SCIENCE

Matter and Energy

Second Edition

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SCIENCE / HEALTH SERIES

Science: Matter and Energy
Second Edition

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Contents

UNIT 4: Chemistry

How to Use This Text

Science: Matter and Energy has many features designed to make your study of physical science interesting and beneficial.

Interesting Content

The Table of Contents gives you an overview of what you will study this year. You will begin by learning the methods scientists use to discover facts about nature and the role of measurement in the physical sciences. Next, you will study how forces affect matter and how motion and forces, both at the visible level and the microscopic level, transfer energy. You will continue by learning about the relationship between electricity and magnetism and about the different ways that God has allowed us to use this relationship for our benefit. Next, you will learn about the chemical principles that not only underlie the manufacture and operation of things like plastics and batteries but also allow life itself to exist. The year will conclude with a brief discussion of the origins of the universe, the earth, and life, showing how evidence from physics and chemistry contradict evolutionary ideas but agree with the biblical teaching that God created all things in six literal days.

Illustrations enhance interest and understanding.

A sentence or phrase in italics is an important concept or definition of which to take particular note.

Italic terms guide you in following the logic of the text or highlight connections to previous chapters.

Pronunciations of unusual or unfamiliar words are given at first use; a pronunciation key is on p. 419.

Mastering key terms in bold will help you understand concepts and prepare for quizzes and tests.

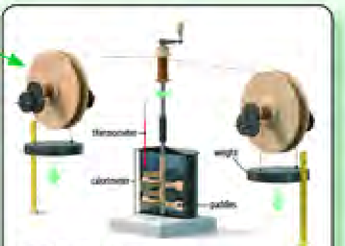


Fig. 6.18 Joule's paddle experiment

gained (or lost) by a system is equal to the energy lost (or gained) by its surroundings; *the first law of thermodynamics is a practical restatement of the law of conservation of energy.* In Joule's paddle experiment, the water in the calorimeter can be considered the system. The falling weights were part of the surroundings, and the only part that had a significant effect on the system. The thermal energy gained by the water (system) equals the mechanical energy lost by the falling weights (surroundings).

Second Law of Thermodynamics

In 1824, Sadi Carnot (sä·dē′ kär·nō′, 1796–1832), a French soldier-scientist, published "Reflections on the Motive Power of Heat," a milestone in the study of thermodynamics. Because of this paper, Carnot *is sometimes considered the founder of the science of thermodynamics.*

As Carnot studied steam engines, he noted that heat was transferred to water, making the water evaporate into steam. As the steam expanded, it did work (such as pushing a piston) and gave up some of its thermal energy. Carnot's research of this process led him to conclude that *mechanical energy can be produced from thermal energy as heat flows from a high-temperature source to a low-temperature receiver.* Carnot used this principle to design the **Carnot engine**, a theoretical device that would generate the maximum possible amount of work from a given amount of heat.

Study Aids

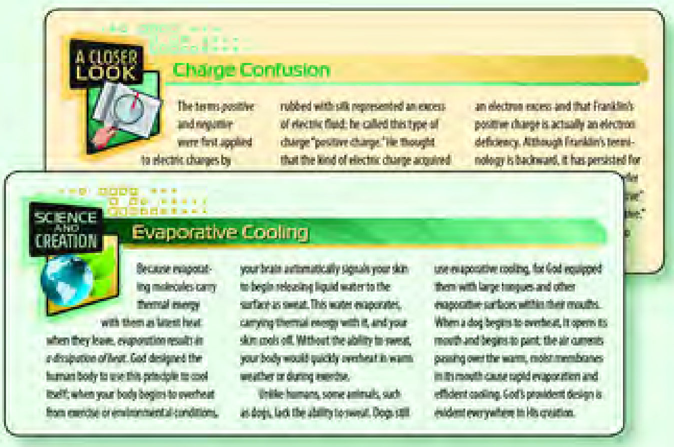
Throughout the text, the most important terms and concepts are marked using bold or italic text. Pronunciations are also given for many terms. In the back of the book, you will find a **Reference Section** with unit conversions, key symbols, and the periodic table (p. 414); a **Glossary** of key terms and definitions (p. 419); and an **Index** listing all references to the major topics (p. 436).

Accurate, Detailed Illustrations

Every photograph and diagram in this book was chosen to enhance your interest in and understanding of the written text. When a figure number is given in the text, refer to the indicated figure; other figures are near the text they correspond to. Read the captions and labels of all figures. If a figure is showing a process, trace the process as you read the text.

Feature Articles

This text includes many articles that will enhance your study of science. "A Closer Look" articles present detailed information of various interesting topics to aid your understanding of the text. "Science and Creation" boxes present specific and interesting examples of God's design in nature.


A CLOSER LOOK

Charge Confusion

The terms *positive* and *negative* were first applied to electric charges by … rubbed with silk represented an excess of electric fluid; he called this type of charge "positive charge." He thought that the kind of electric charge acquired … an electron excess and that Franklin's positive charge is actually an electron deficiency. Although Franklin's terminology is backward, it has persisted for …

SCIENCE AND CREATION

Evaporative Cooling

Because evaporating molecules carry thermal energy with them as latent heat when they leave, evaporation results in *a dissipation of heat.* God designed the human body to use this principle to cool itself; when your body begins to overheat from exercise or environmental conditions, your brain automatically signals your skin to begin releasing liquid water to the surface as sweat. This water evaporates, carrying thermal energy with it, and your skin cools off. Without the ability to sweat, your body would quickly overheat in warm weather or during exercise.

Unlike humans, some animals, such as dogs, lack the ability to sweat. Dogs still use evaporative cooling, for God equipped them with large tongues and other evaporative surfaces within their mouths. When a dog begins to overheat, it opens its mouth and begins to pant; the air currents passing over the warm, moist membranes in its mouth cause rapid evaporation and efficient cooling. God's provident design is evident everywhere in His creation.

Practice and Review Questions

Practice boxes give you an opportunity to apply the mathematical aspects of science. **Section reviews** will be useful as you read the text and prepare for quizzes. **Chapter reviews** will help you study for tests.

Christian Perspective

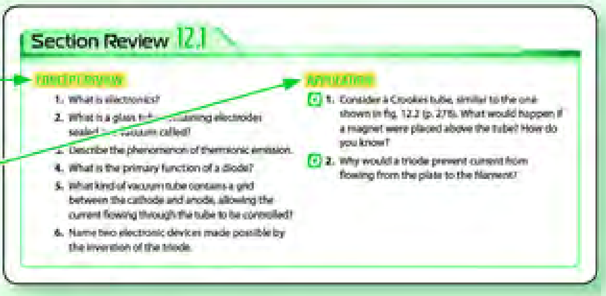
The most important feature of this science textbook is its Christian perspective. The authors believe that the world and all things in it were created exactly as explained in the Bible (Gen. 1, 2) and that the order found in creation is the result of God's wonderful design (Psa. 104). Most of the world's greatest scientists—men like Galileo, Sir Isaac Newton, Robert Boyle, Lord Kelvin, Michael Faraday, Gregor Mendel, Louis Pasteur, Johannes Kepler, and Joseph Lister—worked from this perspective. It is the authors' desire that as you gain a deeper knowledge of the living creation, you will be drawn closer in a personal relationship with the Creator.

STUDY TIPS FOR SCIENCE

- Do your homework right after school, while what you learned is still fresh in your mind.
- Review daily.
- Note key terms and ideas by highlighting them or by recording them in a notebook.
- Summarize or outline the text in your own words.
- Make flashcards of terms and definitions.
- Write review questions and answers. Swap with a friend and answer each other's questions.
- Look for opportunities to apply what you are learning to promote deeper understanding.

Concept Review questions check understanding.

Application questions let you practice calculations and help you develop critical-thinking skills and make connections.



Define key terms.

Identify important characteristics and lists.

Explain terms and concepts.

Apply material to answer critical-thinking questions.

Use math concepts to solve scientific problems.

Critical-thinking questions and problems are marked with a gear icon.

UNIT 2: Energy and Waves

CHAPTER 5 Energy

KEY CONCEPTS

- units of energy
- energy transfers
- conservation of energy
- types of kinetic energy
- potential energy and fundamental forces

Key Symbols and Abbreviations

- *J* joule
- *E* energy
- *m* mass
- *c* speed of light
- *v* speed (magnitude of velocity)
- *g* strength of a gravitational field

5.1 Introduction to Energy

> *It is manifestly absurd to suppose that the powers [energy] with which God has endowed matter can be destroyed any more than that they can be created by man's agency.*
>
> —*James Prescott Joule, "On Matter, Living Force, and Heat"*
>
> (Reprinted in Osborne Reynolds, *Memoir of James Prescott Joule* [Manchester: Manchester Literary and Philosophical Society, 1892], 7.)

Energy is the ability to do work and change matter. Unlike matter, energy cannot be seen, touched, or felt; however, the changes energy causes can be observed. All changes in matter, whether physical or chemical, require energy.

The SI Unit of Energy

Energy cannot be measured directly; it is measured by the amount of change it causes in an object's motion or its physical properties. Since energy is the ability to do work, an amount of energy can be measured by the amount of work it is able to do.

In chapter 3, you learned that the SI unit of work is the **joule** (J), equal to the work done in moving an object a distance of 1 m (39.4 in) by pushing it with a force of 1 N (1 newton; approximately 0.22 lb). Mathematically, this definition can be stated as:

$$1 \text{ joule} = 1 \text{ newton} \times 1 \text{ meter}$$
$$1 \text{ J} = 1 \text{ N} \cdot \text{m}$$

Since 1 N equals 1 $\text{kg} \cdot \text{m/s}^2$, we can also express the joule in terms of the SI base units meter, kilogram, and second:

$$1 \text{ J} = 1\left(\frac{\text{kg} \cdot \text{m}}{\text{s}^2}\right) \cdot \text{m} = 1\ \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2}$$

A CLOSER LOOK: Kinetic Energy and Momentum

In chapter 3, you learned that momentum ($\vec{p}$) is the product of mass and velocity:

$$\vec{p} = m\vec{v}$$

Although both kinetic energy and momentum depend on mass and velocity, they are very different quantities. First, momentum depends on the direction of motion (it is a vector quantity), but kinetic energy does not (it is a scalar quantity). Thus, changing an object's direction of motion changes its momentum but does not change its energy. Also, the vector sum of two objects' momenta may be less than their individual momenta (e.g., if the objects are moving away from each other), but the sum of their kinetic energies will always be greater than either individual kinetic energy.

Second, the total momentum of a system will not change as long as there are no external forces; but the total kinetic energy of a system can be changed by internal forces. For example, when two objects collide, they form a system. Since there are no external forces, the sum of their final momenta will equal the sum of their initial momenta. In most collisions, some kinetic energy is converted to thermal energy, sound energy, and various forms of kinetic energy; although total energy is conserved (as the law of conservation of energy requires), the sum of the objects' kinetic energy is lower after the collision than it was before.

Third, kinetic energy represents how much work a moving object can perform; momentum does not. An object with a greater kinetic energy can transfer more energy to another object, even while momentum is conserved. For example, a parked car bumped by a 30,000 kg (66,000 lb) tractor-trailer traveling at 2 km/h (1.2 mi/h) will be damaged much less than it would be if it were struck by a 1000 kg (2200 lb) car traveling at 60 km/h (37 mi/h). Although both the tractor-trailer and the moving car have the same magnitude of momentum (about 16,700 [kg • m]/s), the tractor-trailer has only $\frac{1}{30}$ of the kinetic energy (4.6 kJ compared to 139 kJ). If both collisions push the parked car 10 m, the tractor-trailer would exert a force of only 460 N (about 104 lb), whereas the lighter but the faster-moving car would exert a force of about 14,000 N (3100 lb).

Practice 5.2

1. An object moving at 10. km/h has a kinetic energy of 10. J. What is the kinetic energy of the same object if it is moving at 20. km/h?
2. At its current speed, a vehicle with a mass of 2.00 Mg has a kinetic energy of 850. kJ. What is the kinetic energy of a 1.00 Mg vehicle moving at the same speed?
3. Calculate the kinetic energy of a 5.0 kg object moving at 4.0 m/s.
4. A box was pushed across a frictionless table 3.2 m long by a force of 250 N. What is its final kinetic energy?

Rotational kinetic energy. An object in *rotational motion* (also called rotary motion) spins or rolls around an internal axis; an example of this is a spinning baseball or a rotating wheel. *Rotational motion is not the same as circular motion:* an object in circular motion changes its position along a circular path, while an object in rotational motion spins in place.

An object may possess both translational and rotational motion (fig. 5.4). For example, a properly bowled bowling ball rolls and spins (rotational

Fig. 5.4 Translational v. rotational motion

Wave energy is energy caused by a disturbance moving through a substance; examples of such disturbances are sound waves, ocean waves, or waves on a rope shaken up and down. The object as a whole remains stationary while parts of it (particles or groups of particles) move back and forth or up and down (fig. 5.6).

Fig. 5.6 Wave energy

Section Review 5.2

CONCEPT REVIEW

1. Define *kinetic energy*.
2. What is the simplest form of kinetic energy?
3. What is the simplest form of motion?
4. What is motion in a circle with the center of the circle outside the object?
5. What four factors affect rotational kinetic energy?

APPLICATION

1. A World War II-era Sherman M4 medium tank had a mass of 30,300 kg and a top speed of 39 km/h. What was its kinetic energy if it was traveling at top speed?
2. A wandering albatross is flying at a speed of 2.8 m/s and has a kinetic energy of 35 J. What is its mass?

5.3 Fundamental Forces and Potential Energy

Potential energy is the energy associated with the position of an object and the forces acting upon it. The type of potential energy an object has depends on the cause of the force. Scientists have identified four **fundamental forces** in nature; these are the natural forces that cause potential energy. Understanding the potential energy that these forces cause requires understanding something about the forces themselves.

The Gravitational Force

The **gravitational force** is an attractive force between all material objects; any object that has mass exerts a gravitational force that pulls nearby objects toward itself. As you learned in chapter 3, the *law of universal gravitation* says that the strength of the gravitational force between two objects is directly proportional to the masses of the two objects and is inversely proportional to the square of the distance between them. The gravitational force weakens quickly but has a theoretically unlimited range; for example, the sun's gravitational force holds the entire solar system together. The gravitational force is the weakest of the four fundamental forces.

It is often convenient to consider a celestial body like Earth as being surrounded by a *gravitational field*. The gravitational field is a model that represents the direction and strength of the body's gravity at every point in space. The direction of a body's gravitational field is always toward the body's center. The strength of a gravitational field is defined as the gravitational force on a much smaller object within the field (the smaller object's weight) divided by the smaller object's mass. According object has from the work needed to move it through another stationary object's electric field. An object's electric potential energy depends on the object's own charge, the strength of the electric field at its location, and the properties of any material separating it from the object producing the electric field.

A charged particle in motion produces a magnetic field that can exert an electromagnetic force on nearby objects. This force causes **magnetic potential energy**, electromagnetic potential energy caused by interacting magnetic fields. Magnetic potential energy is similar to electric potential energy because they are both caused by the electromagnetic force.

Chemical energy is the energy resulting from the chemical combination of atoms into molecules. It can be thought of as the electric potential energy between subatomic particles in molecules. Chemical energy can be released or stored in a chemical reaction. Often, the release of chemical energy is gentle; but it can be explosive under the correct conditions.

When an object is stretched, compressed, bent, sheared, or twisted, a restorative *elastic force* tries to return the object to its original shape; this restorative force is actually the electromagnetic force attempting to maintain an optimal distance between neighboring atoms and molecules. The potential energy caused by these restorative forces is **elastic potential energy**. The elastic potential energy is proportional to both the restorative force and the amount of deformation. According to *Hooke's law*, the strength of the restorative force is itself directly proportional to the amount of deformation; therefore, *elastic potential energy is proportional to the square of the amount of deformation*. For example, doubling the amount by which a spring is stretched quadruples the elastic potential energy. Like gravitational potential energy, *elastic potential energy contributes to an object's mechanical energy*.

The Strong Nuclear Force

The strongest fundamental force acts only within the *nuclei* ("cores"; sing. nucleus) of atoms; therefore, it is called the **strong nuclear force**. This force binds subatomic particles together to form the nucleus of an atom. The strong nuclear force has an extremely short range—about 1.6×10^{-15} m (6.3×10^{-14} in)—but within that distance it is ten times as strong as the electromagnetic force and over 10^{37} times as strong as the gravitational force. The potential energy caused by the strong nuclear force is **nuclear potential energy**. (The weak nuclear force also makes a minor contribution to nuclear potential energy.) Energy transfers and conversions involving nuclear potential energy are not observed in everyday life but are very important in chemical reactions that affect the nucleus of the atom.

TABLE 5.1 **The Four Fundamental Forces** (weakest to strongest)

	Relative strength	Maximum range (m)	Particles affected	Function
Gravitational force	1	unlimited	all matter and energy	holds planets, stars, and galaxies together; determines planetary orbits
Weak nuclear force	1.72×10^{33}	2×10^{-18}	protons, neutrons, electrons, neutrinos, quarks	mostly unclear at present; allows neutrinos to interact with other matter
Electromagnetic force	1.24×10^{36}	unlimited	protons, electrons, quarks	attracts electrons to atomic nuclei; binds atoms together into molecules; responsible for magnetism, electricity, friction, touch, etc.
Strong nuclear force	1.3×10^{37}	1.5×10^{-15}	protons, neutrons, quarks	binds quarks together into protons and neutrons; binds protons and neutrons together into atomic nuclei

Section Review 5.3

CONCEPT REVIEW

1. What is energy associated with the position of an object and the forces upon the object?
2. List and briefly describe the four fundamental forces in order from strongest to weakest.
3. What three factors does gravitational potential energy depend on?
4. Which fundamental force is responsible for elastic potential energy?
5. Which fundamental force holds atomic nuclei together?

APPLICATION

1. Calculate the gravitational potential energy of a 15 kg box that is 5.0 m above the floor.
2. A 77 kg diver jumps off a diving platform 10. m above the water. Ignoring air resistance, how fast is he traveling when he enters the water?

Chapter 5 Review

KEY EQUATIONS

$$E = mc^2 \qquad E_k = \frac{1}{2}mv^2 \qquad E_p = mgh$$

DEFINE

1. kinetic energy
2. translational kinetic energy, rotational kinetic energy
3. thermal energy, wave energy
4. fundamental forces
5. gravitational field
6. magnetic potential energy, chemical energy, elastic potential energy
7. nuclear potential energy

IDENTIFY

1. the ability to do work and change matter
2. the equation relating mass and energy
3. four factors affecting rotational kinetic energy
4. type of energy associated with the position of an object and the forces acting upon it
5. the four fundamental forces in order from weakest to strongest
6. two fundamental forces that affect only subatomic particles

EXPLAIN

1. Why does the SI use the same unit for work and energy?
2. Give an example of a property change in matter and explain how the energy changed or was transferred.
3. How are mechanical and nonmechanical energy different?
4. Describe and explain an example of the law of conservation of energy that you can demonstrate in your home or classroom.

5. What is the relationship between mass and energy? How does this relationship explain the law of conservation of mass and energy?
6. Contrast circular motion and rotational motion.
7. Use the relationship between energy and work to explain how and why increasing mass and height affect the gravitational potential energy.
8. What fundamental force is responsible for most physical interactions? Describe and explain an example of an interaction caused by this force.
9. Contrast electric potential energy and gravitational potential energy.

APPLY

1. In a particle accelerator, particles are accelerated to speeds nearing the speed of light. What happens to the particles' masses? How do you know?
2. A spaceship in orbit has a kinetic energy of 2.5 TJ (2.5 terajoules or 2.5×10^{12} J). How much work was required for the spaceship to accelerate from 0 m/s to its current speed? How do you know?
3. When an increase in speed doubles the momentum of a moving object, what happens to the kinetic energy? How does this relate to the differences between momentum and kinetic energy?
4. A roller coaster car has 18,000 J of gravitational potential energy at the top of the first hill. Near the end of the ride, when the gravitational potential energy is zero but the car has not yet been braked, the car has 14,000 J of kinetic energy. Explain how this does not violate the law of conservation of energy.
5. A scientist experimenting with gravitational potential energy is measuring a weight's height above the top of his laboratory table. How can he determine the final kinetic energy if he drops the weight so that it lands on the floor intead of the table? Explain your answer.

PROBLEMS

1. What is the kinetic energy of a 0.145 kg baseball thrown at a speed of 40.2 m/s?
2. A car has a speed of 75 km/h and a kinetic energy of 130 kJ. What is its magnitude of momentum (mass times speed)? If it speeds up to 150 km/h, what are its new kinetic energy and magnitude of momentum?
3. What is the gravitational potential energy of a 12 kg object that is 0.20 m above the ground?
4. An archer shoots an arrow with a mass of 32.4 g straight up. The arrow reaches a height of 315 m. What is the velocity of the arrow when it hits the ground? Ignore air resistance.
5. The archer in Problem 4 shoots another 32.4 g arrow. This time, he shoots the arrow at a 30° angle. At the peak of its flight, the arrow has a speed of 57.9 m/s and a height of 57.2 m. Assuming air resistance can be ignored, how much work did the archer do in firing the arrow? What was the arrow's initial speed?
6. A dropped object hits the ground with a velocity of 4.95 m/s. Use what you know about energy to calculate the height from which it was dropped, assuming no air resistance.