers found that when vegetation was removed from a stream valley, flowing water from precipitation caused erosion and losses of nutrients, which caused more vegetation to die. With even less vegetation to hold soil in place, flowing water caused even more erosion and nutrient loss, which caused even more plants to die.

Such accelerating positive feedback loops are of great concern in several areas of environmental science. One of the most alarming is the melting of polar ice, which has occurred as the temperature of the atmosphere has risen during the past few decades. As that ice melts, there is less of it to reflect sunlight, and more water that is exposed to sunlight. Because water is darker than ice, it absorbs more solar energy, making the polar areas warmer and causing the ice to melt faster, thus exposing more water. The melting of polar ice is therefore accelerating, causing a number of serious problems that we explore further in Chapter 19.

If a system gets locked into an accelerating positive feedback loop, it can reach a breaking point that can destroy the system or suddenly change its behavior.

A **negative** or **corrective feedback loop** causes a system to change in the opposite direction from which it
Figure 2-16 A positive feedback loop. Decreasing vegetation in a valley causes increasing erosion and nutrient losses that in turn cause more vegetation to die, resulting in more erosion and nutrient losses. Question: Can you think of another positive feedback loop in nature?

CONSIDER THIS...

THINKING ABOUT The Hubbard Brook Experiments and Feedback Loops

How might experimenters have employed a negative feedback loop to stop, or correct, the positive feedback loop that resulted in increasing erosion and nutrient losses in the Hubbard Brook experimental forest (Core Case Study)?

An important example of a negative feedback loop is the recycling and reuse of some resources such as aluminum. For example, an aluminum can is an output of a mining and manufacturing system. When we recycle the can, that output becomes an input. This reduces the amount of aluminum ore that we must mine and process to make aluminum cans. It also reduces the harmful environmental impacts of the mining and processing of aluminum ore. Such a negative feedback loop therefore can help reduce the harmful environmental impacts of human activities by decreasing the use of matter and energy resources and the amount of pollution and solid waste produced by the use of such resources. It is an example of applying the chemical cycling principle of sustainability (see Figure 1-2, p. 6 or back cover).

It Can Take a Long Time for a System to Respond to Feedback

A complex system will often show a time delay, or a lack of response during a period of time between the input of a feedback stimulus and the system's response to it. For example, scientists could plant trees in a degraded area such as the Hubbard Brook experimental forest to slow erosion and nutrient losses (Core Case Study). But it would take years for the trees and other vegetation to grow in order to accomplish this purpose.

Time delays can allow an environmental problem to build slowly until it reaches a threshold level, or tipping point—the point at which a fundamental shift in the behavior of a system occurs. Reaching a tipping point is somewhat like stretching a rubber band. We can get away with stretching it to several times its original length. But at some point, we reach an irreversible tipping point where the rubber band breaks.

Prolonged delays dampen the negative feedback mechanisms that might slow, prevent, or halt environmental problems. In the Hubbard Brook example (Core Case Study), if soil erosion and nutrient losses had reached a certain point where the land could no longer support vegetation, then a tipping point would have been reached and it would have been too late to plant trees in order to try to restore the system. In Chapter 3, we discuss several major environmental tipping points that we may already have exceeded or will likely exceed in the near future.

System Effects Can Be Amplified through Synergy

A synergistic interaction, or synergy, occurs when two or more processes interact so that the combined effect is greater than the sum of their separate effects. For example, scientific studies reveal such an interaction between smoking and inhaling asbestos particles. Nonsmokers who
Scientists use models, or simulations, to learn how systems work. Mathematical models are especially useful when there are many interacting variables, when the time frame of events being modeled is long, and when controlled experiments are impossible or too expensive to conduct. One of our most powerful and useful technologies is mathematical modeling with high-speed supercomputers.

Making a mathematical model usually requires that the modelers go through three steps many times. First, they identify the major components of the system and how they interact, and develop mathematical equations that summarize this information. In succeeding runs, these equations are steadily refined. Second, modelers use a high-speed computer to describe the likely behavior of the system based on the equations. Third, they compare the system's projected behavior with known information about its actual behavior. They keep doing this until the model mimics the past and current behavior of the system.

After building and testing a mathematical model, scientists can use it to project what is likely to happen under a variety of conditions. In effect, they use mathematical models to answer if-then questions: "If we do such and such, then what is likely to happen now and in the future?" This process can give us a variety of projections or scenarios of possible outcomes based on different assumptions. Mathematical models (like all other models) are no better than the assumptions on which they are built and the data we feed into them.

Scientists applied this process of model-building to the data collected by researchers Bormann and Likens in their Hubbard Brook experiments (Core Case Study). These scientists created mathematical models based on the Hubbard Brook data to describe a forest and to project what might happen to soil nutrients and other variables if the forest were disturbed or cut down.

Other areas of environmental science in which computer modeling is becoming increasingly important include studies of the complex systems that govern climate change, deforestation, biodiversity loss, and the oceans.

**Critical Thinking**

What are two limitations of computer models? Does the existence of limitations mean that we should not rely on such models? Explain. What are the alternatives?
are exposed to asbestos particles for long periods of time increase their risk of getting lung cancer fivefold. But people who smoke and are exposed to asbestos have 50 times the risk that nonsmokers have of getting lung cancer.

On the other hand, synergy can be helpful. You may find that you are able to study longer or run farther if you do these activities with a studying or running partner. Your physical and mental systems can do a certain amount of work on their own. But the synergistic effect of you and your partner working together can make your individual systems capable of accomplishing more in the same amount of time. When individuals work together to find and implement win-win solutions to environmental problems, they are applying one of the social science principles of sustainability (see Figure 1-5, p. 9 or back cover).

**Big Ideas**

- You cannot really throw anything away. According to the law of conservation of matter, no atoms are created or destroyed whenever matter undergoes a physical or chemical change. Thus, we cannot do away with matter; we can only change it from one physical state or chemical form to another.

- You cannot get something for nothing. According to the first law of thermodynamics, or the law of conservation of energy, whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed. This means that in causing such changes, we cannot get more energy out than we put in.

- You cannot break even. According to the second law of thermodynamics, whenever energy is converted from one form to another in a physical or chemical change, we always end up with lower-quality or less usable energy than we started with.

**TYING IT ALL TOGETHER The Hubbard Brook Forest Experiment and Sustainability**

The controlled experiment discussed in the Core Case Study that opened this chapter revealed that clearing a mature forest degrades some of its natural capital (see Figure 1-3, p. 7, and photo at left). Specifically, the loss of trees and vegetation altered the ability of the forest to retain and recycle water and other critical plant nutrients—a crucial ecological function based on one of the three scientific principles of sustainability (see Figure 1-2, p. 6 or back cover). In other words, the uncleared forest (Figure 2-1, left) was a more sustainable system than a similar area of cleared forest (Figure 2-1, right).

This clearing of vegetation also violated the other two scientific principles of sustainability. For example, the cleared forest lost most of its plants that had produced food for the forest's animals by using solar energy and that supplied nutrients to the soil when they died. As a result, many of the forest's key nutrients were lost instead of being recycled. And the loss of plants and the resulting loss of animals reduced the life-sustaining biodiversity of the cleared forest.

Humans clear forests to harvest timber, grow crops, build settlements, and expand cities. The key question is, how far can we go in expanding our ecological footprints (see Figure 1-13, p. 14) without threatening the quality of life for our own species and for the other species that help to keep us alive and support our economies? To live more sustainably, we need to find and maintain a balance between preserving undisturbed natural systems and the natural resources and ecosystem services they provide and modifying other natural systems for our use.
Chapter Review

Core Case Study

1. Describe the controlled scientific experiment carried out in the Hubbard Brook Experimental Forest.

Section 2-1

2. What is the key concept for this section? What is science? List the steps involved in a scientific process. What is data? What is a model? Distinguish among a scientific hypothesis, a scientific theory, and a scientific law (law of nature). Summarize Jane Goodall’s scientific and educational achievements. What is peer review and why is it important?

3. Explain why scientific theories are not to be taken lightly and why people often use the term theory incorrectly. Explain why scientific theories and laws are the most important and most certain results of science.

4. Distinguish among tentative science (frontier science), reliable science, and unreliable science. What are four limitations of science in general and environmental science in particular?

Section 2-2

5. What are the two key concepts for this section? What is matter? Distinguish between an element and a compound and give an example of each. Define atoms, molecules, and ions and give an example of each. What is the atomic theory? Distinguish among protons (p), neutrons (n), and electrons (e). What is the nucleus of an atom? Distinguish between the atomic number and the mass number of an element. What is an isotope? What is acidity? What is pH?

6. What is a chemical formula? Distinguish between organic compounds and inorganic compounds and give an example of each. Distinguish among complex carbohydrates, proteins, nucleic acids, and lipids. What is a cell? Define gene, trait, and chromosome.

7. Define and distinguish between a physical change and a chemical change (chemical reaction) and give an example of each. What is a nuclear change? Define and explain the differences among natural radioactive decay, nuclear fission, and nuclear fusion. What is the law of conservation of matter and why is it important?

Section 2-3

8. What are the two key concepts for this section? What is energy? Distinguish between kinetic energy and potential energy and give an example of each. What is heat (thermal energy)? Define and give two examples of electromagnetic radiation. Define and distinguish between renewable energy and nonrenewable energy. What are fossil fuels and how are they formed? Why are they nonrenewable? What is energy quality? Distinguish between high-quality energy and low-quality energy and give an example of each. What is the first law of thermodynamics (law of conservation of energy) and why is it important? What is the second law of thermodynamics and why is it important? Explain why the second law means that we can never recycle or reuse high-quality energy.

9. Define and give an example of a system. Distinguish among the inputs, flows (throughputs), and outputs of a system. Why are scientific models useful? What is feedback? What is a feedback loop? Distinguish between a positive feedback loop and a negative (corrective) feedback loop in a system, and give an example of each. Define time delay and synergistic interaction (synergy), give an example of each, and explain how they can affect systems. What is a tipping point?

10. What are this chapter’s three big ideas? Explain how the Hubbard Brook Experimental Forest controlled experiments illustrated the three scientific principles of sustainability.

Note: Key terms are in bold type.

Critical Thinking

1. What ecological lesson can we learn from the controlled experiment on the clearing of forests described in the Core Case Study that opened this chapter?

2. Suppose you observe that all of the fish in a pond have disappeared. Describe how you might use the scientific process described in the Core Case Study and in Figure 2-2 to determine the cause of this fish kill.

3. Respond to the following statements:
   a. Scientists have not absolutely proven that anyone has ever died from smoking cigarettes.
   b. The natural greenhouse effect theory—that certain gases such as water vapor and carbon dioxide help to warm the lower atmosphere—is not a reliable idea because it is just a scientific theory.
4. A tree grows and increases its mass. Explain why this is not a violation of the law of conservation of matter.

5. If there is no "away" where organisms can get rid of their wastes, due to the law of conservation of matter, why is the world not filled with waste matter?

6. Suppose someone wants you to invest money in an automobile engine, claiming that it will produce more energy than is found in the fuel used to run it. What would be your response? Explain.

7. Use the second law of thermodynamics to explain why we can use oil only once as a fuel, or in other words, why we cannot recycle its high-quality energy.

8. Imagine that for one day (a) you have the power to revoke the law of conservation of matter, and (b) you have the power to violate the first law of thermodynamics. For each of these scenarios, list three ways in which you would use your new power. Explain your choices.

**Doing Environmental Science**

Find (a) a newspaper or magazine article or a report on the Web that attempts to discredit a scientific hypothesis because it has not been proven, or (b) a report of a new scientific hypothesis that has the potential to be controversial. Analyze the piece by doing the following: (1) determine its source (author or organization); (2) detect an alternative hypothesis, if any, that is offered by the author; (3) determine the primary objective of the author (for example, to debunk the original hypothesis, to state an alternative hypothesis, or to raise new questions, and so on); (4) summarize the evidence given by the author(s) for his or her position; and (5) compare the authors' evidence with the evidence for the original hypothesis. Write a report summarizing your analysis and compare it with those of your classmates.

**Global Environment Watch Exercise**

Search Easter Island and under the "News" section, click on "View All." Read current articles on what happened on Easter Island and explain in your own words whether or not the Easter Islanders were living sustainably. How could they have changed their ways in order to live more sustainably in their environment?

**Data Analysis**

Consider the graph on the right that shows loss of calcium from the experimental cutover site of the Hubbard Brook Experimental Forest (Core Case Study) compared with that of the control site. Note that this figure is very similar to Figure 2.5, which compares loss of nitrates from the two sites. After studying this graph, answer the questions below.

1. In what year did the calcium loss from the experimental site begin a sharp increase? In what year did it peak? In what year did it again level off?

2. In what year were the calcium losses from the two sites closest together? In the span of time between 1963 and 1972, did they ever get that close again?

3. Does this graph support the hypothesis that cutting the trees from a forested area causes the area to lose nutrients more quickly than leaving the trees in place? Explain.