Solution Manual for Living in the Environment 18th Edition by G. Tyler Miller and Scott Spoolman

Chapter 2

Science, Matter, Energy, and Systems

Chapter Outline

CORE CASE STUDY How Do Scientists Learn about Nature? Experimenting with a Forest
2-1 What Do Scientists Do?
Individuals matter Jane Goodall: Chimpanzee Researcher and Protector
SCIENCE FOCUS Some Revisions in a Popular Scientific Hypothesis
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?
SCIENCE FOCUS The Usefulness of Models
TYING IT ALL TOGETHER The Hubbard Brook Forest Experiment and Sustainability

Key Concepts

2-1 Scientists collect data and develop hypotheses, theories, models, and laws about how nature works.
2-2A Matter consists of elements and compounds, which in turn are made up of atoms, ions, or molecules.
2-2B Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).

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).
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-usable energy than we started with (second law of thermodynamics).
2-4 Systems have inputs, flows, and outputs of matter and energy, and feedback can affect their behavior.

Key Questions and Case Studies

CORE CASE STUDY: How Do Scientists Learn about Nature? Experimenting with a Forest

Controlled experiments involve an experimental group, in which a known variable is changed, and a control group, in which the variable is not changed. The example involves two drainages that were dammed. One was deforested and one left forested. The deforested landscape showed an increase in erosion and an increase in water flow carrying dissolved nutrients.

2-1 What do scientists do?

A. Scientists use the scientific method to study and understand the patterns in the natural world.
   1. Identify the problem.
   2. Find out what is known about the problem.
   3. Propose a question.
   4. Collect data
   5. Suggest a hypothesis (possible explanation).
   6. Make testable projections
   7. Test with further experiments, models or observations.
      a. Models are approximate representations of a system.
   8. Support or reject the hypothesis.

B. Scientists develop a scientific theory on a well-tested and widely accepted scientific hypothesis.

C. Four important features of the scientific process are curiosity, skepticism, reproducibility, and peer review.

D. Scientists use critical thinking, which entails three main steps:
   1. Be skeptical.
   2. Evaluate available evidence.
   3. Identify and evaluate personal assumptions.
      a. Imagination and creativity are equally important in science.

SCIENCE FOCUS: Some Revisions in a Popular Scientific Hypothesis

An example of how a once accepted hypothesis has been replaced as a result of new evidence.

E. Scientific laws are widely accepted descriptions of phenomena we find happening repeatedly in nature.

F. Science is repeatedly tested.
   1. Frontier science is scientific results that have not been confirmed; reliable science is derived from scientific results that have been well tested and are widely accepted.
   2. Unreliable science has not undergone peer review, or has been discredited.

G. Science has limitations.
   1. Scientists can disprove things, but not prove anything absolutely.
   2. Scientists are sometimes biased.
   3. Environmental phenomena often involve a multitude of interacting variables.
   4. Environmental scientists often rely on estimates based on statistical sampling and other mathematical methods.
   5. Science is limited to understanding the natural world and cannot be applied to morals or ethics.

2-2 What is matter?

A. Matter is anything that has mass and takes up space, living or not. It comes in chemical forms, as an element or a compound.
   1. An element is the distinctive building block that makes up every substance.
   2. Chemists classify elements by their chemical behavior by arranging them in a periodic table of elements.

B. The building blocks of matter are atoms, ions, and molecules.
   1. An atom is the smallest unit of matter that exhibits the characteristics of an element.
   2. An ion is an electrically charged atom or combinations of atoms.
   3. A molecule is a combination of two or more atoms/ions of elements held together by chemical bonds.

C. Each atom has a nucleus containing protons and neutrons. Electron(s) orbit the nucleus of an atom.
   1. A proton (p) is positively charged, a neutron (n) is uncharged, and the electron (e) is negatively charged.
   2. Each atom has an equal number of positively charged protons in the nucleus and negatively charged electrons outside the nucleus, so the atom has no net electrical charge.

3. Each element has a specific atomic number that is equal to the number of protons in the nucleus.
4. The mass number of an atom equals the total number of neutrons and protons in its nucleus.
5. Isotopes are various forms of an element that have the same atomic number, but different mass number.

D. Atoms of some elements can lose or gain one or more electrons to form ions with positive or negative electrical charges.
1. Elements known as metals tend to lose one or more electrons; they are electron givers.
2. Elements known as nonmetals tend to gain more electrons; they are known as electron receivers.
3. Hydrogen ions (H+) in a solution are a measure of how acidic or basic the solution is. Neutral pH is 7, acid solutions are below 7, and basic solutions are above 7.

E. Chemical formulas are a type of shorthand to show the type and number of atoms/ions in a compound.
1. Ionic compounds are made up of oppositely charged ions, (Na^+ and Cl^-).
2. Compounds made of uncharged atoms are called covalent compounds (CH_4).

F. Organic compounds contain carbon atoms combined with one another and with various other atoms.
1. Hydrocarbons: compounds of carbon and hydrogen atoms.
2. Chlorinated hydrocarbons: compounds of carbon, hydrogen, and chlorine atoms.
3. Simple carbohydrates: specific types of compounds of carbon, hydrogen, and oxygen atoms.

G. Polymers are larger and more complex organic compounds that have molecular units.
1. Complex carbohydrates contain two or more monomers of simple sugars linked together.
2. Proteins are formed by linking monomers of amino acids together.
3. Nucleic acids are made of sequences of nucleotides linked together.
4. Lipids are a fourth type of macromolecule.

H. Cells are the fundamental structural and functional unit of life.
1. Genes: specific sequences of nucleotides in a DNA molecule.
2. Chromosomes: combinations of genes that make a single DNA molecule, plus some proteins.

I. All compounds without the combination of carbon atoms and other elements' atoms are inorganic compounds.

J. As a resource, matter is classified as having high or low quality.
   1. High-quality matter is concentrated with great potential for usefulness and is usually found near the earth's surface.
   2. Low-quality matter is dilute and found deep underground and/or dispersed in air or water.

2-3 What happens when matter undergoes change?

A. When matter has a physical change, its chemical composition is not changed; the molecules are organized in different patterns.

B. In a chemical change or reaction, the chemical composition of the elements/compounds change.
   1. Nuclear change occurs in three ways: radioactive decay, nuclear fission and nuclear fusion.

C. The Law of Conservation of Matter states that no atoms are created/destroyed during a physical or chemical change.

2-4 What is energy and what happens when it undergoes change?

A. Energy is the capacity to do work and transfer heat; it moves matter.
   1. Kinetic energy has mass and speed: wind, electricity are examples. Heat is also kinetic energy.
   2. Electromagnetic radiation is energy that travels as a wave, a result of changing electric and magnetic fields.
      a. Each form of electromagnetic radiation has a different wavelength and energy content.
   3. Potential energy is stored energy.
      a. Potential energy can be changed into kinetic energy.

B. 99% of all energy on earth is solar; commercial energy in the marketplace makes up the remaining 1%, primarily derived from fossil fuels.

C. Energy quality is measured by its usefulness; high energy is concentrated and has high usefulness. Low energy is dispersed and can do little work.

D. The First Law of Thermodynamics states that energy can neither be created/destroyed, but can be converted from one form to another.

E. The Second Law of Thermodynamics states that when energy is changed from one form to another, there is always less usable energy. Energy quality is depleted.
   1. In changing forms of energy, there is a loss in energy quality; heat is often produced and lost.
   2. Changing forms of energy produces a small percentage of useful energy; much is lost in the process.
   3. High-quality energy cannot be recycled/reused.

2-5 What are systems and how do they respond to change?

A. A system is a set of components that interact.

SCIENCE FOCUS: The Usefulness of Models

Models or simulations are used to learn how systems work, particularly when dealing with many variable, very long timeframes or situations where controlled experiments are not possible.

1. Most systems have inputs from the environment, throughputs of matter and energy within the system, and outputs to the environment.
2. Systems are affected by feedback and feedback loops (positive and negative).
3. Systems often show time delays between input and response.
4. Problems can build slowly in systems until reaching a tipping point.
5. Synergy involves processes interacting such that the combined effect is greater than the individual effects.

Teaching Tips

Large Lecture Courses:

Brainstorm ways in which the first law of thermodynamics might be applicable to daily life. You might begin with respiration and homeostasis, or jump straight into transportation and fuel costs. Bring in typical levels of efficiency for the internal combustion engine, and let the students calculate roughly how much of the money they spend on transportation actually is applied to mobility. Explain that most of the energy is dissipated as heat, and then compare with the efficiency of mass transit. This is a good opportunity to tie these concepts in to issues that are relevant to the students' lives.

Smaller Lecture Courses:

Focus on experimental design and the scientific method by proposing a hypothetical situation (or perhaps a real one, from the local environment). Think of a problem or issue, such as vegetation change, pollution, a proposed dam or quarry, etc. Ask the students to form small groups and discuss how they might set up an experiment and control, and what variables would be most relevant to the experiment given the issue you presented. As an entire class, explore the perplexing issues that arise in environmental field studies when other factors and interactions within the system influence your study.

Key Terms

acidity
atomic number
atom
atomic theory
cells
chemical change
chemical element
chemical formula
chemical reaction
chromosome
compounds
data
electromagnetic radiation
electrons
elements
energy
energy quality
feedback
feedback loop
first law of thermodynamics
flows
fossil fuels
frontier science
genes
heat
high-quality energy
high-quality matter
inorganic compounds
inputs
ion
isotopes
kinetic energy
law of conservation of energy
law of conservation of matter
low-quality energy
low-quality matter
mass number
matter
matter quality
model
molecule
negative feedback loop
neutrons
nuclear change
nucleus
organic compounds
peer review
pH
physical change
positive feedback loop
potential energy
protons
reliable science
science
scientific hypothesis
scientific (natural) law
scientific theory
second law of thermodynamics
synergistic interaction
synergy
system
throughputs
time delay
tipping point

Term Paper Research Topics

1. The Nature of Science: questions, hypotheses, theories, laws, scientific methods, inductive and deductive reasoning.

2. Technology: applications of science to cultures; appropriate technologies; from the wheel to the assembly line; engines and the transportation revolution; computers and the Age of Information; the information superhighway.

3. Computer modeling: extending the power of the human brain; systems analysis; the consequences of feedback loops; the implications of chaos, homeostasis, delays, leverage, and synergy.

4. The universe: total amounts of matter and energy in the universe; the big bang theory of the origin of the universe; the role of entropy in the destiny of the universe.

5. Low-energy lifestyles: individual case studies such as Amory Lovins, and national case studies such as Sweden.

6. Nature's cycles and economics: recycling attempts in the United States; bottlenecks that inhibit recycling; strategies that successfully enhance recycling efforts.

7. Individual: Analyze your own body and lifestyle as a system with material and energy inputs and outputs. Try to identify dangerous positive feedback loops. Design strategies that can help bring your body and life into balance.

8. Community: Analyze the community in which you live as a system with material and energy inputs and outputs. Identify community services and agencies responsible for inputs and outputs. Try to identify dangerous positive feedback loops. Design strategies that can help bring your community into balance.

9. National: Analyze the country in which you live as a system with material and energy inputs and outputs. Identify national services and agencies responsible for inputs and outputs. Try to identify dangerous positive feedback loops. Design strategies that can help bring your nation into balance. Explore the concept of the information superhighway. Consider its usefulness in addressing national issues of sustainability.

10. Global: Analyze the earth as a system with material and energy inputs and outputs. Identify global services and agencies responsible for inputs and outputs. Try to identify dangerous positive feedback loops. Design strategies that can help bring the earth into balance. Explore the concept of global networking. Find out more about the networking results of the Rio Conference. Consider the usefulness of such networking in addressing global issues of sustainability.

Discussion Topics

1. Describe scientific methods, particularly in the application of critical thinking and creative thinking to the scientific enterprise.

2. What is the role of models in the scientific experience?

3. What are the effects of delays, leverage, and synergism in complex systems?

4. Evaluate the positive and negative contributions of nuclear technologies: nuclear weapons in World War II and the Cold War; radioisotopes in research and medical technology; and nuclear power plants.

5. How much are you willing to pay in the short run to receive economic and environmental benefits in the long run? Explore costs and payback times of energy efficient appliances, energy saving light bulbs, and weather stripping.

6. Is convenience more important than sustainability? Explore the influence of the U.S. frontier origins on the throwaway mentality.

Activities and Projects

1. Ask a systems analyst to visit your classroom. Work with the analyst to produce a class consensus model of the environment.

2. As a class exercise, try to inventory the types of environmental disorders that are created in order to maintain a classroom environment—the lighting, space heating and cooling, electricity for projectors, and other facilities, equipment, and services.

3. Ask an ecologist, a pollution treatment technologist (for instance a technologist who designs sewage treatment equipment) and a worker in pollution prevention to visit your class. Ask the types of questions and problems that concern them. Consider the role that each of these thinkers plays in an ecosystem model.

4. As a class exercise, make lists of the beneficial and harmful consequences that have resulted from America's adoption of automobile technology.

5. Ask a physics professor or physics lab instructor to visit your class and, by using simple experiments, demonstrate the matter and energy laws.

6. As a class exercise, try to inventory the types of environmental disorders that are created in order to maintain a classroom environment—the lighting, space heating and cooling, electricity for projectors, and other facilities, equipment, and services.

7. Invite a medical technician to speak to your class on the beneficial uses of ionizing radiation. What controls are employed to limit the risks associated with the use of radioisotopes for diagnostic and treatment procedures?

8. Use *Green Lives/Green Campuses* as a starting point for analyzing your campus as a system. This is an excellent opportunity to view the campus as an interacting system of material and energy flows governed by human policies as well as to enhance the democratic and team skills of your students. The goal would be to complete a full environmental assessment of the campus with recommendations to move toward a sustainable future. Each student or small group of students could be held accountable for one part of the assessment.

9. A human body at rest yields heat at about the same rate as a 100-watt incandescent light bulb. As a class exercise, calculate the heat production of the student body of your school, the U.S. population, and the global population. Where does the heat come from? Where does it go?

10. As a class exercise, conduct a survey of the students at your school to determine their degree of awareness and understanding of the three basic matter and energy laws. Discuss the results in the context of high-waste, recycling, and low-waste societies.

Attitudes and Values

1. How does it feel to essentially be a system made of inputs, flows, and feedbacks?

2. How does it feel to imagine being one component of a larger system made up of inputs, flows, and feedbacks?

3. How does science contribute to your quality of life? What are its limits?

4. How does technology contribute to your quality of life? What are its limits?

5. Do you feel a part of the flow of energy from the sun?

6. Do you feel you play a role in nature's cycles?

7. What right do you have to use the earth's material resources? Are there any limits to your rights? What are they?

8. What rights do you have to the earth's energy resources? Are there any limits to your rights? What are they?

9. Do you believe that cycles of matter and energy flow from the sun have anything to do with your lifestyle? With your country's policies?

Suggested Answers to End of Chapter Questions

Review Questions

1. Core case study. Describe the controlled scientific experiment carried out at the Hubbard Brook Experimental Forest.
   - Scientists compared the loss of water and nutrients from an uncut forest ecosystem (the control site) with one that was stripped of its trees (the experimental site) in the Hubbard Brook Experimental Forest in New Hampshire. First, the investigators measured the amounts of water and dissolved plant nutrients that entered and left an undisturbed forested area (the control site). They found that an undisturbed mature forest is very efficient at storing water and retaining chemical nutrients in its soils. Then the scientists set up an experimental forested area; they cut down all trees and shrubs in one valley (the experimental site) and sprayed the area with herbicides to prevent regrowth. They compared the inflow and outflow of water and

nutrients in this experimental site with those in the control site for three years. 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 deforested site. Overall, the loss of key nutrients from the experimental forest was six to eight times that in the nearby control forest.

2. Section 2-1. What is the key concept for this section? What is science? Describe the steps involved in the scientific process. What is data? What is a model? Distinguish among a scientific hypothesis, scientific theory, and scientific law (law of nature). Summarize Jane Goodall's scientific and educational achievements. What is peer review and why is it important?
   - Key concept: Scientists collect data and develop hypotheses, theories, models, and laws about how nature works.
   - Science is an attempt to discover how nature works and to use that knowledge to make predictions about what is likely to happen in nature.
   - There are a number of steps in the scientific method. A scientist will use the following procedure to study the natural world.
     - Identify a problem.
     - Find out what is known about the problem. A scientist will search the scientific literature to find out what was known about the area of interest.
     - Ask a question to be investigated.
     - Collect data to answer the question. To collect data— information needed to answer their questions— scientists make observations of the subject area they are studying. Scientific observations involve gathering information by using human senses of sight, smell, hearing, and touch and extending those senses by using tools such as rulers, microscopes, and satellites. Often scientists conduct experiments, or procedures carried out under controlled conditions to gather information and test ideas.
     - Propose a hypothesis to explain the data. Scientists suggest a scientific hypothesis, a possible and test-able explanation of what they observe in nature or in the results of their experiments.
     - Make testable predictions. Scientists use a hypothesis to make testable or logical predictions about what should happen if the

hypothesis is valid. They often do this by making “ If . . . then” predictions.
    - Test the predictions with further experiments, models, or observations. These predictions can be compared with the actual measured losses to test the validity of the models.
    - Accept or reject the hypothesis. If their new data do not support their hypotheses, scientists come up with other testable explanations. This process continues until there is general agreement among scientists in the field being studied that a particular hypothesis is the best explanation of the data.
- Data is the information needed to answer scientific questions usually obtained by making observations and measurements.
- A model is an approximate representation or simulation of a system being studied.
- Scientific hypothesis is a possible and testable explanation of what is observed in nature or in the results of experiments. A well-tested and widely accepted scientific hypothesis or a group of related hypotheses is called a scientific theory. A scientific law, or law of nature is a well-tested and widely accepted description of what we find happening in nature.
- Jane Goodall has researched chimpanzees. She discovered that chimps have more complex social interactions than had previously been known. She discovered that chimps also make and use tools. She established the Jane Goodall Institute to preserve great ape populations and habitats. She also started Roots and Shoots, an environmental education program that is active in more than 100 countries.
- An important part of the scientific process is peer review, in which scientists openly publish details of the methods and models 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. And any evidence gathered to verify a hypothesis must be reproducible. That is, scientists should repeat and analyze the work to see if the data can be reproduced and whether the proposed hypothesis is reasonable and useful.

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.

- A scientific theory should be taken very seriously. It has been tested widely, supported by extensive evidence, and accepted by most scientists in a particular field or related fields of study. Nonscientists often use the word theory incorrectly when they actually mean scientific hypothesis, a tentative explanation that needs further evaluation.
  The statement, “Oh, that’s just a theory,” made in everyday conversation, implies that the theory was stated without proper investigation and careful testing—the opposite of the scientific meaning of the word.
- Scientific theories and laws have a high probability of being valid, but they are not infallible. Occasionally, new discoveries and new ideas can overthrow a well-accepted scientific theory or law in what is called a paradigm shift. This occurs when the majority of scientists in a field or related fields accept a new paradigm, or framework for theories and laws in a particular field.

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?

- Tentative science or frontier science involve preliminary results that capture news headlines and may be controversial because they have not been widely tested and accepted by peer review yet. Reliable science consists of data, hypotheses, theories, and laws that are widely accepted by all or most of the scientists who are considered experts in the field under study, in what is referred to as a scientific consensus. The results of reliable science are based on the self-correcting process of testing, peer review, reproducibility, and debate. New evidence and better hypotheses may discredit or alter accepted views. Scientific hypotheses and results that are presented as reliable without having undergone the rigors of peer review, or that have been discarded as a result of peer review, are considered to be unreliable science.
- Environmental science and science in general have three important limitations:

- Scientists cannot prove or disprove anything absolutely, because there is always some degree of uncertainty in scientific measurements, observations, and models.
- A limitation of science is that scientists are human and thus are not totally free of bias about their own results and hypotheses.
- A limitation—especially important to environmental science—is that many environmental phenomena involve a huge number of interacting variables and complex interactions.
- Another limitation is the use of statistical tools.

5. Section 2-2. 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. Distinguish among atoms, molecules, and ions and give an example of each. What is the atomic theory? Distinguish among protons, neutrons, and electrons. 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?
   - Key concepts: Matter consists of elements and compounds, which in turn are made up of atoms, ions, or molecules. Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).
   - 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.
   - A chemical element is a fundamental substance that has a unique set of properties and cannot be broken down into simpler substances by chemical means. Compounds are a combination of two or more different elements held together in fixed proportions.
   - 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 characteristic chemical properties, such as a single hydrogen atom. A second building block of some types of matter is an ion—an atom or group of atoms with one or more net positive (+) or negative (–) electrical charges, such as H^+. A molecule is a combination of two or more atoms of the same elements held together by forces called chemical bonds, such as O_2, oxygen.
   - The atomic theory is the idea that all elements are made up of atoms.

- Three different types of subatomic particles: positively charged protons (p), neutrons (n) with no electrical charge, and negatively charged electrons (e).
- Each atom consists of an extremely small and dense center called its nucleus—which contains one or more protons and, in most cases, one or more neutrons— and one or more electrons moving rapidly somewhere around the nucleus.

- Each atom has equal numbers of positively charged protons and negatively charged electrons. Because these electrical charges cancel one another, atoms as a whole have no net electrical charge. Each element has a unique atomic number, equal to the number of protons in the nucleus of its atom. The mass of an atom is described by its mass number: the total number of neutrons and protons in its nucleus.
- Forms of an element having the same atomic number but different mass numbers are called isotopes of that element.
- 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.
- Scientists use pH as a measure of acidity, based on the amount of hydrogen ions (H+) and hydroxide ions (OH–) contained in a particular volume of a solution.

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? Distinguish among a gene, a trait, and a chromosome.
    - Chemists use a chemical formula to show the number of each type of atom or ion in a compound.
    - Organic compounds contain at least two carbon atoms combined with atoms of one or more other element, such as table sugar and methane. All other compounds, except methane (CH_4), are called inorganic compounds, such water.
    - Complex carbohydrates, such as cellulose and starch, consist of two or more monomers of simple sugars, such as glucose.
    - Proteins are formed by monomers called amino acids.

- Nucleic acids (DNA and RNA) are formed by monomers called nucleotides.
- Lipids, which include fats and waxes, are not all made of monomers, but are a fourth type of macromolecule essential for life.
- Cells are the smallest and most fundamental structural and functional units of life.
- Within some DNA molecules are certain sequences of nucleotides called genes. Each of these distinct pieces of DNA contains instructions, called genetic information, for making specific proteins. Each of these coded units of genetic information concerns a specific trait, or characteristic, passed on from parents to offspring during reproduction in most animals or plants. Thousands of genes, in turn, make up a single chromosome, a special DNA molecule together with a number of proteins.

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?
    - 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 a chemical change, or chemical reaction, takes place there is a change in chemical composition of the substances involved. Chemists use a chemical equation to show what happens in a chemical reaction. For example, when coal burns completely, the solid carbon (C) in the coal combines with oxygen gas (O_2) from the atmosphere to form the gaseous compound carbon dioxide (CO_2).
    - Nuclear change is the process in which nuclei of certain isotopes spontaneously change, or are forced to change, into one or more different isotopes.
    - 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 plus two or three more neutrons.
    - Nuclear fusion occurs when two isotopes of light elements, 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.

- The law of conservation of matter states whenever matter undergoes a physical or chemical change, no atoms are created or destroyed. This law helps us understand that we need to let our waste cycle back to its original nutrients/products in order for our resources to be sustainable.

8. Section 2-3. 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.
    - Key concepts: 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). 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 (second law of thermodynamics).
    - Energy is the capacity to do work or transfer heat.
    - There are two major types of energy: moving energy (called kinetic energy) and stored energy (called potential energy). Examples of kinetic energy include wind (a moving mass of air), flowing water, and electricity (flowing electrons). An example of potential energy is gasoline.
    - Heat is a form of kinetic energy, the total kinetic energy of all moving atoms, ions, or molecules within a given substance. When two objects at different temperatures contact one another, heat flows from the warmer object to the cooler object.
    - Electromagnetic radiation is energy that travels in the form of a wave as a result of changes in electrical and magnetic fields. Forms of electromagnetic radiation are short wavelengths such as gamma rays and x-rays.
    - Renewable energy is energy gained from resources that are replenished by natural processes in a relatively short time. Nonrenewable energy is energy from resources that can be depleted

and are not replenished by natural processes within a human time scale.

- Fossil fuels are ancient deposits of organic matter 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. The three most widely used fossil fuels are oil, coal, and natural gas. Fossil fuels are nonrenewable because it takes millions of years for them to form.
- Energy quality is a measure of an energy source's capacity to do useful work.
- High-quality energy is concentrated and has a high capacity to do useful work. Examples are very high-temperature heat, nuclear fission, concentrated sunlight, high-velocity wind, and energy released by burning natural gas, gasoline, or coal.
- Low-quality energy is dispersed and has little capacity to do useful work. An example is heat dispersed in the moving molecules of a large amount of matter (such as the atmosphere or an ocean) so that its temperature is low.

- The first law of thermodynamics, also known as the law of conservation of energy, states that whenever energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed. 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 because energy input always equals energy output.
- The second law of thermodynamics states that when energy is changed from one form to another, it always goes from a more useful to a less useful form.
- We can never recycle or reuse high-quality energy because whenever energy is converted from one form to another, we always end up with a lower quality or less "usable" energy than we started with.

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. Distinguish between a time delay

and a synergistic interaction (synergy) in a system and give an example of each. What is a tipping point?

- 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 from the environment, flows or throughputs of matter and energy within the system at certain rates, and outputs to the environment.
- Scientists use models, or simulations, to learn how systems work. Some of our most powerful and useful technologies are mathematical and computer models.
- Most systems are affected by feedback, any process that increases or decreases a change to a system. 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.
- A positive feedback loop causes a system to change further in the same direction. For example, in the Hubbard Brook experiments, researchers found that when vegetation was removed from a stream valley, flowing water from precipitation caused erosion and loss 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 is exposed to sunlight. Because water is darker, it absorbs more solar energy, making the area warmer and causing the ice to melt faster, thus exposing more water. The melting of polar ice thus accelerates.
- A negative, or corrective, feedback loop causes a system to change in the opposite direction from which is it moving. A simple example is a thermostat, a device that controls how often, and how long a heating or cooling system runs. When the furnace in a house is turned on and begins heating the house, the thermostat can be set to turn the furnace off when the temperature in the house reaches the set number. The house then stops getting warmer and starts to cool.

- Complex systems often show time delays between the input of a feedback stimulus and the 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, but it would take years for the trees and other vegetation to grow enough to accomplish this purpose.
- 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.
- Scientific studies reveal such an interaction between smoking and inhaling asbestos particles. For example, lifetime smokers have ten times the risk that nonsmokers have of getting lung cancer. And individuals exposed to asbestos particles for long periods increase their risk of get-ting lung cancer fivefold. But people who smoke and are exposed to asbestos have 50 times the risk that non-smokers have of getting lung cancer.
- Time delays can also allow an environmental problem to build slowly until it reaches a threshold level, or tipping point, causing a fundamental shift in the behavior of a system.

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.
    - The three big ideas are that we cannot do away with matter, we cannot get more energy out than we put in, and 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.
    - 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. 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. The loss of vegetation also violated the other three scientific principles of sustainability. For example, the cleared forest had fewer plants that could use solar energy to produce food for animals. And the loss of plants and animals reduced the life-sustaining biodiversity of the cleared forest. This in turn reduced some of the interactions between different types of plants and animals that help control their populations.

Critical Thinking

The following are examples of the material that should be contained in possible student answers to the end of chapter Critical Thinking questions. They represent only a summary overview and serve to highlight the core concepts that are addressed in the text. It should be anticipated that the students will provide more in-depth and detailed responses to the questions depending on an individual instructor's stated expectations.

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

   Vegetation controls water and nutrient loss from ecosystems. Loss of vegetation diminishes the systems' ability to retain nutrients and water.

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.

   The answer should begin with some observation that can lead to a hypothesis. An observation could be something like increased runoff, increased pollutants, decrease in vegetation or biodiversity, etc.

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) warm the atmosphere—is not a reliable idea because it is just a scientific theory.

   (a) The medical and scientific evidence that links smoking to premature death caused by a number of pathological conditions is overwhelming. As we are exposed to many chemical hazards in our environment it is often difficult to specifically link the cause and effect. The chances of an individual dieing from smoking one cigarette is statistically negligible and highly unlikely, but many years of heavy smoking has a much higher probability that death could result from a disease brought on as a result of smoking.

   (b) Sometimes people with a limited knowledge of the scientific method often confuse a theory with a hypothesis. A theory has been widely tested and is endorsed by a wide group of scientists working in that particular field of study. Many scientists concur with the scientific evidence, obtained through conducting controlled experiments, that water and carbon dioxide are greenhouse gases.

4. A tree grows and increases its mass. Explain why this phenomenon is not a violation of the law of conservation of matter.

   The growth of a tree is an example of a chemical change or chemical reaction. Small inorganic elements and compounds are combined to form more complex molecules that make up the material found in the tree. The components that were present in the soil and air have been rearranged to form other types of chemical components. The amount of material that was present before this rearrangement or chemical change took place is the same as the amount afterwards. A student may discuss photosynthesis to support and explain their answer.

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

   Just like when small molecules are combined to form larger compounds, as in the case of the growth of a tree, when larger compounds are broken down they release smaller molecules back into the environment. An example is that of a rotting log. A tree limb may break off and fall to the forest floor. Over a period of time it is decomposed by a variety of organisms and the materials contained in the log return once again into the environment. In this way nature recycles all matter that exists in the environment. The student may discuss cell respiration to support or explain their answer.

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

   That is not a good investment! The first law of thermodynamics states that energy can be changed from one form to another (such as chemical energy into mechanical energy), but energy cannot be created or destroyed. An engine that produces more energy than it consumes is simply not a feasible scientifically sound prospect.

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.

   The second law of thermodynamics states that when energy changes from one form to another, some of the useful energy is always degraded to lower-quality, more dispersed, less useful energy. When a barrel of oil that contains high-quality chemical energy is used as a fuel in order to do useful work, it is transformed or changed into low-quality energy such as heat, which has little ability to do useful work. Therefore the barrel of oil can only be used once as a fuel.

9. 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.

   (a) Student answers will vary but could include the following: make more oil to offset the world shortage; produce more water to supply areas that desperately need it; transform all chemical pollutants into useful materials that are not harmful.

   (b) Student answers will vary but could include the following: grow more crops to provide food; produce electricity that can be stored in batteries for later use; physically change more of the water in the Arctic Ocean into sea ice to offset the losses that have occurred in the past few decades.

<u>Data Analysis</u>

Consider the graph 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 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?
    - 1965-1966
    - 1967-1968
    - 1971-1972
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?
    - 1964-1965
    - No.
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.
    - Yes, this data supports the hypothesis that the cutover area had an increase in nutrient loss from the site. The data shows that nutrient loss then began to decline over time as the vegetation began growing again.