



The Science
Content
Standards for
Grades Nine
Through
Twelve



The Science Content Standards for Grades Nine Through Twelve

The science content standards for kindergarten through grade eight provide the background for students to succeed with the science content standards for grades nine through twelve. Aligning the high school curriculum to offer standards-based courses for every student will put new demands on schools and science departments. However, the reward for successfully meeting the challenge will be that high school graduates can attain the highest level of science literacy achieved by students in more than two decades.

Changing to a program based on the science content standards will require a restructuring of the high school curriculum, although the science that was generally taught in California before the *Science Content Standards for California Public Schools* was published is mostly included in the standards.¹ The successful implementation of standards-based kindergarten through grade eight programs aligned to this *Science Framework* should enable more students to take standards-based courses in high school. This chapter provides guidance for teaching students who have mastered the kindergarten through grade eight materials. To achieve this mastery will require many years of effort, and school districts should adjust their programs appropri-

ately as their students have the opportunity to learn the prerequisite material in the earlier grades.

School districts are responsible for their curriculum and must decide how to structure their courses to teach the science standards. Traditionally, biology has been taught in the tenth grade, followed by chemistry and then possibly by physics. However, this sequence dates from a time when the content of the biology course was descriptive and that of the physics course was the most quantitative among the science disciplines. The high school science standards allow for other structures. Because districts need flexibility to design their own course structure, this chapter is presented in modular format—no sequence or emphasis is prescribed.

Appropriate to the rigor of the standards, each section covers a particular scientific discipline: physics, chemistry, biology/life sciences, and earth sciences. Along with meeting the subject-matter requirements for science, every student should learn the content in the full set of Investigation and Experimentation standards and have an opportunity to learn the slightly more advanced material in the standards that are marked with an asterisk.

In 1997 California established the Digital High School program, ensuring that all high schools throughout the

state would have access to technology to improve student achievement in science and other academic subjects. Many schools purchased materials for scientific-based technology, and their use should be integrated into science programs. Technology can be used to teach some science standards and to assess students' understanding. Science education provides an opportunity to instruct students in gathering, graphing, tracking, and interpreting data through the use of technological tools, such as word processing, spreadsheets, and database development. Related concepts from science, mathematics, and language arts can be merged in the development of a science experiment and its subsequent analysis.

Safety is always the foremost consideration in the design of demonstrations, laboratories, and science experiments. The importance of safety is evident because scientists and engineers in universities and industries are required to follow strict health and safety regulations. Safety needs to be taught. Teachers should be familiar with the *Science Safety Handbook for California Public Schools*.² It contains specific, useful information relevant to classroom science teachers. School administrators, teachers, parents/guardians, and students have a legal and moral obligation to promote safety in science education. Knowing and following safe practices in science are a part of understanding the nature of science and scientific enterprise.

Physics

Many scientists and engineers consider physics the most basic of all sciences. It covers the study of motion, forces, energy, heat, waves, light, electricity, and magnetism. Physics focuses on the development of models deeply rooted in scientific inquiry, in which mathematics is used to describe and predict natural phenomena and to express principles and theories. Understanding physics requires the ability to use algebra, geometry, and trigonometry. This need for mathematics has kept all but a very few students in this country from studying physics. Other countries, however, have met this challenge by introducing the concepts of physics to students during a period of several years, starting in the earlier grade levels. Topics requiring little or no mathematics are introduced first, and students progress to more sophisticated and quantitative treatments as they learn more mathematics. The California standards emulate this successful approach.

All students can learn high school physics. Many will have enough foundational skills and knowledge of mathematics from their science curriculum in kindergarten through grade eight to study motion, forces, heat, and light. In high school, students should develop a working knowledge of algebra, geometry, and simple trigonometry to understand and gain access to the power of physics. Some will need to learn or relearn algebra, geometry, and trigonometry skills while studying physics. The need for such mathematics review should lessen over time as California's rigorous mathematics standards are implemented. Students who intend to pursue careers in science or engineering will need to master the physics content called for in the California standards, including the standards marked with an asterisk. (Note that equations appearing in this section are numbered consecutively.)



STANDARD SET I. Motion and Forces

Motion deals with the changes of an object's position over time. Inherent in any useful study of motion is the concept of force, which represents the existence of physical interactions. Although Newton's laws provide a good platform from which to analyze forces, those laws do not address the origin of forces. Fundamental forces in nature govern the physical behavior of the universe. One of these fundamental forces, gravity, influences objects with mass but acts at a distance, or without any direct contact between the objects. The electromagnetic force is also a fundamental force that operates across a distance. These standards on motion and forces provide the foundation for understanding some key similarities—and differences—between these two forces. A working knowledge of basic algebra and geometry is an essential prerequisite for studying these concepts.

In standard sets presented earlier at lower grade levels, students were introduced to the idea that the motion of objects can be observed and measured, and they learned that a force can change the motion of an object by giving it a push or a pull. The topic of “Motion and Forces” at the high school level builds directly on the eighth grade Standard Set 1, “Motion,” and Standard Set 2, “Forces,” both of which introduce the notions of balanced forces and of net force (see Chapter 4). Students should know the difference between speed and velocity and should be able to interpret graphs for linear motion that plot relationships between two variables, such as speed versus time. Students should also understand the vector nature of forces. The concepts of gravity and of inertia as a resistance to a change in motion should have been introduced in the eighth grade.

I. Newton’s laws predict the motion of most objects. As a basis for understanding this concept:

- a. Students know how to solve problems that involve constant speed and average speed.

The rate at which an object moves is called its *speed*. Speed is measured in distance per unit time (e.g., meters/second). Velocity v is a vector quantity and therefore has both a magnitude—the speed—and a direction. If an object travels at a constant speed, a simple linear relationship exists between the speed, or rate of motion r ; distance traveled d ; and time t , as shown in

$$d = rt. \quad (\text{eq. 1})$$

If speed does not remain constant but varies with time, *average speed* can be defined as the total distance traveled divided by the total time required for the trip.

- I. b.** Students know that when forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest (Newton’s first law).

If an object’s velocity v changes with time t , then the object is said to accelerate. For motion in one dimension, the definition of acceleration a is

$$a = \Delta v / \Delta t, \quad (\text{eq. 2})$$

where the Greek capital letter delta (Δ) stands for “a change of.” *Acceleration* is defined as change in velocity per unit time. (Another way to state this definition is that *acceleration* is a change in distance per unit time per unit time, producing acceleration units of, for example, m/s^2 [meters per second squared or meters per second per second].) Acceleration is a vector quantity and therefore has both magnitude and direction. A push or a pull (force) needs to be applied to make an object accelerate. Force is another vector quantity.

A vector quantity, such as force, can be resolved into its x , y , and z components, F_x , F_y , and F_z . More than one force can be applied to an object simultaneously. If the forces point in the same direction, their magnitudes add; if the forces point in

opposite directions, their magnitudes subtract. The net (overall) force can be calculated by adding forces along a line algebraically and keeping track of the direction and signs. If an object is subject to only one force, or to multiple forces whose vector sum is not zero, there must be a net force on the object. However, if there is no net force on an object already in motion, that object continues to move at a constant velocity. An object at rest remains at rest if no net force is applied to it. This principle is Newton's first law of motion.

I. c. *Students know how to apply the law $F = ma$ to solve one-dimensional motion problems that involve constant forces (Newton's second law).*

If a net force is applied to an object, the object will accelerate. The relationship between the net force F applied to an object, the object's mass m , and the resulting acceleration a is given by Newton's second law of motion

$$F = ma . \quad (\text{eq. 3})$$

If mass is in kilograms (kg) and acceleration is in meters per second squared (m/s^2), then force is measured in Newtons, with 1 Newton = 1 kilogram-meter per second squared ($1 \text{ kg}\cdot\text{m/s}^2$).

If the net force on an object is constant, then the object will undergo constant acceleration. When studying constant force, students should be able to make use of the following equations to describe the motion of an object in one dimension at any elapsed time t by calculating its velocity v and distance from the origin d :

$$v = v_0 + at , \quad (\text{eq. 4})$$

$$d = d_0 + v_0 t + \frac{1}{2} at^2 . \quad (\text{eq. 5})$$

In these equations m is the mass, v_0 is the initial velocity, d_0 is the initial position (distance from origin) of the object, and t is the time during which the force F is applied.

I. d. *Students know that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's third law).*

Newton's third law of motion is more commonly stated as, "To every action there is always an equal and opposite reaction." The mutual reactions of two bodies are always equal and point in opposite directions. Mathematically stated, if object 1 pushes on object 2 with a force F_{12} , then object 2 pushes on object 1 with a force F_{21} such that

$$F_{21} = -F_{12} . \quad (\text{eq. 6})$$

This universal law applies, for example, to every object on the surface of Earth. Trees, rocks, buildings, and cars, even the atmosphere, are all subject to the downward force of gravity. In all cases Earth exerts an equal and opposite upward push on the objects. Stars exist because of the balance between the inward force of gravity and the outward pressure of their hot interior gases.

1. e. *Students know* the relationship between the universal law of gravitation and the effect of gravity on an object at the surface of Earth. (See Standard 1.m.*)

Since the time of Galileo's reputed experiment of dropping objects from the tower of Pisa, it has been understood that in the absence of air resistance, all objects near Earth's surface, regardless of their mass or composition, accelerate downward toward Earth's center at 9.8 m/s^2 . Through Newton's second law, this principle can be expressed as

$$F = w = mg \text{ (where } g \approx 9.8 \text{ m/s}^2 \text{ is the acceleration due to gravity).} \quad (\text{eq. 7})$$

The gravitational force pulling on an object is called the object's weight w and is measured in Newtons.

1. f. *Students know* applying a force to an object perpendicular to the direction of its motion causes the object to change direction but not speed (e.g., Earth's gravitational force causes a satellite in a circular orbit to change direction but not speed).

A force that acts on an object may act in any direction. The component of the force parallel to the direction of motion changes the speed of the object, and the components perpendicular to the motion change the direction in which the object travels.

1. g. *Students know* circular motion requires the application of a constant force directed toward the center of the circle.

An object moving with constant speed in a circle is in uniform circular motion. The direction of motion continuously changes because of a force that always points inward toward the center of the circle. Such a centrally directed force is called a *centripetal force*. If the mass of the object is m , its speed is v , and the radius of the circle in which the object travels is r , then the magnitude of the force causing the circular motion is

$$F_c = mv^2/r. \quad (\text{eq. 8})$$

Examples of centripetal forces are the tension in a string attached to a ball that is swung in a circle, the pull of gravity on a satellite in orbit around Earth, the electrical forces that deflect electrons in a television tube, and the magnetic forces that turn a charged particle.

1. h.* *Students know* Newton's laws are not exact but provide very good approximations unless an object is moving close to the speed of light or is small enough that quantum effects are important.

Newton's laws are not exact but are excellent approximations valid in domains involving low speeds and macroscopic objects. However, when the speed of an object approaches the speed of light ($3 \times 10^8 \text{ m/s}$), Einstein's theory of special

relativity is required to describe the motion of the object accurately. Among the major differences between Einstein's and Newton's theories of mechanics are that (1) the maximum attainable speed of an object is the speed of light; (2) a moving clock runs more slowly than does a stationary one; (3) the length of an object depends on its velocity with respect to the observer; and (4) the apparent mass of an object increases as its speed increases.

The other domain in which Newtonian mechanics breaks down is that of very small objects, such as atoms or atomic nuclei. Here the wavelike nature of matter becomes important, and quantum mechanics better describes the submicroscopic world. Newtonian mechanics assumes that if the motion of a particle is measured with great accuracy and all the masses and forces that are involved are also known, it is always possible to predict with equally great accuracy the future state of motion of the particle. Quantum mechanics shows that such certainty is not always possible. Sometimes only the probability of an outcome can be predicted.

I. i.* *Students know how to solve two-dimensional trajectory problems.*

Students can consider the problem of a ball of mass m thrown upward into the air at some angle. The motion of the ball will have horizontal and vertical components that are independent of one another. If air resistance is ignored, there will be no horizontal force acting against the ball to slow it down. While the ball is in flight then, only a single vertical force, gravity, is acting on the ball (e.g., $F = w = mg$ downward). If students know the angle and the height from which the ball is thrown and the ball's initial velocity, they will be able to predict the path of the ball and to calculate how high the ball will go, how far it will travel before it strikes the ground, and how long it will be in the air.

I. j.* *Students know how to resolve two-dimensional vectors into their components and calculate the magnitude and direction of a vector from its components.*

In a two-dimensional system, two quantities are needed to describe a vector. A vector \mathbf{r} can be completely specified by a magnitude r and an angle Φ or by its x and y components (i.e., r_x and r_y). Simple trigonometry can be applied to resolve a vector into its components (e.g., $r_x = r \cos \Phi$ and $r_y = r \sin \Phi$) and to calculate the magnitude and direction of a vector from its components ($r^2 = r_x^2 + r_y^2$ and $\tan \Phi = r_y/r_x$).

I. k.* *Students know how to solve two-dimensional problems involving balanced forces (statics).*

A body at rest that is subject to no net force is in static equilibrium. Examples of static equilibrium are a book resting on the surface of a table and a ladder leaning at rest against a wall. Because the book and table remain at rest does not imply that no forces act on these objects but does imply that the vector sum of all these

forces is zero. In particular, the components of the forces in any particular direction sum to zero. Thus for an object that remains at rest,

$$\sum F_y = 0 \quad (\text{eq. 9})$$

where the Greek capital letter sigma (Σ) means to “sum over or add” and F_y represents the components in any chosen direction y of the forces acting on the object. One sample problem appears in Figure 2, “Calculation of Force.” Students are given the weight of a hanging object, the lengths of the ropes holding it in place, and the distance between the anchors. The students are asked to calculate the forces, called *tension*, along ropes of equal length. Students find this problem difficult because the vector force diagram they should use to solve the problem is often confused with the physical lengths of the ropes.

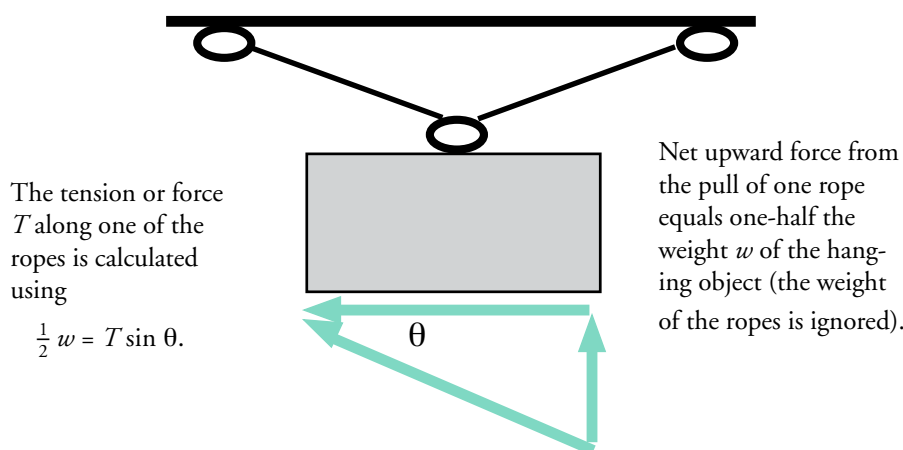


Fig. 2. Calculation of Force

1.1.* *Students know how to solve problems in circular motion by using the formula for centripetal acceleration in the following form: $a = v^2/r$.*

The speed of an object undergoing uniform circular motion does not vary, but the object’s direction does and hence the object’s velocity. Thus the object is constantly accelerating. The magnitude of this centripetal acceleration is

$$a_c = F_c/m = v^2/r, \quad (\text{eq. 10})$$

and the direction of the centripetal acceleration vector rotates so that it always points inward toward the center of the circle.

1.m.* *Students know how to solve problems involving the forces between two electric charges at a distance (Coulomb’s law) or the forces between two masses at a distance (universal gravitation).*

Standard Set 5 for physics, “Electric and Magnetic Phenomena,” which appears later in this section, shows that the origin of the force between two masses and between two electric charges is entirely different. However, the forces involved, the

gravitational and the electromagnetic forces, are both inverse square relationships. Coulomb's law (in a vacuum) is written

$$F_q = kq_1q_2/r^2, \quad (\text{eq. 11})$$

where $k = 9 \times 10^9 \text{ Nm}^2/\text{coul}^2$, q_1 and q_2 are charges (positive [+] or negative [-]), r is the distance separating the charges, and F_q is the force resulting from the two charges. The force is repulsive if the charges are the same sign and attractive if they are different.

Newton's law of universal gravitation states that if two objects have masses m_1 and m_2 , with centers of mass separated from each other by a distance r , then each object exerts an attractive force on the other; the magnitude of this force is

$$F_g = Gm_1m_2/r^2, \quad (\text{eq. 12})$$

where G is the universal gravitational constant, equal to $6.67 \times 10^{-11} \text{ newton-m}^2/\text{kg}^2$. For the case of a small object falling freely near the surface of Earth, students should understand that

$$g = Gm_e/r_e^2 = 9.8 \text{ m/s}^2, \quad (\text{eq. 13})$$

where m_e and r_e are the mass and radius of Earth. Students might be interested to know that Henry Cavendish's measurement of G , completed around the year 1800, was the last piece of information needed to calculate the mass of Earth.



STANDARD SET 2. Conservation of Energy and Momentum

The concept of energy was introduced and discussed several times in the lower grades, from the physical sciences through the life sciences. In fact, every process involves some transfer of energy. In Standard Set 2 *energy* is classified as *kinetic*, meaning related to an object's motion, or as *potential*, meaning related to an object's stored energy. The energy of a closed system is conserved. Another useful conservation law, conservation of momentum, is introduced and is shown to be a direct consequence of Newton's laws. The power and importance of these conservation laws are that they allow physicists to predict the motion of objects without having to know the details of the dynamics and interactions in a given system.

Through the standard sets introduced in the lower grade levels, students should have learned about forces and motion and the idea of energy. They should have been taught the role of energy in living organisms and the effects of energy on Earth's weather. The standards presented earlier also call for student exposure to energy conservation, a concept that is essential to the topics contained in the high school physics standard sets 3, 4, and 5 and in several standard sets in chemistry and earth sciences.

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

- a.** Students know how to calculate kinetic energy by using the formula

$$E = \frac{1}{2} mv^2.$$

Kinetic energy is energy of motion. The kinetic energy of an object equals the work that was needed to create the observed motion. This work can be related to the net force applied to the object along the line of the motion. The work done on an object by a force is equal to the component of the force along the direction of motion multiplied by the distance the object moved:

$$W = Fd. \quad (\text{eq. 14})$$

The work needed to accelerate an object of mass m from rest to a speed v is $\frac{1}{2} mv^2$. This quantity is defined as the kinetic energy E . The units of energy are joules, in which 1 joule = 1 kilogram-meter squared per second squared ($1 \text{ kg}\cdot\text{m}^2/\text{s}^2$) = 1 newton-meter. Energy is a *scalar* quantity, meaning that energy has a magnitude but no direction.

- 2. b.** Students know how to calculate changes in gravitational potential energy near Earth by using the formula (change in potential energy) = mgh (h is the change in the elevation).

Students can combine equations (3) and (14) to find the work done in lifting an object of weight mg through a vertical distance h , as shown in

$$W = mgh. \quad (\text{eq. 15})$$

Work and energy have the same units. Therefore, one can define mgh as the change in gravitational potential energy associated with the change in elevation h of the mass m .

- 2. c.** Students know how to solve problems involving conservation of energy in simple systems, such as falling objects.

Equations (4) and (5) can be used to show that if the object dealt with in Standard 2.b is released from rest and allowed to fall freely, it will strike the ground with a speed

$$v = \sqrt{2gh}, \quad (\text{eq. 16})$$

and its kinetic energy at the instant of impact will be

$$E = \frac{1}{2} mv^2 = \frac{1}{2} m(2gh) = mgh. \quad (\text{eq. 17})$$

The total energy T of the object is then defined as the sum of kinetic plus potential energy

$$T = E + PE. \quad (\text{eq. 18})$$

This sum is conserved in a closed system for such forces as gravity and electromagnetic interactions and those produced by ideal springs. Thus,

$$\Delta E + \Delta PE = 0. \quad (\text{eq. 19})$$

Therefore, the change in kinetic energy equals the negative of the change in potential energy. This principle is a consequence of the law of the conservation of energy. Energy can be converted from one form to another, but in a closed system the total energy remains the same.

2. d. Students know how to calculate momentum as the product mv .

The momentum \mathbf{p} of an object is defined as the product of its mass m and its velocity \mathbf{v} . Momentum is thus a vector quantity, having both a magnitude and a direction. The units of momentum are kg-m/s. The magnitude of the momentum is mv , the product of the object's mass and its speed.

2. e. Students know momentum is a separately conserved quantity different from energy.

If no net force is acting on an object or on a system of objects, the momentum remains constant. That is, neither its magnitude nor its direction changes with time. Conservation of momentum is another fundamental law of physics.

2. f. Students know an unbalanced force on an object produces a change in its momentum.

As discussed in the section for Standard 1.c, if the net force on an object is not zero, then its velocity and hence its momentum will change. Motion resulting from a constant force \mathbf{F} acting on an object for a time Δt causes a change in momentum of $\mathbf{F}\Delta t$. This change in momentum is called an *impulse*. (Note that the units of impulse are the same as those of momentum [i.e., newton-second = kg-m/s].) Depending on the direction of the force, the impulse can increase, decrease, or change the direction of the momentum of an object.

2. g. Students know how to solve problems involving elastic and inelastic collisions in one dimension by using the principles of conservation of momentum and energy.

Momentum is always conserved in collisions. Collisions that also conserve kinetic energy are called *elastic collisions*; that is, the kinetic energy before and after the collision is the same. Billiard balls colliding on smooth pool tables and gliders colliding on frictionless air tracks are approximate examples. Collisions in which kinetic energy is not conserved are called *inelastic collisions*. An example is a golf ball

colliding with a ball of putty and the two balls sticking together. Some of the kinetic energy in inelastic collisions is transformed into other types of energy, such as thermal or potential energy. In all cases the total energy of the system is conserved.

2. h.* *Students know how to solve problems involving conservation of energy in simple systems with various sources of potential energy, such as capacitors and springs.*

An ideal spring is an example of a conservative system. The force required either to stretch or to compress a spring by a displacement x from its equilibrium (unstretched) length is

$$F = kx, \quad (\text{eq. 20})$$

where k is the spring constant that measures a spring's stiffness. A graph of the magnitude of this force as a function of the compression shows that the force varies linearly from zero to kx as the spring is compressed. The area under this graph is the work done in compressing the spring and is equal to

$$\frac{1}{2}(\text{base})(\text{height}) = \frac{1}{2}kx^2. \quad (\text{eq. 21})$$

This is also the potential energy stored in the spring.

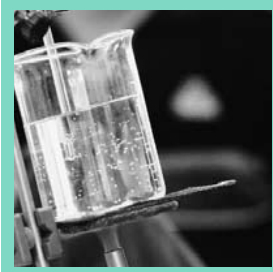
A capacitor stores charge. The charge Q that is stored depends on the voltage V according to

$$Q = CV, \quad (\text{eq. 22})$$

where the constant C is called the *capacitance*. (Notice that this equation and the equation for a spring [eq. 20] have the same form.) The energy stored in a capacitor is given by the equation

$$E = \frac{1}{2}CV^2, \quad (\text{eq. 23})$$

which also has the same form as the equation that gives the energy stored by a spring.



STANDARD SET 3. Heat and Thermodynamics

The concept of heat (thermal energy) is related to all scientific disciplines. Energy transfer, molecular motion, temperature, pressure, and thermal conductivity are integral parts of physics, chemistry, biology, and earth science.

Thermodynamics deals with exchanges of energy between systems.

If students in high school have not yet covered the chemistry standards, the related topics from those standards should be introduced. (See the following standards for chemistry in this chapter: 4.a through 4.h, “Gases and Their Properties,” and 7.a through 7.d, “Chemical Thermodynamics.” Specific chemistry topics that are useful or necessary for promoting a more complete understanding of Standard

Set 3 are specifically mentioned, when relevant, under the sections with detailed descriptions.

At the atomic and molecular levels, all matter is continuously in motion. For example, individual molecules of nitrogen, oxygen, and other gases that make up the air inside a balloon move at varying speeds in random directions, vibrating and rotating. The collisions of these molecules with the inner surface of the balloon create the pressure that supports the balloon against atmospheric pressure.

Considerable confusion exists in scientific literature about the definitions of the terms *heat* and *thermal energy*. Some texts define *heat* strictly as “transfer of energy.” These science content standards use the term *heat* interchangeably with *thermal energy*. However, it is less confusing to reserve the term *heat* for thermodynamic situations in which energy is transferred either because of differences in temperature or through work done by or on a system. In this sense both *heat* and *work* have meaning only as they describe energy exchanges into and out of the system, adding or subtracting from a system’s store of internal energy.

Students, just like scientists of the eighteenth century, might easily fall prey to the misconception that heat is a substance. Students should be cautioned that heat is energy, not a material substance, and that *heat flow* refers not to material flow but to the transfer of energy from one place to another. Confusion is most apt to arise when dealing with heat transfer by convection; that is, when heat is transferred through actual motion of hot and cold material along a thermal gradient. Heating a material such as air causes it to expand and leads to differences in density that drive the movement of heated material.

Students also often confuse temperature and heat. From a molecular viewpoint, *temperature* is a measure of the average translational kinetic energy of a molecule, as shown in equation (27). (See also Standard Set 7 in the chemistry section in this chapter.) Studies of the temperature of materials as they pass through phase transitions may also help students understand the differences and relationships between heat and temperature.

A way to avoid confusion is to reserve the use of the word *heat* for situations in which heat transfer is involved, as described in the next section.

3. Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

- a. Students know heat flow and work are two forms of energy transfer between systems.

Heat transfer is energy flow from one system to another because of differences in temperature or because of mechanical work. The energy that flows into a pot of cold water put on a hot stove is an example of heat transfer. This energy increases the kinetic energy of the random motion of the molecules of water and therefore the temperature of the water rises. When the water reaches 100°C, a new phenomenon, a phase transition, occurs: the water vaporizes, or boils. Although energy continues to flow into the water, the kinetic energy of the water molecules does

not increase; therefore the temperature of the water remains constant. As the water changes from a liquid to a gas, the energy goes instead into breaking the bonds that hold one molecule of liquid water to another. The energy required (per unit mass or mole of liquid) to change a particular liquid at its boiling temperature into a gas is called the liquid's *latent heat of vaporization*.

Mechanical work can change temperature too (e.g., when the forces of friction heat objects or when a gas is compressed and so warms). Conversely, changes in temperature can do mechanical work (e.g., warming a container of gas that is sealed by a piston will cause the gas to expand and the piston to move).

Heat is energy that moves between a system and its environment because of a temperature difference between them. Every system has its internal energy, that is, the energy required to assemble the system; and this energy is independent of any particular path or means by which the system is assembled. The transfer of internal energy from one system to another, because of a temperature difference, is known as *heat flow*. There are three basic kinds of heat flow: conduction, convection, and radiation. Students should have first learned about these processes in the sixth grade.

As heat is transferred to a system (object), the temperature of the system (object) may increase. Substances vary in the amount of heat necessary to raise their temperatures by a given amount. More mass in the system clearly requires more heat for a given temperature change. An expression that illustrates the relationship between the amount of heat transferred and the corresponding temperature change is shown in equation (24). The change in temperature ΔT is proportional to the amount of heat added. This relationship is specified by

$$Q = mC\Delta T, \quad (\text{eq. 24})$$

where Q is the internal energy added by heat transfer to the system from the surroundings, ΔT is the difference in temperature between the final and initial states of the system, m is the system's mass, and C is the specific heat of the substance (in joules/gram- $^{\circ}\text{C}$ or calories/gram- $^{\circ}\text{C}$). *Specific heat* is a characteristic property of a material. The unit of specific heat is energy divided by mass and temperature change (e.g., calories/gram-degree).

Water, which serves as a standard against which all other materials may be compared, has a specific heat of one calorie/gram-degree. In other words, one calorie of heat is required to raise one gram of water one degree Celsius. When a gram of water cools one degree, one calorie is liberated. This value is large compared with those of other substances. Therefore, it takes much more heat to warm water than it does to raise the temperature of the same amount of most other substances. This fact has important implications for weather and climate and is one reason the weather is "tempered" in coastal areas (e.g., summers are cooler and winters are warmer than they are in inland areas at a similar latitude).

Equation (24) makes the distinction between heat and temperature quite clear. It specifies that heat can flow in or out of a system because of temperature difference alone. There are, however, other situations in which the addition or removal of heat is not accompanied by changes in temperature. These situations occur when a

substance undergoes a change of phase, or state, such as when water evaporates or freezes. During phase changes, the absorption or release of heat takes place while the system remains at a constant temperature. For example, when ice melts in a glass of water that is sufficiently well mixed, the temperature of the water remains at the freezing point of water. Additional heating of the water raises its temperature only after the ice has melted.

3. b. *Students know that the work done by a heat engine that is working in a cycle is the difference between the heat flow into the engine at high temperature and the heat flow out at a lower temperature (first law of thermodynamics) and that this is an example of the law of conservation of energy.*

The total energy of an isolated system is the sum of the kinetic, potential, and thermal energies. A system is isolated when the boundary between the system and the surroundings is clearly defined. Total energy is conserved in all classical processes. Thus, the law of conservation of energy can be restated as the first law of thermodynamics; that is, for a closed system the change in the internal energy ΔU is given by the expression

$$\Delta U = Q - W, \quad (\text{eq. 25})$$

where Q is the internal energy added by heat transfer to the system from the surroundings and W is the work done by the system. The quantities ΔU , Q , and W in equation (25) can be negative or positive, depending on whether energy is converted from mechanical form into heat, as when work is done on the system, or on whether heat is transformed into mechanical energy, as when the system is doing work. By convention, Q is positive for heat added to the system and negative for heat transferred to the surroundings, and W is positive for work done by the system and negative for work done on the system. As a practical matter, energy that cannot be obtained as work is considered a loss to the system. Thus, the first law of thermodynamics indicates how much energy is available to do work.

A heat engine is a device for getting useful mechanical work from thermal energy. While part of the input heat energy Q_H , sometimes known as *heat of combustion*, is converted into useful work W , the remaining heat is lost to the environment as exhaust heat Q_L . That is, the work done by a heat engine is the difference between thermal energy flowing in at higher temperature and heat flowing out at lower temperature, as shown in the following equation:

$$W = Q_H - Q_L. \quad (\text{eq. 26})$$

This simple relationship is valid for an idealized engine, also called a *Carnot engine*.

3. c. *Students know* the internal energy of an object includes the energy of random motion of the object's atoms and molecules, often referred to as *thermal energy*. The greater the temperature of the object, the greater the energy of motion of the atoms and molecules that make up the object.

The internal energy of objects is in the motion of their atoms and molecules and in the energy of the electrons in the atoms. For ideal gases, nearly realized by air molecules, heat transferred to the gas increases the average speed of the gas molecules. The higher the temperature, the greater the average speed. If it were possible to observe the motion of molecules in a gas at a fixed temperature, one would see molecules with different masses moving on average at different speeds. More massive molecules, for example, move more slowly because the average kinetic energy of each type of molecule is the same in the gas, and the kinetic energy is proportional to the product of the mass and the square of the velocity of the gas molecules. The pressure of a gas results from individual molecules bumping against containing walls and other objects. Each hit and change of direction causes a change in momentum and therefore a net force or push on the object hit. One molecule's contribution to total pressure is very small, but measurable pressures result when large numbers of fast-moving atoms or molecules participate in these collisions.

For an ideal gas system at thermal equilibrium, the kinetic energy of an individual gas molecule averaged over time is

$$E = \frac{3}{2} kT, \quad (\text{eq. 27})$$

where $k = 1.38 \times 10^{-23}$ joule/K, and T is the absolute temperature in Kelvin (K). The Kelvin temperature scale and its conversion to the customary Fahrenheit and Celsius scales are discussed in standards 4.d and 4.e in the chemistry section in this chapter.

3. d. *Students know* that most processes tend to decrease the order of a system over time and that energy levels are eventually distributed uniformly.

Energy in the form of heat transfers from hot to cold, but not from cold to hot, regardless of whether that energy transfers by radiation, conduction, or convection. Why? Matter exists in discrete energy states (or levels). For tiny objects, such as a single electron, the difference in energy between one state and the next is big enough to be detected and measured. For the larger objects of everyday experience, such as a pebble, the difference is too small to detect; still, the discrete states exist, and it makes sense to speak of the probability with which any given system is to be found in any one of its possible states.

A system of many components has many states of given total energy because some components can have a larger fraction of that energy if others have less. Such

a system evolves so that all states with the same total energy become equally probable. Heat flows from hot to cold because states in which components share energy equally vastly outnumber states in which they do not. A copper bar with one end hot and the other cold has many atoms with more kinetic energy on the hot end and many atoms with less kinetic energy on the cold end. Later, however, because the kinetic energy has been transferred from the hot end of the bar to the cold end, all the atoms will have nearly the same kinetic energy. The change can be interpreted as heat flowing from hot to cold until the temperature of the bar is uniform. Similarly, most physical processes disorder a system because disordered states vastly outnumber ordered ones. A drop of perfume evaporates because states in which molecules of perfume are scattered throughout a large volume of air vastly outnumber states in which the molecules are confined in the tiny volume of a drop.

3. e. *Students know that entropy is a quantity that measures the order or disorder of a system and that this quantity is larger for a more disordered system.*

Students know from Standard 3.d that energy transferred as heat leads to the redistribution of energy among energy levels in the substances that compose the system. This redistribution increases the disorder of material substances. A quantity called *entropy* has been defined to track this process and to measure the randomness, or disorder, of a system. Entropy is larger for a disordered system than for an ordered one. Thus, a positive change in entropy, in which the final entropy is larger than the initial entropy, indicates decreasing order, also considered as increasing disorder. The properties of entropy fix the maximum efficiency with which energy stored as a temperature difference can be converted into work.

For a system at constant temperature, such as during melting or boiling, the change in entropy ΔS is given by

$$\Delta S = Q/T, \quad (\text{eq. 28})$$

where Q is the heat (thermal energy) that flows into or out of the system and T is the absolute temperature. The units of entropy are joules/K. All processes that require energy, for example, biochemical reactions that support life, occur only because the entropy increases as a result of the process.

3. f.* *Students know the statement “Entropy tends to increase” is a law of statistical probability that governs all closed systems (second law of thermodynamics).*

The second law of thermodynamics states that all spontaneous processes lead to a state of greater disorder. When an ice cube melts and the water around it becomes cooler, for example, the internal energy of the ice-water system becomes more uniformly spread, or more disordered. Most processes in nature are irreversible because they move toward a state of greater disorder. A broken egg, for instance, is almost impossible to restore to its original ordered state.

Another statement of the second law of thermodynamics is that in a closed system all states tend to become equally probable. Calculating the statistical probability of a condition involves counting all the ways to distribute energy in a system, and that procedure involves mathematics that is more complex than most students will have mastered. However, most students can recognize that there are many more ways to distribute energy approximately evenly within a system than there are ways to have energy concentrated. As spontaneous processes make all ways equally probable, a system thus becomes more likely to be found with its energy distributed than concentrated, and so the system becomes disordered.

Students who complete these standards will have learned the first and second laws of thermodynamics. They should understand that when physical change occurs, energy must be conserved, and some of this energy cannot be recovered for useful work because it has added to the disorder of the universe.

3. g.* *Students know how to solve problems involving heat flow, work, and efficiency in a heat engine and know that all real engines lose some heat to their surroundings.*

As implied in Standard 3.b, when heat flows from a body at high temperature to one at low temperature, some of the heat can be transformed into mechanical work. This principle is the basic concept of the heat engine. The remainder of the heat is transferred to the surroundings and therefore is no longer available to the system to do work. This transferred heat is never zero; therefore, some heat must always be transferred to the surroundings. Examples of practical heat engines are steam engines and internal combustion engines. Steam at a high temperature T_H pushes on a piston or on a turbine and does work. Steam at a lower temperature T_L is then drawn off from the engine into the air. When an idealized (i.e., reversible) engine completes a cycle, the change in entropy is zero. Equation (28) shows that

$$Q_H/T_H = Q_L/T_L. \quad (\text{eq. 29})$$

When this relation is combined with the conservation law of equation (26), the maximum possible efficiency, denoted as “eff,” can be calculated as

$$\text{eff} (\%) = 100 \times W/Q_H = 100 \times (T_H - T_L)/T_H, \quad (\text{eq. 30})$$

where efficiency is the ratio of work done by the engine to the heat supplied to the engine. The efficiency of converting heat to work is proportional to the difference between the high and low temperatures of the engine’s working fluids, usually gases. For a Carnot engine to be 100 percent efficient, the temperature of the exhaust heat needs to be absolute zero, an impossible occurrence.



STANDARD SET 4. Waves

Students can be introduced to this standard set by learning to distinguish between mechanical and electromagnetic waves. In general, a *wave* is defined as the propagation of a disturbance. The nature of the disturbance may be mechanical or electromagnetic. Mechanical waves, such as ocean waves, acoustic waves, seismic waves, and the waves that ripple down a flag stretched taut by a wind, require a medium for their propagation and gradually lose energy to that medium as they travel. Electromagnetic waves can travel in a vacuum and lose no energy even over great distances. When electromagnetic waves travel through a medium, they lose energy by absorption, a phenomenon that explains why light signals sent through the most transparent of optical fibers still need to be amplified and repeated. In contrast, light emitted from distant galaxies has traveled great distances without the aid of amplification, an indication that a relatively small amount of material is in the light's path.

Waves transfer energy from one place to another without net circulation or displacement of matter. Light, sound, and heat energy can be transmitted by waves across distances measured from fractions of a centimeter to many millions of kilometers. Exertion of a direct mechanical force, such as a push or a pull, on a physical body is an example of energy transfer by direct contact. However, for transfer to occur, objects do not need to be in direct physical contact with a source of energy. For instance, light transmits from a distant star, heat radiates from a fire, and sound propagates from distant thunder. Energy may be transferred by radiation, for example, from the Sun to Earth; therefore, radiation is also an example of a non-contact energy transfer. Both sight and hearing are senses that can perceive energy patterned to convey information without direct contact between the source and the sensing organ.

If students take physics before they have studied other high school science courses, the teacher may find it useful to cross-reference materials on pressure, heat, and solar radiation from the following standards in this chapter: 4.a and 7.a in the chemistry section and 4.a through 4.c in the earth sciences section. Algebra, geometry, and simple trigonometric skills are required for some of the advanced topics in this standard set. Students with a good foundation in algebra and geometry can be taught the trigonometry necessary to solve problems in this standard set.

4. Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:

- a.** *Students know waves carry energy from one place to another.*

Waves may transport energy through a vacuum or through matter. Light waves, for example, transport energy in both fashions, but sound waves and most other waves occur only in matter. However, even waves propagating through matter trans-

port energy without any net movement of the matter, thus differing from other means of energy transport, such as convection, a waterfall, or even a thrown object.

4. b. *Students know how to identify transverse and longitudinal waves in mechanical media, such as springs and ropes, and on the earth (seismic waves).*

Waves that propagate in mechanical media are either longitudinal or transverse waves. The disturbance in longitudinal waves is parallel to the direction of propagation and causes compression and expansion (rarefaction) in the medium carrying the wave. The disturbance in transverse waves is perpendicular to the direction of propagation of the wave. Examples of longitudinal waves are sound waves and *P*-type earthquake waves. In transverse waves a conducting medium, or a test particle inserted in the wave, moves perpendicular to the direction in which the wave propagates. Examples of transverse waves are *S*-type earthquake waves and electromagnetic (or light) waves.

4. c. *Students know how to solve problems involving wavelength, frequency, and wave speed.*

All waves have a velocity v (propagation speed and direction), a property that represents the rate at which the wave travels. Only periodic, sustained waves can be easily characterized through the properties of wavelength and frequency. However, most real waves are *composite*, meaning they can be understood as the sum of a few or of many waveforms, each with an amplitude, a wavelength, and a frequency.

Wavelength λ is the distance between any two repeating points on a periodic wave (e.g., between two successive crests or troughs in a transverse wave or between adjacent compressions or expansions [rarefactions] in a longitudinal wave). Wavelength is measured in units of length.

Frequency f is the number of wavelengths that pass any point in space per second. A wave will make any particle it encounters move in regular cycles, and frequency is also the number of such cycles made per second and is often abbreviated as cycles per second. The unit of frequency is the inverse second (s^{-1}), a unit also called the hertz (Hz).

Periodic wave characteristics are related to each other. For example,

$$v = f\lambda . \quad (\text{eq. 31})$$

4. d. *Students know sound is a longitudinal wave whose speed depends on the properties of the medium in which it propagates.*

Sound waves, sometimes called *acoustic waves*, are typically produced when a vibrating object is in contact with an elastic medium, which may be a solid, a liquid, or a gas. A sound wave is longitudinal, consisting of regions of high and low pressure (and therefore of compression and rarefaction) that propagate away from the source. (Note that sound cannot travel through a vacuum.) In perceiving sound, the human

cardrum vibrates in response to the pattern of high and low pressure. This vibration is translated into a signal transmitted by the nervous system to the brain and interpreted by the brain as the familiar sensation of sound. Microphones similarly translate vibrations into electrical current. Sound speakers reverse the process and change electrical signals into vibrational motion, recreating sound waves.

An acoustic wave attenuates, or reduces in amplitude, with distance because the energy in the wave is typically spread over a spherical shell of ever-increasing area and because interparticle friction in the medium gradually transforms the wave's energy into heat. The speed of sound varies from one medium to another, depending primarily on the density and elastic properties of the medium. The speed of sound is typically greater in solid and liquid media than it is in gases.

4. e. Students know radio waves, light, and X-rays are different wavelength bands in the spectrum of electromagnetic waves whose speed in a vacuum is approximately 3×10^8 m/s (186,000 miles/second).

Electromagnetic waves consist of changing electric and magnetic fields. Because these fields are always perpendicular to the direction in which a wave moves, an electromagnetic wave is a transverse wave. The electric and magnetic fields are also always perpendicular to each other. Concepts of electric and magnetic fields are introduced in Standard Set 5, "Electric and Magnetic Phenomena," in this section. The range of wavelengths for electromagnetic waves is very large, from less than nanometers (nm) for X-rays to more than kilometers for radio waves. The human eye senses only the narrow range of the electromagnetic spectrum from 400 nm to 700 nm. This range generates the sensation of the rainbow of colors from violet through the respective colors to red. In a vacuum all electromagnetic waves travel at the same speed of 3×10^8 m/s (or 186,000 miles per second). In a medium the speed of an electromagnetic wave depends on the medium's properties and on the frequency of the wave. The ratio of the speed of a wave of a given frequency in a vacuum to its speed in a medium is called that medium's *index of refraction*. For visible light in water, this number is approximately 1.33.

4. f. Students know how to identify the characteristic properties of waves: interference (beats), diffraction, refraction, Doppler effect, and polarization.

A characteristic and unique property of waves is that two or more can occupy the same region of space at the same time. At a particular instant, the crest of one wave can overlap the crest of another, giving a larger displacement of the medium from its condition of equilibrium (*constructive interference*); or the crest of one wave can overlap the trough of another, giving a smaller displacement (*destructive interference*). The effect of two or more waves on a test particle is that the net force on the particle is the algebraic sum of the forces exerted by the various waves acting at that point.

If two overlapping waves traveling in opposite directions have the same frequency, the result is a standing wave. There is a persistent pattern of having no

displacement in some places, called *nulls* or *nodes*, and large, oscillating displacements in others, called *maxima* or *antinodes*. If two overlapping waves have nearly the same frequency, a node will slowly change to a maximum and back to a node, and a maximum will slowly change to a node and back to a maximum. For sound waves this periodic change leads to audible, periodic changes from loud to soft, known as *beats*.

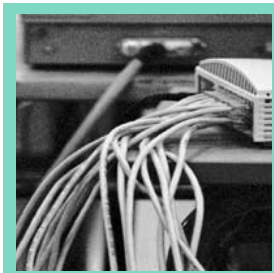
Diffraction describes the constructive and destructive patterns of waves created at the edges of objects. Diffraction can cause waves to bend around an obstacle or to spread as they pass through an aperture. The nature of the diffraction patterns of a wave interacting with an object depends on the ratio of the size of the obstacle to the wavelength. If this ratio is large, the shadows are nearly sharp; if it is small, the shadows may be fuzzy or not appear at all. Therefore, a hand can block a ray of light, whose average wavelength is about 500 nm, but cannot block an audible sound, whose average wavelength is about 100 cm. The bending of water waves around a post and the diffraction of light waves when passing through a slit in a screen are examples of diffraction patterns.

Refraction describes a change in the direction of a wave that occurs when the wave encounters a boundary between one medium and another provided that the media have either different wave velocities or indexes of refraction and provided that the wave arrives at some angle to the boundary other than perpendicular. At a sharp boundary, the change in direction is abrupt; however, if the transition from one medium to another is gradual, so that the velocity of the wave changes slowly, then the change in the wave's direction is also gradual. Therefore, a ray of light that passes obliquely from air to water changes its direction at the water's surface, but a ray that travels through air that has a temperature gradient will follow a bent path. A ray of light passing through a saturated solution of sugar (sucrose) and water, which has an index of refraction of 1.49, will not change direction appreciably on entering a colorless, transparent piece of quartz submerged in the solution because the quartz has an almost identical index of 1.51. The match in indexes makes the quartz nearly invisible in the sugar-water solution.

Another interesting phenomenon, the *Doppler effect*, accounts for the shift in the frequency of a wave when a wave source and an observer are in motion relative to each other compared with when they are at relative rest. This effect is most easily understood when the source is at rest in some medium and the observer is approaching the source at constant speed. The interval in time between each successive wave crest is shorter than it would be if the observer were at rest, and so the frequency observed is larger. The general rule, for observers moving at velocities much less than the velocity of the wave in its medium, is that the change in frequency depends only on the velocity of the observer relative to the source. Therefore, the shriek of an ambulance siren has a higher pitch when the source approaches and a lower pitch when the source recedes. For an observer following the ambulance at the same speed, the siren would sound normal. Similar shifts are observed for visible light.

Polarization is a property of light and of other transverse waves. *Transverse waves*

are those in which the displacement of a test particle is always perpendicular to the direction in which the wave travels. When that displacement is always parallel to a particular direction, the wave is said to be (*linearly*) *polarized*. A ray of light emitted from a hot object, like a lamp filament or the sun, is unpolarized; such a ray consists of many component waves overlapped so that there is no special direction perpendicular to the ray in which a test particle is favored to move. The components of an unpolarized ray can be sorted to select such a special direction and so make one or more polarized rays. An unpolarized ray that is partly reflected and partly transmitted by an angled sheet of glass is split into rays that are polarized; an unpolarized ray can become polarized by going through a material that allows only waves corresponding to one special direction to pass through. Polarized sunglasses and stretched cellophane wrap are examples of polarizing materials.



STANDARD SET 5. Electric and Magnetic Phenomena

The electromagnetic force is one of only four fundamental forces; the others are the gravitational force and the forces that govern the strong and weak nuclear interactions.

Electric and magnetic phenomena are well understood by scientists, and the unifying theory of the electromagnetic force is one of the great successes of science. The electromagnetic force accounts for the structure and for the unique chemical and physical properties of atoms and molecules. This force binds atoms and molecules and largely accounts for the properties of matter. Photons convey this force and electromagnetic energy.

Using electromagnetism for practical technological applications is taken for granted in modern society. Many devices of daily life, such as household appliances, computers, and equipment for communication, entertainment, and transportation, were developed from electromagnetic phenomena. Understanding the fundamental ideas of electricity and magnetism is basic to achieving success in a vast array of endeavors, from auto mechanics to nuclear physics.

Electricity and magnetism are now known to be two manifestations of a single phenomenon, the electromagnetic force. The originally separate theories explaining electricity and magnetism have been combined into a single theory of electromagnetism, whose predictive power is greater than that of either of the two previous, separate theories. The joining of these theories into a common mathematical framework is an example of how seemingly disparate phenomena can sometimes be unified in physics.

Studies of electric and magnetic phenomena build directly on the high school physics standards presented earlier and require a thorough understanding of the concepts of motion, forces, and conservation of energy. The subject of energy transport by waves is also important. Students in the lower grade levels are introduced to electricity as they learn that electric current can carry energy from one place to another. They also learn about light and the relationship between electricity and

magnetism. To understand the concepts in Standard Set 5, students will need a strong grasp of beginning algebra and geometry. Basic trigonometry is also required for some of the advanced topics. Several topics covered in the lower grade levels may need to be reviewed as a part of teaching this standard set, particularly during the transition to standards-based education. In particular, the following facts are pertinent: (1) charge occurs in definite, discrete amounts; (2) charge comes in two varieties: positive and negative; and (3) the smallest amount of observable charge is the charge on an electron (or a proton).

Students should be acquainted with Newton's law of gravitation from standards studied previously (see Standard 1.e for grade two and Standard 4.c for grade five in Chapter 3 and standards 2.g and 4.e for grade eight in Chapter 4). Both Newton's law and Coulomb's law describe forces that diminish as the square of distance, and it may be helpful to compare those forces as a part of teaching some of the standards (see standards 1.e and 1.m* in this section). However, the comparison should be done with attention to the fundamental differences between the two types of forces, and certain points must be clearly understood to avoid sowing misconceptions. For example:

- Only the difference in electric or gravitational potential between two points has physical significance; the value of the potential at a particular point can be defined only relative to some reference point.
- The direction of an electric current is defined as the same as the direction of motion of charge carriers, conventionally assumed to be positive, although the charge carriers (the electrons) in wires are in fact negative. Therefore the direction of the electric current in wires is opposite to the direction of motion of the charge carriers.
- A *direct current* (DC) flows in one direction only, and an *alternating current* (AC) reverses at regular intervals.
- Ohm's law applies to conducting material under the assumption that resistance is independent of the magnitude and polarity of the potential difference (or of the applied electric field) across the material. The formulas used in Ohm's law to calculate an unknown amount of current, voltage, or resistance are $I = V/R$, $V = IR$, and $R = V/I$.

It may be helpful to describe *electric potential* as a measure of the tendency of a charged body to move from one point to another in an electrostatic field in the same way that *gravitational potential* is a measure of a body with mass to move from one point to another in a gravitational field. In both fields the work done to move the body does not depend on the path taken between the points but can be computed from the difference in the potential at the points.

As students solve simple circuit problems for this standard, they will also need to know the schematic representations of the various circuit elements, including a battery, a resistor, and a capacitor.

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

- a. Students know how to predict the voltage or current in simple direct current (DC) electric circuits constructed from batteries, wires, resistors, and capacitors.

Electric current I is the flow of net charge, and a complete, continuous path of current is called an *electric circuit*. If the charge carriers are positive, the electric current flows in the direction the carriers move; but if the carriers are negative, as they are in ordinary wires, the electric current flows in the opposite direction. Wires that carry currents are usually made of highly conducting metals, such as copper. If net charge q passes by a point a in a conducting wire in time t , the current I_a at that point is

$$I_a = q/t. \quad (\text{eq. 32})$$

In the case of uniform current I , the rate of charge flow is the same through the entire length of the wire. Current is measured in units of amperes (A), which are equal to coulombs/second ($A = C/s$), the logical consequence of equation (32).

A particle with a charge q placed in an electric field will be subject to electrostatic forces and will have a potential energy. Moving the charge will change its potential energy from some value PE_a to PE_b , reflecting the work W_{ba} done by the electric field (see Standard 2.a in this section). Potential energy depends also on the magnitude of the charge being transported. A more convenient quantity is the potential energy per unit charge, which has a unique value at any point, independent of the actual charge of the particle in the electric field. This quantity is called *electric potential*, or just *potential*, and the difference V_{ab} between the potentials at two points a and b is the *voltage*. By this definition, voltage provides a measure of the work per unit charge required to move the charge between two points a and b in the field; alternatively, it represents the corresponding difference in potential energy per unit charge. This principle is expressed as

$$V_{ab} = V_a - V_b = W_{ba}/q = PE_a/q - PE_b/q. \quad (\text{eq. 33})$$

Electric potential and voltage are measured in units of volt (V), which, as required by the preceding definition, is equal to joules per coulomb (J/C).

For a current-carrying wire, the potential difference between two points along the wire causes the current to flow in that segment.

5. b. Students know how to solve problems involving Ohm's law.

Resistance, measured in ohms, of a conducting medium (conductor) is the opposition offered by the conductor to the flow of electric charge. A potential difference V is required to cause electrons to move continuously. Ohm's law gives the relationship between the current I that results when a voltage V is applied across a wire with resistance R . This law is expressed as

$$I = V/R. \quad (\text{eq. 34})$$

Capacitors, which are devices for storing electrical charge, generally consist of two conductors with a potential difference that are separated by an insulator. A typical capacitor consists of two parallel metal plates insulated from each other by a *dielectric*, a material that does not conduct electricity. Capacitance C , the ability of a capacitor to store electric charge, can be measured in units of farads. The capacitance can be found from the following relation:

$$C = q/V, \quad (\text{eq. 35})$$

where q is the charge stored ($+q$ on one plate and $-q$ on the other) and V is the potential difference between the conducting surfaces. Based on equation (35), the unit of farad is defined as coulomb/volt (C/V).

5. c. *Students know any resistive element in a DC circuit dissipates energy, which heats the resistor. Students can calculate the power (rate of energy dissipation) in any resistive circuit element by using the formula Power = IR (potential difference) \times I (current) = I^2R .*

Electric power P is defined as the rate of dissipation of electric energy, or the rate of production of heat energy, in a resistor and is given by Joule's law, in which

$$P = IV. \quad (\text{eq. 36})$$

Through the use of Ohm's law, this equation can also be written as $P = I^2R$ or $P = V^2/R$. Power is measured in watts, where 1 watt = 1 ampere-volt (W = A-V) = 1 joule/second.

Dissipation of energy as heat is a consequence of electrical resistance. In other words *electric power* is equivalent to the work per second that must be done to maintain an electric current. Alternatively, *power* is the rate at which electrical energy is transferred from the source to other parts of the circuit. The unit of kilowatt hour (kWH) is sometimes used commercially to represent energy production and consumption, where 1 kWH = 3.6×10^6 J.

5. d. *Students know the properties of transistors and the role of transistors in electric circuits.*

Semiconductors are materials with an energy barrier such that only electrons with energy above a certain amount can "flow." As the temperature rises, more electrons are free to move through these materials. A transistor is made of a combination of differently "doped" materials arranged in a special way. Transistors can be used to control large current output with a small bias voltage. A common role of transistors in electric circuits is that of amplifiers. In that role transistors have almost entirely replaced vacuum tubes that were widely used in early radios, television sets, and computers.

5. e. *Students know* charged particles are sources of electric fields and are subject to the forces of the electric fields from other charges.

Electrostatic force represents an interaction across space between two charged bodies. The magnitude of the force is expressed by a relationship similar to that for the gravitational force between two bodies with mass. For both gravity and electricity, the force varies inversely as the square of the distance between the two bodies. For two charges q_1 and q_2 separated by a distance r , the relationship is called Coulomb's law,

$$F = kq_1q_2/r^2, \quad (\text{eq. 37})$$

where k is a constant. Customary units for charge are coulombs (C), in which case $k = 9 \times 10^9 \text{Nm}^2/\text{C}^2$.

An electric field is a condition produced in space by the presence of charges. A field is said to exist in a region of space if a force can be measured on a test charge in the region. Many different and complicated distributions of electric charge can produce the same simple motion of a test charge and therefore the same simple field; for that reason it is usually easier to study first the effect of a model field on a test charge and to consider only later what distribution of other charges might produce that field.

5. f. *Students know* magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources.

A magnetic force exists between magnets or current-carrying conductors or both. A stationary charge does not produce magnetic forces. Furthermore, no evidence for the existence of magnetic monopoles, which would be the magnetic equivalent of electric charges, has yet been found. Iron and other materials that can be magnetized have domains in which the combined motion of electrons produces the equivalent of small magnets in the metal. When many of these domains are aligned, the entire metal object becomes a strong magnet. Therefore, to the best of scientific knowledge, all magnetic effects result from the motion of electrical charges.

The concept of a field applies to magnetism just as it does to electricity (see Standard 5.e in this section). Magnetic fields are generated either by magnetic materials or by electric currents caused by the motion of charged particles. A standard unit for the magnetic field strength is the Tesla (T). Electric charges moving through a magnetic field experience a magnetic force. The direction of the magnetic force is always perpendicular to the line of motion of the electric charges. The force is at maximum when the direction of motion of the electric charges (their velocity vector) is perpendicular to the magnetic field and at zero when the two are parallel.

5. g. *Students know how to determine the direction of a magnetic field produced by a current flowing in a straight wire or in a coil.*

The direction of a magnetic field is by convention taken to be outward from a north pole and inward from a south pole. The right-hand rule finds the direction of the magnetic field produced by a current flowing in a wire or coil. To find the direction in a wire, a student wraps the fingers of the right hand around the wire with the thumb pointing in the direction in which the electric current flows (in a wire electrons and electric current move in opposite directions). The fingers encircling the wire then point in the direction of the magnetic field outside the wire. The same rule will find the direction of the magnetic field inside a coil if one imagines that the right hand wraps around a wire that forms one of the loops that make up the coil. A different rule using the right hand also works for coils. The coil is held in the palm of the right hand with the fingers wrapped around the coil and pointing in the direction in which the electric current flows through the loops. The thumb then points in the direction of the magnetic field inside the coil.

5. h. *Students know changing magnetic fields produce electric fields, thereby inducing currents in nearby conductors.*

The concept of electromagnetic induction is based on the observation that changing magnetic fields create electric fields, just as changing electric fields are sources of magnetic fields. In a conductor these induced electric fields can drive a current. The direction of the induced current is always such as to oppose the changing magnetic field that caused it. This principle is called Lenz's law.

5. i. *Students know plasmas, the fourth state of matter, contain ions or free electrons or both and conduct electricity.*

A *plasma* is a mixture of positive ions and free electrons that is electrically neutral on the whole but that can conduct electricity. A plasma can be created by very high temperatures when molecules disassociate and their constituent atoms further break up into positively charged ions and negatively charged electrons. Much of the matter in the universe is in stars in the form of plasma, a mixture of electrified fragments of atoms. Plasma is considered a fourth state of matter, as fundamental as solid, liquid, and gas.

5. j.* *Students know electric and magnetic fields contain energy and act as vector force fields.*

Both the electric field E and the magnetic field B are vector fields; therefore, they have a magnitude and a direction. The fields from matter whose distributions in space and in velocity do not change with time are easy to visualize; for example, charges fixed in space, steady electric currents in wires, or permanent magnets. Electric fields from matter like this are generally represented by "lines of force" that

start on positive charges and end on negative charges but never form closed loops (see Standard 5.m*, which appears later in this section). In contrast, the lines for magnetic fields always form closed loops; they never start and end—magnetic field lines do not have terminal points. Even the magnetic field lines around simple bar magnets, which are typically drawn as emanating from the north pole and entering the south pole, in fact continue through the body of the magnet to form closed loops.

The reason magnetic fields form loops while electric fields do not has to do with their different sources in matter at rest. Electric fields come from point charges, and magnetic fields come from point dipoles, which are more complicated; no sources of magnetic field with the simple properties of charge—that is, no magnetic monopoles—are known to exist. The direction in which an electric field points along a line of force is away from positive charge and toward negative charge; the direction in which a magnetic field (that is due to a current) points along a closed loop can be found by the right-hand rule (see Standard 5.g, which appears earlier in this section).

Electric and magnetic fields are associated with the existence of potential energy. The fields are usually said to *contain* energy. For example, the potential energy of a system of two charges q_1 and q_2 located a distance r apart, is given by

$$PE = kq_1q_2/r. \quad (\text{eq. 38})$$

In general, the potential energy of a system of fixed-point charges is defined as the work required to assemble the system bringing each charge in from an infinite distance.

5. k.* Students know the force on a charged particle in an electric field is $q\mathbf{E}$, where \mathbf{E} is the electric field at the position of the particle and q is the charge of the particle.

The electric field strength \mathbf{E} at a given point is defined as the force experienced by a unit positive charge, $\mathbf{E} = \mathbf{F}/q$. The units of \mathbf{E} are newton/coulomb (N/C). By this definition the force experienced by a charged particle is

$$\mathbf{F} = q\mathbf{E}, \quad (\text{eq. 39})$$

where q is the magnitude of the particle's charge in coulombs and \mathbf{E} is the electric field at the position of the charged particle.

5. l.* Students know how to calculate the electric field resulting from a point charge.

Coulomb's law is used in calculating the electric field caused by a point charge. According to equation (39), $\mathbf{E} = \mathbf{F}/q$, the magnitude of the field produced by a point charge q_1 is found by substituting equation (37) for \mathbf{F} and dividing by the magnitude of the positive test charge q_2 , which gives

$$E = kq_1/r^2. \quad (\text{eq. 40})$$

The direction of E is determined by the type of the source charge q_1 , so that the vector is away from the positive charge (+) and toward the negative charge (-). (Remember that by definition the *field strength* is the force per unit of positive test charge.)

5. m.* *Students know static electric fields have as their source some arrangement of electric charges.*

The existence of a static electric field in a region of space implies a distribution of charges as the source. Conversely, any set of charges or charged surfaces sets up an electric field in the space around the charge. The customary first step in visualizing an electric field is to draw smooth curves, each of which contains only points of equal electric potential. Electric field lines (“lines of force”) can then be drawn as curves that are everywhere perpendicular to the curves of equal potential. Electric field lines are assigned a direction that runs from regions of high potential to low and, therefore, from positive point charges to negative ones. The lines of force represent the path a particle with a small positive charge would take if released in the field.

The method used in deriving equation (40) can be used, in principle, to determine the field produced from any distribution of charges. At each point a net vector E is obtained by summing the vector contributions from each charge. This process can be readily done for a two-charge system in which the geometry is relatively simple. For more complicated distributions the methods of calculus are generally required to obtain the field.

5. n.* *Students know the magnitude of the force on a moving particle (with charge q) in a magnetic field is $qvB \sin(a)$, where a is the angle between \mathbf{v} and \mathbf{B} (v and B are the magnitudes of vectors \mathbf{v} and \mathbf{B} , respectively), and students use the right-hand rule to find the direction of this force.*

The force on a moving particle of charge q traveling at velocity v in a magnetic field B is given by

$$F = qvB \sin(a) , \quad (\text{eq. 41})$$

where a is the angle between the direction of the motion of the charged particle and the direction of the magnetic field. (If $a = 0$, then the particle is traveling parallel to the direction of the field and the magnetic force on it is zero.) The maximum force is obtained when the particle is traveling perpendicular to the magnetic field. Students can determine the direction of the magnetic force through the use of the right-hand rule. The magnetic force is perpendicular to both the direction of motion of the charge and to the direction of the magnetic field. Equation (41) shows that Tesla, a standard unit for the magnetic field mentioned previously, is equal to 1 N-s/C-m (see the discussion for Standard 5.f, which appears previously in this section).

5. o.* Students know how to apply the concepts of electrical and gravitational potential energy to solve problems involving conservation of energy.

In standards 2.a and 2.b in this section, students learned that if a stone is raised from Earth's surface, the work done against Earth's gravitational attraction is stored as potential energy in the system of stone plus Earth. If the stone is released, the stored potential energy is transformed into kinetic energy, which steadily increases as the stone moves faster toward Earth. Once the stone comes to rest, this kinetic energy will ultimately be transformed into thermal energy. A similar situation exists in electrostatics. If the separation between two opposite charges is increased, work must be performed. The work is positive if the charges are opposite and negative. The energy represented by this work can be thought of as stored in the system of charges as electric potential energy (see also Standard 5.j* in this section) and, like gravitational potential energy, may be transformed into other forms, such as kinetic and thermal energy.

A simple example is a charge q moving freely between point a and point b , with a potential difference V_{ab} between the two points. If q is positive, the change in electric potential energy can be found from equation (35) and is

$$\Delta PE = qV_{ab} . \quad (\text{eq. 42})$$

By conservation of energy a corresponding amount of the kinetic energy is acquired, or released, by the charge at point b such that

$$\Delta KE = \Delta PE = qV_{ab} . \quad (\text{eq. 43})$$

Through substitution of the standard expression $\frac{1}{2}mv^2$ for the kinetic energy, a variety of predictions can be made, assuming the accelerating potential does not result in velocities approaching the velocity of light. The final velocity v can be found if the charge q , the mass m , and the potential V are known. *This method of imparting energy to charged particles is applied in such devices as television sets and in accelerators*

Notes

1. *Science Content Standards for California Public Schools, Kindergarten Through Grade Twelve.* Sacramento: California Department of Education, 2000.
2. *Science Safety Handbook for California Public Schools.* Sacramento: California Department of Education, 1999.

Chemistry

A sign in a university professor's office asks, What in the world isn't chemistry? Although meant to amuse, this question has a world of truth behind it. High school students come into contact with chemistry every day, often without realizing it. Discussions of daily interactions with chemistry often provide an entry into teaching the subject in high school. Although relating chemistry to daily life is helpful, this approach does not diminish the need for students to have a high level of readiness before entering the class. Of paramount importance is a firm grounding in algebra.

Chemistry is a sequential, hierarchical science that is descriptive and theoretical. It requires knowing the macroscopic properties of matter and the microscopic properties of matter's constituent particles. Although chemical demonstrations may engage students, going beyond a superficial appreciation of chemistry is a critical step. Chemistry requires high-level problem-solving skills, such as designing experiments and solving word problems. For students to learn concepts of chemistry, they must learn new vocabulary, including the rules for naming simple compounds and ions.

Students can discover chemistry's tremendous power to explain the nature of matter and its transformations when they study the periodic table of the elements. Students who move beyond a trivial treatment of the discipline can explore the many useful, elegant, and even beautiful aspects of chemistry. Bringing students to this understanding is a great achievement.



STANDARD SET I. Atomic and Molecular Structure

Starting with atomic and molecular structure in the study of high school chemistry is important because this topic is a foundation of the discipline. However, because structural concepts are highly theoretical and deal with the quantum realm, they can be hard to relate to real-world experience. Ideally, from grades three through eight, students have been gradually introduced to the atomic theory; and by the end of the eighth grade, they should have covered the major concepts in the structure of atoms and molecules. By the time students reach high school, they should be familiar with basic aspects of this theory.

The study of structure can begin with the simplest element, hydrogen. Students can progress from a simple model of the atom (see standards 1.a, 1.d, 1.e, 1.h*, and 11.a in this section) to the historic Bohr model (see Standard 1.i* in this section) and, finally, to a quantum mechanical model (see standards 1.g* and 1.j* in this section), which is the picture of the atom that students should ultimately develop. Students should learn that the quantum mechanical model takes into account

the particle and wave properties of the electron and uses mathematical equations to solve for electron energies and regions of electron density.

Students should understand that the energy carried by electrons either within an atom or as electricity can be transformed into light energy. Those who have completed high school physics will be familiar with the properties of electromagnetic waves. In chemistry students learn to apply the equations $E = h\nu$ and $c = \lambda\nu$. Students without significant training in physics will need to understand electromagnetic radiation as energy, frequency, and wavelength. The necessary mathematical background for the study of chemistry includes algebraic isolation of variables, use of conversion factors, and manipulation of exponents, all of which are covered in the mathematics standards for the middle grades.

I. The periodic table displays the elements in increasing atomic number and shows how periodicity of the physical and chemical properties of the elements relates to atomic structure. As a basis for understanding this concept:

- a. *Students know* how to relate the position of an element in the periodic table to its atomic number and atomic mass.

An atom consists of a nucleus made of protons and neutrons that is orbited by electrons. The number of protons, not electrons or neutrons, determines the unique properties of an element. This number of protons is called the element's atomic number. Elements are arranged on the periodic table in order of increasing atomic number. Historically, elements were ordered by atomic mass, but now scientists know that this order would lead to misplaced elements (e.g., tellurium and iodine) because differences in the number of neutrons for isotopes of the same element affect the atomic mass but do not change the identity of the element.

- I. b.** *Students know* how to use the periodic table to identify metals, semimetals, nonmetals, and halogens.

Most periodic tables have a heavy stepped line running from boron to astatine. Elements to the immediate right and left of this line, excluding the metal aluminum, are semimetals and have properties that are intermediate between metals and nonmetals. Elements further to the left are metals. Those further to the right are nonmetals. Halogens, which are a well-known family of nonmetals, are found in Group 17 (formerly referred to as Group VIIA). A group, also sometimes called a "family," is found in a vertical column in the periodic table.

- I. c.** *Students know* how to use the periodic table to identify alkali metals, alkaline earth metals and transition metals, trends in ionization energy, electronegativity, and the relative sizes of ions and atoms.

A few other groups are given family names. These include the alkali metals (Group 1), such as sodium and potassium, which are soft and white and extremely

reactive chemically. Alkaline earth metals (Group 2), such as magnesium and calcium, are found in the second column of the periodic table. The transition metals (Groups 3 through 12) are represented by some of the most common metals, such as iron, copper, gold, mercury, silver, and zinc. All these elements have electrons in their outer *d* orbitals.

Electronegativity is a measure of the ability of an atom of an element to attract electrons toward itself in a chemical bond. The values of electronegativity calculated for various elements range from one or less for the alkali metals to three and one-half for oxygen to about four for fluorine. *Ionization energy* is the energy it takes to remove an electron from an atom. An element often has multiple ionization energies, which correspond to the energy needed to remove first, second, third, and so forth electrons from the atom. Generally in the periodic table, ionization energy and electronegativity increase from left to right because of increasing numbers of protons and decrease from top to bottom owing to an increasing distance between electrons and the nucleus. Atomic and ionic sizes generally decrease from left to right and increase from top to bottom for the same reasons. Exceptions to these general trends in properties occur because of filled and half-filled subshells of electrons.

I. d. Students know how to use the periodic table to determine the number of electrons available for bonding.

Only electrons in the outermost energy levels of the atom are available for bonding; this outermost bundle of energy levels is often referred to as the *valence shell* or *valence shell of orbitals*. All the elements in a group have the same number of electrons in their outermost energy level. Therefore, alkali metals (Group 1) have one electron available for bonding, alkaline earth metals (Group 2) have two, and elements in Group 13 (once called Group III) have three. Unfilled energy levels are also available for bonding. For example, Group 16, the chalcogens, has room for two more electrons; and Group 17, the halogens, has room for one more electron to fill its outermost energy level.

To find the number of electrons available for bonding or the number of unfilled electron positions for a given element, students can examine the combining ratios of the element's compounds. For instance, one atom of an element from Group 2 will most often combine with two atoms of an element from Group 17 (e.g., MgCl_2) because Group 2 elements have two electrons available for bonding, and Group 17 elements have only one electron position open in the outermost energy level. (Note that some periodic tables indicate an element's electron configuration or preferred oxidation states. This information is useful in determining how many electrons are involved in bonding.)

I. e. Students know the nucleus of the atom is much smaller than the atom yet contains most of its mass.

The volume of the hydrogen nucleus is about one trillion times less than the volume of the hydrogen atom, yet the nucleus contains almost all the mass in the

form of one proton. The diameter of an atom of any one of the elements is about 10,000 to 100,000 times greater than the diameter of the nucleus. The mass of the atom is densely packed in the nucleus.

The electrons occupy a large region of space centered around a tiny nucleus, and so it is this region that defines the volume of the atom. If the nucleus (proton) of a hydrogen atom were as large as the width of a human thumb, the electron would be on the average about one kilometer away in a great expanse of empty space. The electron is almost 2,000 times lighter than the proton; therefore, the large region of space occupied by the electron contains less than 0.1 percent of the mass of the atom.

I. f.* *Students know how to use the periodic table to identify the lanthanide, actinide, and transactinide elements and know that the transuranium elements were synthesized and identified in laboratory experiments through the use of nuclear accelerators.*

The lanthanide series, or rare earths, and the actinide series, all of which are radioactive, are separated for reasons of practical display from the main body of the periodic table. If these two series were inserted into the main body, the table would be wider by 14 elements and less manageable for viewing. Within each of these series, properties are similar because the configurations of outer electrons are similar. As a general rule elements in both series appear to have three electrons available for bonding. They combine with halogens to form compounds with the general formula MX_3 , such as LaF_3 . The transactinide elements begin with rutherfordium, element 104.

All the elements with atomic numbers greater than 92 were first synthesized and identified in experiments. These experiments required the invention and use of accelerators, which are electromagnetic devices designed to create new elements by accelerating and colliding the positively charged nuclei of atoms. Ernest O. Lawrence, at the University of California, Berkeley, invented one of the most useful nuclear accelerators, the cyclotron. Many transuranium elements, such as 97-berkelium, 98-californium, 103-lawrencium, and 106-seaborgium, were first created and identified at the adjacent Lawrence Berkeley National Laboratory. Today a few transuranium elements are produced in nuclear reactors. For example, hundreds of metric tons of plutonium have been produced in commercial nuclear reactors.

I. g.* *Students know how to relate the position of an element in the periodic table to its quantum electron configuration and to its reactivity with other elements in the table.*

Each element has a unique electron configuration (also known as quantum electron configuration) that determines the properties of the element. Quantum mechanical calculations predict these electron energy states, which provide the theoretical justification for the organization of the periodic table, previously organized on the basis of chemical properties.

Students can learn the principal quantum numbers—which are 1, 2, 3, 4, 5, 6, and 7—and the corresponding periods, or horizontal rows, on the periodic table. They can learn the angular momentum quantum numbers that give rise to s, p, d, and f subshells of orbitals and the rules for the sequence of orbital filling. The electrons in the highest energy orbitals with the same principal quantum number are the *valence electrons*. For example, for all elements in Group 1, the valence electron configuration is ns^1 , where n is the principal quantum number. Analogously, all elements in Group 16 have valence electron configurations of ns^2np^4 . Particular configurations of valence electrons are associated with regular patterns in chemical reactivity. Generally, those elements with one electron in excess or one electron short of a full octet in the highest occupied energy level, the alkali metals and halogens, respectively, are the most reactive.

I. h.* *Students know the experimental basis for Thomson’s discovery of the electron, Rutherford’s nuclear atom, Millikan’s oil drop experiment, and Einstein’s explanation of the photoelectric effect.*

In 1887 J. J. Thomson performed experiments from which he concluded that cathode rays are streams of negative, identical particles, which he named *electrons*. In 1913 E. R. Rutherford headed a group that shot a beam of helium nuclei, or alpha particles, through a very thin piece of gold foil; the unexpectedly large deflections of some helium nuclei led to the hypothesis that the charged mass of each gold atom is concentrated in a small central nucleus. Robert Millikan confirmed Thomson’s conclusion that electrons are identical particles when he balanced tiny, electrically charged oil droplets between electric and gravitational fields and so discovered that the droplets always contained charge equal to an integral multiple of a single unit.

Albert Einstein found he could explain the photoelectric effect, in which light ejects electrons from metal surfaces, by proposing that light consists of discrete bundles of energy, or *photons*, each photon with an energy directly proportional to the frequency of the light, and by proposing that each photon could eject one and only one electron. Photons with sufficient energy will eject an electron whose kinetic energy is equal to the photon energy minus the energy required to free the electron from the metal. If the frequency of the light and therefore the energy of each photon is too low to free an electron, then merely increasing the light’s intensity (that is, merely producing more photons) does not cause electrons to eject.

I. i.* *Students know the experimental basis for the development of the quantum theory of atomic structure and the historical importance of the Bohr model of the atom.*

Niels Bohr combined the concepts of Rutherford’s nuclear atom and Einstein’s photons with several other ideas to develop a model that successfully explains the observed spectrum, or wavelengths, of electromagnetic radiation that is emitted when a hydrogen atom falls from a high energy state to a low energy state. In classical physics all accelerating charges emit energy. If electrons in an atom behaved in

this way, light of ever-decreasing frequencies would be emitted from atoms. Bohr explained why this phenomenon does not occur when he suggested that electrons in atoms gain or lose energy only by making transitions from discrete energy levels. This idea was a key to the development of nonclassical descriptions of atoms. Louis de Broglie advanced the understanding of the nature of matter by proposing that particles have wave properties. On the basis of these ideas, Erwin Schrödinger and others developed quantum mechanics, a theory that describes and predicts atomic and nuclear phenomena.

1. j.* Students know that spectral lines are the result of transitions of electrons between energy levels and that these lines correspond to photons with a frequency related to the energy spacing between levels by using Planck's relationship ($E = h\nu$).

The Bohr model gives a simple explanation of the spectrum of the hydrogen atom. An electron that loses energy in going from a higher energy level to a lower one emits a photon of light, with energy equal to the difference between the two energy levels. Transitions of electrons from higher energy states to lower energy states yield *emission*, or *bright-line spectra*. *Absorption spectra* occur when electrons jump to higher energy levels as a result of absorbing photons of light. When atoms or molecules absorb or emit light, the absolute value of the energy change is equal to hc/λ , where h is a number called *Planck's constant*, c is the speed of light, and λ is the wavelength of light emitted, yielding Planck's relationship $E = h\nu$.

The transition from the Bohr model to the quantum mechanical model of the atom requires students to be aware of the probabilistic nature of the distribution of electrons around the atom. A "dart board" made of concentric rings can serve as a two-dimensional model of the three-dimensional atom. A graph as a function of radius of the number of random hits by a dart can be compared with a similar graph as a function of radius of the probability density of the electron in a hydrogen atom.



STANDARD SET 2. Chemical Bonds

Standard Set 2 deals with two distinct topics: chemical bonds and intermolecular attractive forces, such as hydrogen bonds. A logical place to begin the study of this standard is with a discussion of the chemical bond. A key point to emphasize is that when atoms of two different elements join to form a covalent bond, energy is almost always released. Conversely, breaking bonds always requires the addition of energy. Students should understand that the sum of these two processes determines the net energy released or absorbed in a chemical reaction.

This standard set requires a basic knowledge of electrostatics and electronegativity and a thorough knowledge of the periodic table. After studying standards for chemistry for the elementary grades, students should know that matter is made of atoms and that atoms combine to form molecules. Students can also be expected to

know that atoms consist of protons, neutrons, and electrons. Although knowledge of complex mathematics is not required for this standard, some background in three-dimensional geometry will be helpful.

2. Biological, chemical, and physical properties of matter result from the ability of atoms to form bonds from electrostatic forces between electrons and protons and between atoms and molecules.

As a basis for understanding this concept:

- a. *Students know* atoms combine to form molecules by sharing electrons to form covalent or metallic bonds or by exchanging electrons to form ionic bonds.

In the localized electron model, a covalent bond appears as a shared pair of electrons contained in a region of overlap between two atomic orbitals. Atoms (usually nonmetals) of similar electronegativities can form covalent bonds to become molecules. In a covalent bond, therefore, bonding electron pairs are localized in the region between the bonded atoms. In metals valence electrons are not localized to individual atoms but are free to move to temporarily occupy vacant orbitals on adjacent metal atoms. For this reason metals conduct electricity well.

When an electron from an atom with low electronegativity (e.g., a metal) is removed by another atom with high electronegativity (e.g., a nonmetal), the two atoms become oppositely charged ions that attract each other, resulting in an ionic bond. Chemical bonds between atoms can be almost entirely covalent, almost entirely ionic, or in between these two extremes. The triple bond in nitrogen molecules (N_2) is nearly 100 percent covalent. A salt such as sodium chloride (NaCl) has bonds that are nearly completely ionic. However, the electrons in gaseous hydrogen chloride are shared somewhat unevenly between the two atoms. This kind of bond is called *polar covalent*.

(Note that elements in groups 1, 2, 16, and 17 in the periodic table usually gain or lose electrons through the formation of either ionic or covalent bonds, resulting in eight outer shell electrons. This behavior is sometimes described as “the octet rule.”)

- 2. b.** *Students know* chemical bonds between atoms in molecules such as H_2 , CH_4 , NH_3 , H_2CCH_2 , N_2 , Cl_2 , and many large biological molecules are covalent.

Organic and biological molecules consist primarily of carbon, oxygen, hydrogen, and nitrogen. These elements share valence electrons to form bonds so that the outer electron energy levels of each atom are filled and have electron configurations like those of the nearest noble gas element. (Noble gases, or inert gases, are in the last column on the right of the periodic table.) For example, nitrogen has one lone pair and three unpaired electrons and therefore can form covalent bonds with three hydrogen atoms to make four electron pairs around the nitrogen. Carbon has four unpaired electrons and combines with hydrogen, nitrogen, and oxygen to form covalent bonds sharing electron pairs.

The great variety of combinations of carbon, nitrogen, oxygen, and hydrogen make it possible, through covalent bond formation, to have many compounds from just these few elements. Teachers can use ball and stick or gumdrop and toothpick models to explore possible bonding combinations.

2. c. *Students know salt crystals, such as NaCl, are repeating patterns of positive and negative ions held together by electrostatic attraction.*

The energy that holds ionic compounds together, called *lattice energy*, is caused by the electrostatic attraction of *cations*, which are positive ions, with *anions*, which are negative ions. To minimize their energy state, the ions form repeating patterns that reduce the distance between positive and negative ions and maximize the distance between ions of like charges.

2. d. *Students know the atoms and molecules in liquids move in a random pattern relative to one another because the intermolecular forces are too weak to hold the atoms or molecules in a solid form.*

In any substance at any temperature, the forces holding the material together are opposed by the internal energy of particle motion, which tends to break the substance apart. In a solid, internal agitation is insufficient to overcome intermolecular or interatomic forces. When enough energy is added to the solid, the kinetic energy of the atoms and molecules increases sufficiently to overcome the attractive forces between the particles, and they break free of their fixed lattice positions. This change, called *melting*, forms a liquid, which is disordered and nonrigid. The particles in the liquid are free to move about randomly although they remain in contact with each other.

2. e. *Students know how to draw Lewis dot structures.*

A Lewis dot structure shows how valence electrons and covalent bonds are arranged between atoms in a molecule. Teachers should follow the rules for drawing Lewis dot diagrams provided in a chemistry textbook. Students should be able to use the periodic table to determine the number of valence electrons for each element in Groups 1 through 3 and 13 through 18. Carbon, for example, would have four valence electrons. Lewis dot diagrams represent each electron as a dot or an *x* placed around the symbol for carbon, which is C. A covalent bond is shown as a pair of dots, or *x*'s, representing a pair of electrons. For example, a Lewis dot diagram for methane, which is CH₄, would appear as shown in Figure 3.

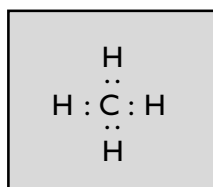


Fig. 3. Lewis Dot Diagram

Lewis dot diagrams provide a method for predicting correct combining ratios between atoms and for determining aspects of chemical bonds, such as whether they are covalent or consist of single, double, or triple bonds.

2. f.* *Students know how to predict the shape of simple molecules and their polarity from Lewis dot structures.*

Using information obtained from Lewis dot structures of covalently bonded molecules, students can predict the overall geometry of those molecules. This model assumes that valence electron pairs repel each other and that atoms covalently bonded around a central atom position themselves as far apart as possible while maintaining the covalent bond. The model also assumes that double or triple bonds define a single electronic region.

To predict shapes, students start with a correct Lewis dot structure. From the number of electron pairs or regions, both bonded and nonbonded, students can determine the molecular geometry of the molecule because Lewis dot structures, although drawn in two dimensions, represent the three-dimensional symmetry of the molecule. A symmetrical distribution of the electron clouds around a central atom leads to a nonpolar molecule in which charge is evenly distributed. Students should be able to predict that a molecule such as methane, with one carbon and four hydrogen atoms, forms a tetrahedral shape and because of its symmetry is a nonpolar molecule.

2. g.* *Students know how electronegativity and ionization energy relate to bond formation.*

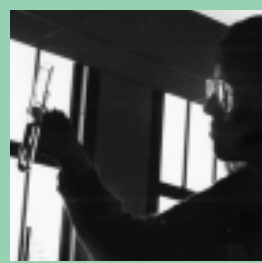
During bond formation atoms with large electronegativity values, such as fluorine and oxygen, attract electrons away from lower electronegativity atoms, such as the alkali metals. The difference in electronegativity between the two bonding atoms gives information on how evenly an electron pair is shared. A large difference in electronegativity leads to an ionic bond, with essentially no sharing of electrons. This phenomenon usually occurs between metal and nonmetal atoms. A small difference in electronegativity leads to a covalent bond with more equal sharing of electrons. This result typically occurs between two nonmetal atoms. Electronegativity is related to *ionization energy*, the energy needed to remove an electron from an isolated gaseous atom, leaving a positively charged ion. High ionization energies usually correlate with large electronegativities.

2. h.* *Students know how to identify solids and liquids held together by van der Waals forces or hydrogen bonding and relate these forces to volatility and boiling/melting point temperatures.*

Liquids and solids that are held together not by covalent or ionic bonds but only by weaker intermolecular forces tend to have low to moderate melting and boiling points and to be from somewhat to very volatile. The *volatility* of a substance means how readily it evaporates at ordinary temperatures and pressures.

Two kinds of intermolecular forces are hydrogen bonding and van der Waals attractions (often referred to as London dispersion forces). Hydrogen bonding is essential to life and gives water many of its unusual properties. A hydrogen bond occurs when a hydrogen atom on one molecule, bonded directly to a highly electronegative atom (fluorine, oxygen, or nitrogen), is weakly attracted to the electronegative atom on a neighboring molecule. In the important case of water, this attraction exists between the hydrogen on one water molecule and the oxygen on a neighboring water molecule. This attraction happens because of water's polar nature and bent shape.

Van der Waals forces exist between all molecules, polar or nonpolar. Even when the molecule is nonpolar, the electrons move around and may sometimes find themselves temporarily closer to one nucleus than to the other. The atom with the greater share of the electron density becomes, for an instant, slightly negatively charged, and the other atom becomes a little bit positive. If the same thing happens in a nearby molecule, the positive and negative centers on the two molecules temporarily attract each other. Bigger molecules have more electrons, and their van der Waals forces are greater. This phenomenon leads to molecules with lower volatility and higher melting and boiling temperatures.



STANDARD SET 3. Conservation of Matter and Stoichiometry

Standard Set 3 demands more facility with mathematics than do the previous two chemistry standard sets. For this reason students need prerequisite mathematical skills in two broad categories. First, they must be able to manipulate very large and very small numbers by using exponents as expressed in scientific notation, and they should learn the rules of significant digits when reporting measurements and the results of calculations. Second, students must be able to manipulate simple equations in symbolic form, such as the isolation of variables, and to write equations numerically with correct units. Handling units successfully is necessary for problems involving mole-to-mass and mass-to-mole conversions. The ability to make other types of unit conversion and to square and cube linear measurements will also be required. An understanding of ratios will help students to see the logic behind problems related to Standard Set 3.

Simple metric conversions are relatively easy to grasp, and they contain the basic elements of stoichiometric calculations. For example, to convert 510 nanometers to meters, students write the unknown unit, which in this case is meters; set it equal to the given unit, which in this case is nanometers; and then multiply by the correct conversion factor, making sure that the desired unit is in the numerator and the unit to be cancelled is in the denominator. The following equation demonstrates this procedure:

$$510 \text{ nm} = 510 \text{ nm} \times (10^{-9} \text{ m}/1 \text{ nm}) = 510 \times 10^{-9} \text{ m} = 5.1 \times 10^{-7} \text{ m}$$

This technique converts any units however complicated. For example, centimeters can be converted to nanometers by multiplying by two factors: one that converts from centimeters to meters and another that converts from meters to nanometers. Converting to an area requires the square of a conversion factor; converting to a volume requires the cube. Once students have tackled simple problems, they can move on to more complex stoichiometric relations. They will also need to learn to balance equations easily.

3. The conservation of atoms in chemical reactions leads to the principle of conservation of matter and the ability to calculate the mass of products and reactants. As a basis for understanding this concept:

- a. Students know how to describe chemical reactions by writing balanced equations.

Reactions are described by balanced equations because all the atoms of the reactants must be accounted for in the reaction products. An equation with all correct chemical formulas can be balanced by a number of methods, the simplest being by inspection. Given an unbalanced equation, students can do an inventory to determine how many of each atom are on each side of the equation. If the result is not equal for all atoms, coefficients (not subscripts) are changed until balance is achieved. Sometimes, reactions refer to substances with written names rather than to chemical symbols. Students should learn the rules of chemical nomenclature. This knowledge can be acquired in stages as new categories of functional groups are introduced.

3. b. Students know the quantity one mole is set by defining one mole of carbon-12 atoms to have a mass of exactly 12 grams.

The mole concept is often difficult for students to understand at first, but they can be taught that the concept is convenient in chemistry just as a dozen is a convenient concept, or measurement unit, in the grocery store. The mole is a number. Specifically, a *mole* is defined as the number of atoms in 12 grams of carbon-12. When atomic masses were assigned to elements, the mass of 12 grams of carbon-12 was selected as a standard reference to which the masses of all other elements are compared. The number of atoms in 12 grams of carbon-12 is defined as one *mole*, or conversely, if one mole of ^{12}C atoms were weighed, it would weigh exactly 12 grams. (Note that carbon, as found in nature, is a mixture of isotopes, including atoms of carbon-12, carbon-13, and trace amounts of carbon-14.) The definition of the mole refers to pure carbon-12.

The *atomic mass* of an element is the weighted average of the mass of one mole of its atoms based on the abundance of all its naturally occurring isotopes. The atomic mass of carbon is 12.011 grams. If naturally occurring carbon is combined with oxygen to form carbon dioxide, the mass of one mole of naturally occurring oxygen can be determined from the combining mass ratios of the two elements. For example, the weight, or atomic mass, of one mole of oxygen containing mostly oxygen-16 and a small amount of oxygen-18 is 15.999 grams.

3. c. Students know one mole equals 6.02×10^{23} particles (atoms or molecules).

A mole is a very large number. Standard 3.b describes the mole as the number of atoms in 12 grams of ^{12}C . The number of atoms in a mole has been found experimentally to be about 6.02×10^{23} . This number, called Avogadro's number, is known to a high degree of accuracy.

3. d. Students know how to determine the molar mass of a molecule from its chemical formula and a table of atomic masses and how to convert the mass of a molecular substance to moles, number of particles, or volume of gas at standard temperature and pressure.

The molar mass of a compound, which is also called either the *molecular mass* or *molecular weight*, is the sum of the atomic masses of the constituent atoms of each element in the molecule. Molar mass is expressed in units of grams per mole. The periodic table is a useful reference for finding the atomic masses of each element. For example, one mole of carbon dioxide molecules contains one mole of carbon atoms weighing 12.011 grams and two moles of oxygen atoms weighing 2×15.999 grams for a total molecular mass of 44.009 grams per mole of carbon dioxide molecules.

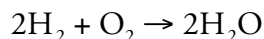
The mass of a sample of a compound can be converted to moles by dividing its mass by the molar mass of the compound. This process is similar to the unit conversion discussed in the introduction to Standard Set 3. The number of particles in the sample is determined by multiplying the number of moles by Avogadro's number. The volume of an ideal or a nearly ideal gas at a fixed temperature and pressure is proportional to the number of moles. Students should be able to calculate the number of moles of a gas from its volume by using the relationship that at standard temperature and pressure (0°C and 1 atmosphere), one mole of gas occupies a volume of 22.4 liters.

3. e. Students know how to calculate the masses of reactants and products in a chemical reaction from the mass of one of the reactants or products and the relevant atomic masses.

Atoms are neither created nor destroyed in a chemical reaction. When the chemical reaction is written as a balanced expression, it is possible to calculate the mass of any one of the products or of any one of the reactants if the mass of just one reactant or product is known.

Students can be taught how to use balanced chemical equations to predict the mass of any product or reactant. Teachers should emphasize that the coefficients in the balanced chemical equation are mole quantities, not masses. Here is an example: How many grams of water will be obtained by combining 5.0 grams of

hydrogen gas with an excess of oxygen gas, according to the following balanced equation?



This calculation is often set up algebraically, for example, as

and can be easily completed by direct calculation and unit cancellation (dimensional analysis). Students should learn to recognize that the coefficients in the balanced equations refer to moles rather than to mass.

3. f.* Students know how to calculate percent yield in a chemical reaction.

Students can use a balanced equation for a chemical reaction to calculate from the given masses of reactants the masses of the resulting products. The masses so calculated represent the theoretical 100 percent conversion of reactants to products. When one or more of the products are weighed, the masses are often less than the theoretical 100 percent yield. One explanation is that the reaction may not go to completion and therefore will not convert all the reactants to products. A second possible explanation is that product material is lost in the separation and purification process. A third reason is that alternative reactions are taking place, leading to products different from those predicted. Percent yield is a standard way to compare actual and theoretical yields. It is defined as

3. g.* Students know how to identify reactions that involve oxidation and reduction and how to balance oxidation-reduction reactions.

Oxidation of an element is defined as an increase in oxidation number, or a loss of electrons. *Reduction of an element* is defined as a decrease in oxidation number, or a gain in electrons. The assignment of oxidation numbers, or oxidation states, is a bookkeeping device. This process may be defined as the charge assigned to an atom, as though all the electrons in each bond were located on the more electronegative atom in the bond. Students should be taught how to assign oxidation numbers to atoms in free elements and in compounds. Lists of rules for this procedure are commonly found in chemistry textbooks.

In many important chemical reactions, elements change their oxidation states. These changes are called *redox*, or *oxidation-reduction reactions*. Respiration and photosynthesis are common examples with which students are familiar.

Any chemical reaction in which electrons are transferred from one substance to another is an oxidation-reduction reaction. Transfer can be determined by checking the oxidation states of atoms in reactants and products. A single displacement

reaction, such as zinc metal in a copper sulfate solution, is a typical redox reaction because the zinc atoms lose two electrons and the copper ions gain two electrons. Redox reactions may be balanced by ensuring that the number of electrons lost in one part of the reaction equals the number of electrons gained in another part of the reaction. This principle and the conservation of atoms will hold true in any balanced oxidation/reduction reaction.

Students should be taught how to use the half-reaction method for balancing redox equations. This method divides the reaction into an oxidation portion and a reduction portion, both of which are balanced separately and then combined into an overall equation with no net change in number of electrons.



STANDARD SET 4. Gases and Their Properties

Standard Set 4 requires a knowledge of applicable physical concepts and sufficient skills in mathematical problem solving to describe (1) gases at the molecular level; (2) the behavior of gases; and (3) the measurable properties of gases.

As background, students should know the physical states of matter and their properties and know how mixtures, especially homogeneous mixtures, differ from pure substances. Students should know that temperature measures how hot a system is, regardless of the system's size, and that heat flows from a region of higher temperature to one of lower temperature. Familiarity with the Celsius and Kelvin temperature scales is necessary. Knowledge of the motion of particles (and objects) and of kinetic energy is also required. Students should have the mathematical background to recognize and use directly and inversely proportional relationships. The ability to solve algebraic equations with several given quantities and one unknown is essential.

The main assumptions of the kinetic molecular theory should be covered in presenting this material, and a connection should be made to the behavior of ideal gases. Students are often more comfortable with studying the volume and temperature of a gas, but the concept of pressure also needs to be dealt with thoroughly. With knowledge of the kinetic molecular theory, students should see how motions and collisions of particles produce measurable properties, such as pressure.

4. The kinetic molecular theory describes the motion of atoms and molecules and explains the properties of gases. As a basis for understanding this concept:

- a. *Students know* the random motion of molecules and their collisions with a surface create the observable pressure on that surface.

Fluids consist of molecules that freely move past each other in random directions. Intermolecular forces hold the atoms or molecules in liquids close to each other. Gases consist of tiny particles, either atoms or molecules, spaced far apart from each other and reasonably free to move at high speeds, near the speed of sound. In the study of chemistry, gases and liquids are considered fluids.

Pressure is defined as force per unit area. The force in fluids comes from collisions of atoms or molecules with the walls of the container. Air pressure is created by the weight of the gas in the atmosphere striking surfaces. Gravity pulls air molecules toward Earth, the surface that they strike. Water pressure can be understood in the same fashion, but the pressures are much greater because of the greater density of water. Pressure in water increases with depth, and pressure in air decreases with altitude. However, pressure is felt equally in all directions in fluids because of the random motion of the molecules.

4. b. *Students know* the random motion of molecules explains the diffusion of gases.

Another result of the kinetic molecular theory is that gases diffuse into each other to form homogeneous mixtures. An excellent demonstration of diffusion is the white ammonium chloride ring formed by simultaneous diffusion of ammonia vapor and hydrogen chloride gas toward the middle of a glass tube. The white ring forms nearer the region where hydrogen chloride was introduced, illustrating both diffusion and the principle that heavier gases have a slower rate of diffusion.

4. c. *Students know* how to apply the gas laws to relations between the pressure, temperature, and volume of any amount of an ideal gas or any mixture of ideal gases.

A fixed number of moles n of gas can have different values for pressure P , volume V , and temperature T . Relationships among these properties are defined for an ideal gas and can be used to predict the effects of changing one or more of these properties and solving for unknown quantities. Students should know and be able to use the three gas law relationships summarized in Table 1, “Gas Law Relationships.”

Table 1
Gas Law Relationships

Expression of gas laws	Fixed values	Variable relationships	Form for calculations
$PV = \text{constant}$	n, T	Inverse	$P_1V_1 = P_2V_2$
$V/T = \text{constant}$	n, P	Direct	$V_1/T_1 = V_2/T_2$
$P/T = \text{constant}$	n, V	Direct	$P_1/T_1 = P_2/T_2$

The first expression of the gas law shown in Table 1 is sometimes taught as Boyle’s law and the second as Charles’s law, according to the historical order of their discovery. They are both simpler cases of the more general ideal gas law introduced in Standard 4.h in this section. For a fixed number of moles of gas, a combined gas law has the form $PV/T = \text{constant}$, or $P_1V_1/T_1 = P_2V_2/T_2$. This law is useful in calculations where P , V , and T are changing. By placing a balloon over the

mouth of an Erlenmeyer flask, the teacher can demonstrate that volume divided by temperature equals a constant. When the flask is heated, the balloon inflates; when the flask is cooled, the balloon deflates.

4. d. *Students know the values and meanings of standard temperature and pressure (STP).*

Standard temperature is 0°C , and standard pressure (STP) is 1 atmosphere (760 mm Hg). These standards are an agreed-on set of conditions for gases against which to consider other temperatures and pressures. When volumes of gases are being compared, the temperature and pressure must be specified. For a fixed mass of gas at a specified temperature and pressure, the volume is also fixed.

4. e. *Students know how to convert between the Celsius and Kelvin temperature scales.*

Some chemical calculations require an absolute temperature scale, called the Kelvin scale (K), for which the coldest possible temperature is equal to zero. There are no negative temperatures on the Kelvin scale. In theory if a sample of any material is cooled as much as possible, the lowest temperature that can be reached is 0 K, experimentally determined as equivalent to -273.15°C . The Kelvin scale starts with absolute zero (0 K) because of this theoretical lowest temperature limit. A Kelvin temperature is always 273.15 degrees greater than an equivalent Celsius temperature, but a Kelvin temperature is specified without the degree symbol. The magnitude of one unit of change in the K scale is equal to the magnitude of one unit of change on the $^{\circ}\text{C}$ scale.

4. f. *Students know there is no temperature lower than 0 Kelvin.*

The kinetic molecular theory is the basis for understanding heat and temperature. The greater the atomic and molecular motion, the greater the observed temperature of a substance. If all atomic and molecular motion stopped, the temperature of the material would reach an absolute minimum. This minimum is absolute zero, or -273.15°C . The third law of thermodynamics states that this temperature can never be reached. Experimental efforts to create very low temperatures have resulted in lowering the temperature of objects to within a fraction of a degree of absolute zero.

4. g.* *Students know the kinetic theory of gases relates the absolute temperature of a gas to the average kinetic energy of its molecules or atoms.*

The value of the average kinetic energy for an ideal gas is directly proportional to its Kelvin temperature. Average kinetic energy can be related to changes in pressure and volume as a function of temperature. At 0 K all motion in an ideal monatomic gas ceases, meaning that the average kinetic energy equals zero.

4. h.* Students know how to solve problems by using the ideal gas law in the form $PV = nRT$.

The relationships among pressure, volume, and temperature for a fixed mass of gas can be expressed as the ideal gas law, $PV = nRT$, where n represents moles and R represents the universal gas constant, which is 0.0821 liter-atmosphere per mole-Kelvin (this unit can be abbreviated as (L atm)/(mol K) or as L atm mol⁻¹ K⁻¹).

4. i.* Students know how to apply Dalton's law of partial pressures to describe the composition of gases and Graham's law to predict diffusion of gases.

It is important to distinguish clearly between *diffusion* and *effusion*. *Diffusion* is the process by which separate atoms or molecules intermingle as a result of random motion. *Effusion* is the process by which gas molecules pass from one container to another at lower pressure through a very small opening.

Graham's law states that the rates of effusion of two gases at the same temperature and pressure are inversely proportional to the square roots of their molar masses. Graham's law also approximately applies to rates of diffusion for gases, although diffusion is a more complicated process to describe than effusion.

Dalton's law of partial pressures states that total pressure in a gas-filled container is equal to the sum of the partial pressures of the component gases. This law can be introduced by showing that ideal gases have properties based solely on the number of moles present in the sample, without regard to the chemical identities of the gas particles involved.



STANDARD SET 5. Acids and Bases

Students who learn the concepts in this standard set will be able to understand and explain aqueous acid–base reactions, properties of acids and bases, and pH as a measure of acidity and basicity. Careful thought should be given to how this standard set best fits with the other chemistry standards. It may be desirable to cover Standard Set 6, “Solutions,” in this section first so that students will know about the aqueous dissolving process and about concentration calculations and units. Familiarity with Standard Set 9, “Chemical Equilibrium,” in this section may help students to conceptualize the strengths of acids and bases.

Students should be able to represent and balance chemical reactions. They should also be able to interpret periodic trends in electronegativity for the upper two rows of the periodic table (see Standard Set 1, “Atomic and Molecular Structure,” in this section). Hydrogen with its low electronegativity easily forms the positive hydrogen ion, H⁺. Students need to know the charge and formula of the hydroxide ion, OH⁻. With knowledge of polar covalent bonding, students should

be able to distinguish between two important types of neutral molecular compounds: those that dissolve in an aqueous solution and remain almost completely as neutral molecules and those that dissolve in an aqueous solution and partially or almost completely produce charged ions (see Standard Sets 1 and 2 in this section).

Students should be able to compare the three descriptions of acids and bases—the Arrhenius, Brønsted-Lowry, and Lewis acid–base definitions—and recognize electron lone pairs on Lewis dot structures of molecules (see Standard Set 2, “Chemical Bonds,” in this section). To calculate pH, students should understand and be able to use base-10 logarithms and antilogarithms and know how to obtain logarithms by using a calculator. Students should become proficient at converting between pH, pOH, $[H^+]$, and $[OH^-]$.

5. Acids, bases, and salts are three classes of compounds that form ions in water solutions. As a basis for understanding this concept:

- a. *Students know the observable properties of acids, bases, and salt solutions.*

Comparing and contrasting the properties of acids and bases provide a context for understanding their behavior. Some observable properties of acids are that they taste sour; change the color of litmus paper from blue to red; indicate acidic values on universal indicator paper; react with certain metals to produce hydrogen gas; and react with metal hydroxides, or bases, to produce water and a salt. Some observable properties of bases are that basic substances taste bitter or feel slippery; change the color of litmus paper from red to blue; indicate basic values on universal indicator paper; and react with many compounds containing hydrogen ions, or acids, to produce water and a salt.

These properties can be effectively demonstrated by using extracted pigment from red cabbage as an indicator to analyze solutions of household ammonia and white vinegar at various concentrations. When the indicator is added, basic solutions turn green, and acidic solutions turn red. Students can also use universal indicator solutions to test common household substances. **Students need to follow established safety procedures while conducting experiments.**

- 5. b.** *Students know acids are hydrogen-ion-donating and bases are hydrogen-ion-accepting substances.*

According to the Brønsted-Lowry acid–base definition, acids donate hydrogen ions, and bases accept hydrogen ions. Acids that are formed from the nonmetals found in the first and second rows of the periodic table easily dissociate to produce hydrogen ions because these nonmetals have a large electronegativity compared with that of hydrogen. Once students know that acids and bases have different effects on the same indicator, they are ready to deepen their understanding of acid–base behavior at the molecular level. Examples and studies of chemical reactions should be used to demonstrate these definitions of acids and bases.

5. c. *Students know strong acids and bases fully dissociate and weak acids and bases partially dissociate.*

Acids dissociate by donating hydrogen ions, and bases ionize by dissociating to form hydroxide ions (from a hydroxide salt) or by accepting hydrogen ions. Some acids and bases either dissociate or ionize almost completely, and others do so only partially. Nearly complete dissociation is strong; partial dissociation is weak. The strength of an acid or a base can vary, depending on such conditions as temperature and concentration.

5. d. *Students know how to use the pH scale to characterize acid and base solutions.*

The pH scale measures the concentrations of hydrogen ions in solution and the acidic or basic nature of the solution. The scale is not linear but logarithmic, meaning that at pH 2, for example, the concentration of hydrogen ions is ten times greater than it is at pH 3. The pH scale ranges from below 0 (very acidic) to above 14 (very basic). Students should learn that pH values less than 7 are considered acidic and those greater than 7 are considered basic.

5. e.* *Students know the Arrhenius, Brønsted-Lowry, and Lewis acid–base definitions.*

Other acid–base definitions beside Brønsted-Lowry (see Standard 5.b in this section) are the Arrhenius and Lewis definitions. An Arrhenius base must contain hydroxide, such as in the chemical KOH. NH_3 does not contain hydroxide and therefore would not be a base according to the Arrhenius definition. However, because NH_3 accepts hydrogen ions, it would be a base according to the Brønsted-Lowry definition. A Lewis acid is an electron pair receptor, and a Lewis base is an electron pair donor. Using the Lewis definition extends the concept of acid–base reactions to nonaqueous systems. The compound BF_3 , for example, is an acid because it accepts a lone electron pair, but BF_3 would not be an acid according to the Brønsted-Lowry definition because the hydrogen ion is not present.

5. f.* *Students know how to calculate pH from the hydrogen-ion concentration.*

The pH scale is defined as $-\log_{10}[\text{H}^+]$, where $[\text{H}^+]$ is the hydrogen-ion concentration in moles per liter of solution. Students should be taught to convert between hydrogen-ion concentration and pH.

5. g.* *Students know buffers stabilize pH in acid–base reactions.*

A buffer is a solution that stabilizes H^+ concentration levels. Such a solution may release hydrogen ions as pH rises or consume hydrogen ions as pH decreases. A critically important, but extremely complex example is the equilibria between

carbon dioxide, carbonic acid, bicarbonate, carbonate, and solid calcium carbonate that keeps the world's oceans at a nearly constant pH of about 8. Another measure students should learn is pOH, which is the negative logarithm of the OH^- concentration expressed in moles per liter of solution. The sum of pH and pOH is always 14.0 for a given solution at 25°C .



STANDARD SET 6. Solutions

As background for this standard set, students must know the physical states of matter and the corresponding properties. Specifically, the properties of the liquid state are important because most discussions will focus on liquid solutions. Students also need an understanding of molecules and ions and sufficient mathematical skills (especially an understanding of unit conversions) to describe solutions at the ionic or molecular level, describe the dissolution process, and quantify solution concentrations. Moreover, students should be able to calculate mass and volume in a variety of units and work with ratios, percentages, and moles (see Standard Set 3, “Conservation of Matter and Stoichiometry”).

The sequencing of instruction regarding these standards deserves special attention and consideration. The knowledge of mixtures (especially of homogeneous mixtures), which will be acquired from the study of these standards, can be helpful in reinforcing the concepts of electronegativity, covalent bonding, shapes of molecules, and ionic compounds (see Standard Set 1, “Atomic and Molecular Structure,” and Standard Set 2, “Chemical Bonds”). Some of these standards may also be helpful prerequisite knowledge for understanding Standard Set 5, “Acids and Bases.” These standards also help prepare students to study the separation or purification of solution components as covered in Standard Set 9, “Chemical Equilibrium.” Toward that end, instruction in these standards should include the concept of solubility as an equilibrium between solid and solute forms of a substance and the study of reactions that lead to precipitate formation.

6. Solutions are homogeneous mixtures of two or more substances.

As a basis for understanding this concept:

- a. *Students know* the definitions of *solute* and *solvent*.

Simple solutions are homogeneous mixtures of two substances. A *solute* is the dissolved substance in a solution, and a *solvent* is, by quantity, the major component in the solution.

- b. *Students know* how to describe the dissolving process at the molecular level by using the concept of random molecular motion.

The kinetic molecular theory as applied to gases can be extended to explain how the solute and solvent particles are in constant random motion. The kinetic energy

of this motion causes diffusion of the solute into the solvent, resulting in a homogeneous solution. When a solid is in contact with a liquid, at least some small degree of dissolution always occurs. The equilibrium concentration of solute in solvent will depend on the surface interactions between the molecules of solute and solvent. Equilibrium is reached when all competing processes are in balance. Those processes include the tendency for dissolved molecules to spread randomly in the solvent and the competing strength of the bonds and other forces among solute molecules, among solvent molecules, and between solute and solvent molecules. When salts dissolve in water, positive and negative ions are separated and surrounded by polar water molecules.

6. c. *Students know temperature, pressure, and surface area affect the dissolving process.*

In a liquid solvent, solubility of gases and solids is a function of temperature. Students should have experience with reactions in which precipitates are formed or gases are released from solution, and they should be taught that the concentration of a substance that appears as solid or gas must exceed the solubility of the solvent.

Increasing the temperature usually increases the solubility of solid solutes but always decreases the solubility of gaseous solutes. An example of a solid ionic solute compound that decreases in solubility as the temperature increases is Na_2SO_4 . An example of one that increases in solubility as the temperature increases is NaNO_3 . The solubility of a gas in a liquid is directly proportional to the pressure of that gas above the solution. It is important to distinguish solubility equilibrium from rates of dissolution. Concepts of equilibrium describe only how much solute will dissolve at equilibrium, not how quickly this process will occur.

6. d. *Students know how to calculate the concentration of a solute in terms of grams per liter, molarity, parts per million, and percent composition.*

All concentration units listed previously are a measure of the amount of solute compared with the amount of solution. Grams per liter represent the mass of solute divided by the volume of solution. *Molarity* describes moles of solute divided by liters of solution. Students can calculate the number of moles of dissolved solute and divide by the volume in liters of the total solution, yielding units of moles per liter. Parts per million, which is a ratio of one part of solute to one million parts of solvent, is usually applied to very dilute solutions. Percent composition is the ratio of one part of solute to one hundred parts of solvent and is expressed as a percent. To calculate parts per million and percent composition, students determine the mass of solvent and solute and then divide the mass of the solute by the total mass of the solution. This number is then multiplied by 10^6 and expressed as parts per million (ppm) or by 100 and expressed as a percent.

6. e.* Students know the relationship between the molality of a solute in a solution and the solution's depressed freezing point or elevated boiling point.

The physical properties of the freezing point and boiling point of a solution are directly proportional to the concentration of the solution in molality. *Molality* is similar to *molarity* except that molality expresses moles of solute dissolved in a kilogram of solvent rather than in a liter of solution. In other words, *molality* is the amount of solute present divided by the amount of solvent present. Molality is a convenient measure because it does not depend on volume and therefore does not change with temperature. Sometimes physical properties change with concentration of solute; for example, salt, such as sodium chloride or calcium chloride, is sprinkled on icy roads to lower the freezing point of water and melt the snow or ice. The freezing point is lowered, or depressed, in proportion to the amount of salt dissolved.

6. f.* Students know how molecules in a solution are separated or purified by the methods of chromatography and distillation.

Chromatography is a powerful, commonly used method to separate substances for analysis, including DNA, protein, and metal ions. The principle takes advantage of a moving solvent and a stationary substrate to induce separation. A useful, interesting example is paper chromatography. In this laboratory technique a mixture of solutes, such as ink dyes, is applied to a sheet of chromatographic paper. One end of the paper is dipped in a solvent that moves (wicks) up or along the paper. Solutes (the various ink dyes, for example) separate into bands of colors. Solutes with great affinity for the paper move little, those with less move more, and those with very little affinity may travel with the leading edge of the solvent.

Mixtures can sometimes be separated by distillation, which capitalizes on differences in the forces holding molecules in a liquid state. Crude oil, for example, is processed by commercial refineries (by a catalytic reaction called "cracking") and separated by heat distillation to give a variety of commercial products, from highly volatile kerosene and gasoline to heavier oils used to lubricate engines or to heat homes.



STANDARD SET 7. Chemical Thermodynamics

Students should know the relationship between heat and temperature and understand the concepts of kinetic energy and motion at the molecular level. They should also know how to differentiate between chemical and physical change and understand that both types of change entail the loss of free energy, a process that results in increased stability. The standards marked with an asterisk in this

section require students to know the concepts presented in the physics section of this chapter, Standard Set 3, “Heat and Thermodynamics.” Those standards provide a foundation for understanding the kinetic molecular model and introduce students to concepts of heat and entropy.

7. Energy is exchanged or transformed in all chemical reactions and physical changes of matter. As a basis for understanding this concept:

- a.** Students know how to describe temperature and heat flow in terms of the motion of molecules (or atoms).

Temperature is a measure of the average kinetic energy of molecular motion in a sample. *Heat* is energy transferred from a sample at higher temperature to one at lower temperature. Often, heat is described as flowing from the system to the surroundings or from the surroundings to the system. The system is defined by its boundaries, and the surroundings are outside the boundaries, with “the universe” frequently considered as the surroundings.

- 7. b.** Students know chemical processes can either release (exothermic) or absorb (endothermic) thermal energy.

Endothermic processes absorb heat, and their equations can be written with heat as a reactant. *Exothermic processes* release heat, and their equations can be written with heat as a product. The net heat released to or absorbed from the surroundings comes from the making and breaking of chemical bonds during a reaction. Students understand and relate heat to the internal motion of the atoms and molecules. They also understand that breaking a bond always requires energy and that making a bond almost always releases energy. The amount of energy per bond depends on the strength of the bond.

The potential energy of the reaction system may be plotted for the different reaction stages: reactants, transition states, and products. This plot will show reactants at lower potential energy than products for an endothermic reaction and reactants at higher potential energy than products for an exothermic reaction. A higher energy transition state usually exists between the reactant and product energy states that affect the reaction rate covered in Standard Set 8, “Reaction Rates,” in this section.

- 7. c.** Students know energy is released when a material condenses or freezes and is absorbed when a material evaporates or melts.

Physical changes are accompanied by changes in internal energy. Changes of physical state either absorb or release heat. Evaporation and melting require energy to overcome the bonds of attractions in the corresponding liquid or solid state. Condensation and freezing release heat to the surroundings as internal energy is reduced and bonds of attraction are formed.

7. d. Students know how to solve problems involving heat flow and temperature changes, using known values of specific heat and latent heat of phase change.

Qualitative knowledge that students gained by mastering the previous standards will help them to solve problems related to the heating or cooling of a substance over a given temperature range. *Specific heat* is the energy needed to change the temperature of one gram of substance by one degree Celsius. The unit of specific heat is joule/gram-degree.

During phase changes, energy is added or removed without a corresponding temperature change. This phenomenon is called *latent* (or *hidden*) *heat*. There is a latent heat of fusion and a latent heat of vaporization. The unit of latent heat is joule/gram or kilojoule/mole. Students should be able to diagram the temperature changes that occur when ice at a temperature below zero is heated to superheated steam, which has temperatures above 100°C.

7. e.* Students know how to apply Hess's law to calculate enthalpy change in a reaction.

As samples of elements combine to make compounds, heat may be absorbed from the environment. If one mole of a compound is formed from elements and all substances begin and end at 25°C and are under standard atmospheric pressure, the heat absorbed during the compound's synthesis is known as its *standard enthalpy of formation*, H_f° . If heat is not absorbed but released, H_f° is negative. Values for the enthalpy of formation of thousands of compounds are available in reference books.

Hess's law states that if a chemical reaction is carried out in any imaginable series of steps, the net enthalpy change (heat absorbed) in the reaction is the sum of the enthalpy changes for the individual steps. For example, a reaction can be imagined to proceed in just two steps: first, making its reactants into elements, and second, making those elements into products. The enthalpy change in a reaction $aA + bB = cC + dD$ is the quantity ΔH_r° defined as "the heat absorbed when a moles of chemical A and b moles of B react to make c moles of C and d moles of D." Through the use of Hess's law and the two steps of the example, the enthalpy change for this reaction can be expressed in terms of the enthalpy of formation H_f° of each of the chemicals: the enthalpy change is the (weighted) sum of the heat of formation for each of the products minus the sum for each of the reactants, or

$$\Delta H_r^\circ = [c H_f^\circ(\text{C}) + d H_f^\circ(\text{D})] - [a H_f^\circ(\text{A}) + b H_f^\circ(\text{B})]$$

By using the balanced equation for a chemical reaction and the enthalpy of formation for each chemical, students can calculate the heat absorbed or released when a given quantity of a reactant is consumed.

7. f.* *Students know how to use the Gibbs free energy equation to determine whether a reaction would be spontaneous.*

Endothermic and exothermic reactions can be spontaneous under standard conditions of temperature and pressure. Therefore, releasing heat and going to a lower energy state cannot be the only force driving chemical reactions. The tendency to disorder, or entropy, is the other driving force. A convenient conceptual way to account for the balance between these two driving forces, enthalpy changes and changes in disorder, was developed by J. Willard Gibbs and is called the Gibbs free-energy change ΔG .

In the Gibbs free-energy equation (shown below), ΔH is the change in enthalpy, T is the Kelvin temperature, and ΔS is the change in entropy. (Note that students may need to be introduced to the basics of entropy, as presented in Standard Set 3 for physics in this chapter).

$$\Delta G = \Delta H - T\Delta S$$

The Gibbs free-energy change is used to predict in which direction a reaction will proceed. A negative value for the Gibbs free-energy change predicts the formation of products (a spontaneous reaction); a positive value predicts, or favors, reactants (a nonspontaneous reaction). Standard values for the Gibbs free energy of elements and compounds at a specified temperature are available in tables.



STANDARD SET 8. Reaction Rates

To describe rates of chemical reactions, factors affecting rates, and the energy changes involved, students need to know that chemical reactions consume reactants and form products (see Standard Set 3, “Conservation of Matter and Stoichiometry,” in this section). Students should be able to

explain chemical reactions at the molecular level and know how kinetic energy at the molecular level is measured by temperature (see Standard Sets 3 and 7 in this section). Students have acquired knowledge of pressure and volume relationships for gases (see Standard Set 4, “Gases and Their Properties,” in this section) and can plot potential energy versus course of reaction for endothermic and exothermic reactions (see Standard Set 7, “Chemical Thermodynamics,” in this section). The ability to calculate rates of change from slopes of lines and curves is required.

8. Chemical reaction rates depend on factors that influence the frequency of collision of reactant molecules. As a basis for understanding this concept:

- a. *Students know* the rate of reaction is the decrease in concentration of reactants or the increase in concentration of products with time.

Students may have an intuitive idea that reaction rate is a measure of how fast reactions proceed, but a quantitative measure for reaction rate also is needed. For

example, explosive reactions are very fast, as are many biological reactions in the cell; and other reactions, such as iron rusting, are very slow. *Reaction rate* is defined as the rate of decrease in concentration of reactants or as the rate of increase in concentration of products, and these reciprocal changes form a balanced equation that reflects the conservation of matter. Students can see from the balanced equation that as the reaction proceeds, the concentration of reactants must decrease, and the concentration of products must increase in proportion to their mole ratios.

8. b. *Students know how reaction rates depend on such factors as concentration, temperature, and pressure.*

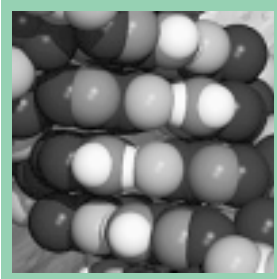
Concentration, temperature, and pressure should be emphasized because they are major factors affecting the collision of reactant molecules and, thus, affecting reaction rates. Increasing the concentration of reactants increases the number of collisions per unit time. Increasing temperature (which increases the average kinetic energy of molecules) also increases the number of collisions per unit time. Though the collision rate modestly increases, the greater kinetic energy dramatically increases the chances of each collision leading to a reaction (e.g., the Arrhenius effect). Increasing pressure increases the reaction rate only when one or more of the reactants or products are gases. With gaseous reactants, increasing pressure is the same as increasing concentration and results in an elevated reaction rate.

8. c. *Students know the role a catalyst plays in increasing the reaction rate.*

A *catalyst* increases the rate of a chemical reaction without taking part in the net reaction. A catalyst lowers the energy barrier between reactants and products by promoting a more favorable pathway for the reaction. Surfaces often play important roles as catalysts for many reactions. One reactant might be temporarily held on the surface of a catalyst. There the bonds of the reactant may be weakened, allowing another substance to react with it more quickly. Living systems speed up life-dependent reactions with biological catalysts called *enzymes*. Catalysts are used in automobile exhaust systems to reduce the emission of smog-producing unburned hydrocarbons.

8. d.* *Students know the definition and role of activation energy in a chemical reaction.*

Even in a spontaneous reaction, reactants are usually required to pass through a transition state that has a higher energy than either the reactants or the products. The additional energy, called the *activation energy*, or the *activation barrier*, is related to such factors as strength of bonding within the reactants. The more energy required to go from reactants to activated transition complex, the higher the activation barrier, and the slower a reaction will be. Catalysts speed up rates by lowering the activation barrier along the reaction pathway between products and reactants.



STANDARD SET 9. Chemical Equilibrium

Chemical equilibrium is a dynamic state. To understand the factors affecting equilibrium and to write expressions used to quantify a state of equilibrium, students will need a thorough knowledge of reaction rates (see Standard Set 8, “Reaction Rates,” in this section) and of chemical thermodynamics (see Standard Set 7, “Chemical Thermodynamics,” in this section). Changes in heat accompanying chemical reactions and spontaneity of chemical reactions are key topics. Students should be able to identify the physical states of substances undergoing chemical reactions and use knowledge of substances at the atomic and molecular levels (see Standard Set 3, “Conservation of Matter and Stoichiometry,” in this section).

Students need to know how gases respond to changes in pressure and volume (see Standard Set 4, “Gases and Their Properties,” in this section). Students need to be able to calculate concentration and molarity for solutions, particularly for aqueous solutions (see Standard Set 6, “Solutions,” in this section). Students familiar with acid–base reactions (see Standard Set 5, “Acids and Bases,” in this section) and precipitation reactions (see Standard Set 6 in this section) will have an advantage in learning the concept of equilibrium.

To calculate equilibrium constants, students should be able to balance chemical equations (see Standard Set 3 in this section), work readily with concentration and pressure units (see Standard Sets 4 and 6 in this section), and use exponents in mathematical calculations.

Students often have difficulty in understanding that equilibrium, which is a dynamic process, occurs when no net changes in a product or reactant concentration take place. An analogy can be made with a pair of escalators operating between two floors. If the same number of people go up as go down in a ten-minute interval, the rate of people moving up equals the rate of people moving down. Overall, any extra people arriving on one floor are canceled out by others leaving the floor. Therefore, the number of people on each floor will be constant over time, and the population of the two floors is in dynamic equilibrium. This analogy can be extended to a chemical reaction by considering that if the number of moles produced in one direction of the reaction is the same as the number consumed in the opposite direction, then the reaction has reached a state of dynamic equilibrium. Students will learn that when a stress is applied to a chemical reaction in equilibrium, a shift will occur to partly relieve the stress.

9. Chemical equilibrium is a dynamic process at the molecular level.

As a basis for understanding this concept:

- a. Students know how to use Le Chatelier’s principle to predict the effect of changes in concentration, temperature, and pressure.

Le Chatelier’s principle can be introduced by emphasizing the balanced nature of an equilibrium system. If an equilibrium system is stressed or disturbed, the

system will respond (change or shift) to partially relieve or undo the stress. A new equilibrium will eventually be established with a new set of conditions. When the stress is applied, the reaction is no longer at equilibrium and will shift to regain equilibrium. For instance, if the concentration of a reactant in a system in dynamic equilibrium is decreased, products will be consumed to produce more of that reactant. Students need to remember that heat is a reactant in endothermic reactions and a product in exothermic reactions. Therefore, increasing temperature will shift an endothermic reaction, for example, to the right to regain equilibrium. Students should note that any endothermic chemical reaction is exothermic in the reverse direction.

Pressure is proportional to concentration for gases; therefore, for chemical reactions that have a gaseous product or reactant, pressure affects the system as a whole. Increased pressure shifts the equilibrium toward the smaller number of moles of gas, alleviating the pressure stress. If both sides of the equilibrium have an equal number of moles of gas, increasing pressure does not affect the equilibrium. Adding an inert gas, such as argon, to a reaction will not change the partial pressures of the reactant or product gases and therefore will have no effect on the equilibrium.

9. b. *Students know* equilibrium is established when forward and reverse reaction rates are equal.

Forward and reverse reactions at equilibrium are going on at the same time and at the same rate, causing overall concentrations of each reactant and product to remain constant over time.

9. c.* *Students know* how to write and calculate an equilibrium constant expression for a reaction.

Because the concentrations of substances in a system at chemical equilibrium are constant over time, chemical expressions related to each concentration will also be constant. Here is a general equation for a reaction at equilibrium:



The general expression for the equilibrium constant of a chemical reaction is K_{eq} , defined at a particular temperature, often 25°C. Its formula is

When K_{eq} is being calculated, only gaseous substances and aqueous solutions are considered. Equilibrium concentrations of products, in moles per liter, are in the numerator, and equilibrium concentrations of reactants are in the denominator. The exponents are the corresponding coefficients from the balanced chemical equation. A large K_{eq} means the forward reaction goes almost to completion; that is, little reverse reaction occurs. A very small K_{eq} means the reverse reaction goes almost to completion, or little forward reaction occurs. The solubility product constant K_{sp} is the equilibrium constant for salts in solution.



STANDARD SET 10. Organic and Biochemistry

A solid understanding of chemical and biological concepts is required to describe the versatility with which carbon atoms form molecules and to illustrate the structure of organic and biological molecules and the polymers they

form. An understanding of these concepts is also necessary to be able to name organic molecules and to identify organic functional groups. Students also need to know the material in atomic and molecular structure (see Standard Set 1, “Atomic and Molecular Structure,” in this section), especially as the concepts pertain to carbon and nearby nonmetals and to electronegativity.

Chemical bonds (see Standard Set 2, “Chemical Bonds,” in this section), especially the topics of covalent bonding and Lewis dot structures, should also be well understood. Students should know the importance of biochemical compounds—proteins, carbohydrates, and nucleic acids—and understand their roles in living organisms. They must be familiar with single, double, and triple bonds to name organic molecules correctly (see Standard Set 2 in this section) and with the covalent bonding and electronegativity of nitrogen and oxygen to identify functional groups of organic molecules and to understand amino acids and proteins (see Standard Sets 1 and 2 in this section).

10. The bonding characteristics of carbon allow the formation of many different organic molecules of varied sizes, shapes, and chemical properties and provide the biochemical basis of life. As a basis for understanding this concept:

- a.** *Students know* large molecules (polymers), such as proteins, nucleic acids, and starch, are formed by repetitive combinations of simple subunits.

Students can readily visualize large molecules called polymers as consisting of repetitive and systematic combinations of smaller, simpler groups of atoms, including carbon. All polymeric molecules, including biological molecules, such as proteins, nucleic acids, and starch, are made up of various unique combinations of a relatively small number of chemically simple subunits. For example, starch is a polymer made from a large number of simple sugar molecules joined together.

- 10. b.** *Students know* the bonding characteristics of carbon that result in the formation of a large variety of structures ranging from simple hydrocarbons to complex polymers and biological molecules.

Building on what they learned in grade eight about the unique bonding characteristics of carbon, students explore in greater depth the incredible diversity of carbon-based molecules. They are reminded that, given carbon’s four bonding electrons and four vacancies available to form bonds, carbon is able to form stable

covalent bonds—single or multiple—with other carbon atoms and with atoms of other elements.

Students learn how the presence of single, double, and triple bonds determines the geometry of carbon-based molecules. The variety of these molecules is enormous: over 16 million carbon-containing compounds are known. The compounds range from simple hydrocarbon molecules (e.g., methane and ethane) to complex organic polymers and biological molecules (e.g., proteins) and include many manufactured polymers used in daily life (e.g., polyester, nylon, and polyethylene).

10. c. *Students know amino acids are the building blocks of proteins.*

Proteins are large single-stranded polymers often made up of thousands of relatively small subunits called *amino acids*. The bond attaching two amino acids, known as the *peptide bond*, is identical for any pair of amino acids. The chemical composition of the amino acid itself varies. Variation in composition and ordering of amino acids gives protein molecules their unique properties and shapes. These properties and shapes define the protein's functions, many of which are essential to the life of an organism. The blueprint for building the protein molecules is deoxyribonucleic acid (DNA). Biotechnology is advancing rapidly as more is learned about DNA, amino acid sequences, and the shapes and functions of proteins.

10. d.* *Students know the system for naming the ten simplest linear hydrocarbons and isomers that contain single bonds, simple hydrocarbons with double and triple bonds, and simple molecules that contain a benzene ring.*

Organic molecules can be simple or extremely complex. The naming system for these molecules, however, is relatively straightforward and reflects the composition and structure of each molecule. Each name is made up of a prefix and a suffix. The prefix tells the number of carbon atoms in the longest continuous sequence of the molecule, and the suffix indicates the kind of bond between carbon atoms. For example, the four simplest hydrocarbon molecules are methane, ethane, propane, and butane. The prefixes, *meth-*, *eth-*, *prop-*, and *but-* refer to one, two, three, and four carbons, respectively. The *-ane* ending indicates that there are only carbon-carbon single bonds. *Ene* endings are used for double bonds and *-yne* for triple bonds. Benzene, C₆H₆, is a flat hexagonally shaped molecule of six carbon atoms bonded to each other. Many compounds can be built by substitutions on straight-chain hydrocarbons and benzene rings.

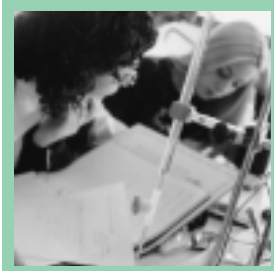
10. e.* *Students know how to identify the functional groups that form the basis of alcohols, ketones, ethers, amines, esters, aldehydes, and organic acids.*

Organic molecules are grouped into classes based on patterns of bonding between carbon and noncarbon atoms (e.g., nitrogen and oxygen). Groups based on unique patterns of bonding are called *functional groups*. Examples of these groups

are alcohols, ketones, ethers, amines, esters, aldehydes, and organic (carboxylic) acids.

10. f.* Students know the R-group structure of amino acids and know how they combine to form the polypeptide backbone structure of proteins.

Amino acid molecules have a well-known structure, and all contain a side chain called an *R-group*. Differences in the R-group are the basis for differences between the amino acids. Bonding two amino acids creates a *dipeptide*, bonding three creates a *tripeptide*, and adding more creates a polymer called a *polypeptide*. Polypeptides made biologically are called *proteins*.



STANDARD SET 11. Nuclear Processes

This section requires a knowledge of chemical and physical concepts and sufficient mathematical skills to describe the nucleus and its subatomic particles. Topics covered are nuclear reactions and their accompanying changes in energy and forms of radiation and quantification of radioactive decay as a function of time. Students should know about nuclear structure and properties, the mass and charge of the proton and neutron, and the use of the periodic table to determine the number of protons in an atom's nucleus (see Standard Set 1, "Atomic and Molecular Structure," in this section). Students should also know how to calculate and use percentages to determine the amount of radioactive substance remaining after a time interval of disintegration.

Students should be introduced to this standard set with a review of the nucleus and its constituent protons and neutrons. Simple hydrogen, deuterium, and tritium nuclei can be used to introduce and define *isotopes*. Students should be reminded of the difference between an element's average atomic mass and the mass number for a specific isotope. They should already know that electrons and protons attract each other as do any particles of opposite charge, but they probably do not know what holds the protons and neutrons in the nucleus together. Teachers should introduce students to the strong nuclear force and explain how it holds protons and neutrons together and how it can overcome the repulsion between charged protons at very close distances. Students should also be introduced to quarks as the constituents of protons and neutrons.

II. Nuclear processes are those in which an atomic nucleus changes, including radioactive decay of naturally occurring and human-made isotopes, nuclear fission, and nuclear fusion.

As a basis for understanding this concept:

- a. *Students know* protons and neutrons in the nucleus are held together by nuclear forces that overcome the electromagnetic repulsion between the protons.

The nucleus is held together by the strong nuclear force. The strong nuclear force acts between protons, between neutrons, and between protons and neutrons but has a limited range comparable to the size of an atomic nucleus. The nuclear force is able to overcome the mutual electrostatic repulsion of the protons only when the protons and neutrons are near each other as they are in the nucleus of an atom.

- b. *Students know* the energy release per gram of material is much larger in nuclear fusion or fission reactions than in chemical reactions. The change in mass (calculated by $E = mc^2$) is small but significant in nuclear reactions.

Two major types of nuclear reactions are fusion and fission. In *fusion* reactions two nuclei come together and merge to form a heavier nucleus. In *fission* a heavy nucleus splits apart to form two (or more) lighter nuclei. The binding energy of a nucleus depends on the number of neutrons and protons it contains. A general term for a proton or a neutron is a *nucleon*. In both fusion and fission reactions, the total number of nucleons does not change, but large amounts of energy are released as nucleons combine into different arrangements. This energy is one million times more than energies involved in chemical reactions.

- c. *Students know* some naturally occurring isotopes of elements are radioactive, as are isotopes formed in nuclear reactions.

Sometimes atoms with the same number of protons in the nucleus have different numbers of neutrons. These atoms are called *isotopes* of an element. Both naturally occurring and human-made isotopes of elements can be either stable or unstable. Less stable isotopes of one element, called *parent isotopes*, will undergo radioactive decay, transforming to more stable isotopes of another element, called *daughter products*, which can also be either stable or radioactive. For a radioactive isotope to be found in nature, it must either have a long half-life, such as potassium-40, uranium-238, uranium-235, or thorium-232, or be the daughter product, such as radon-222, of a parent with a long half-life, such as uranium-238.

II. d. *Students know the three most common forms of radioactive decay (alpha, beta, and gamma) and know how the nucleus changes in each type of decay.*

Radioactive isotopes transform to more stable isotopes, emitting particles from the nucleus. These particles are helium-4 nuclei (alpha radiation), electrons or positrons (beta radiation), or high-energy electromagnetic rays (gamma radiation). Isotopes of elements that undergo alpha decay produce other isotopes with two less protons and two less neutrons than the original isotope. Uranium-238, for instance, emits an alpha particle and becomes thorium-234.

Isotopes of elements that undergo beta decay produce elements with the same number of nucleons but with one more proton or one less proton. For example, thorium-234 beta decays to protactinium-234, which then beta decays to uranium-234. Alpha and beta decay are ionizing radiations with the potential to damage surrounding materials. After alpha and beta decay, the resulting nuclei often emit high-energy photons called *gamma rays*. This process does not change the number of nucleons in the nucleus of the isotope but brings about a lower energy state in the nucleus.

II. e. *Students know alpha, beta, and gamma radiation produce different amounts and kinds of damage in matter and have different penetrations.*

Alpha, beta, and gamma rays are *ionizing radiations*, meaning that those rays produce tracks of ions of atoms and molecules when they interact with materials. For all three types of rays, the energies of particles emitted in radioactive decay are typically for each particle on the order of 1MeV, equal to 1.6×10^{-13} joule, which is enough energy to ionize as many as half a million atoms.

Alpha particles have the shortest ranges, and matter that is only a few millimeters thick will stop them. They will not penetrate a thick sheet of paper but will deposit all their energy along a relatively short path, resulting in a high degree of ionization along that path.

Beta particles have longer ranges, typically penetrating matter up to several centimeters thick. Those particles are electrons or positrons (the antimatter electron), have one unit of either negative or positive electric charge, and are approximately 1/2000 of the mass of a proton. These high-energy electrons have longer ranges than alpha particles and deposit their energy along longer paths, spreading the ionization over a greater distance in the material.

Gamma rays can penetrate matter up to several meters thick. Gamma rays are high-energy photons that have no electric charge and no rest mass (the structural energy of the particle). They will travel unimpeded through materials until they strike an electron or the nucleus of an atom. The gamma ray's energy will then be either completely or partially absorbed, and neighboring atoms will be ionized. Therefore, these three types of radiation interact with matter by losing energy and ionizing surrounding atoms.

Alpha radiation is dangerous if ingested or inhaled. For example, radon-222, a noble gas element, is a naturally occurring hazard in some regions. Living organisms or sensitive materials can be protected from ionizing radiation by shielding them and increasing their distance from radiation sources.

Because many people deeply fear and misunderstand radioactivity, chemistry teachers should address and explore the ability of each form of radiation to penetrate matter and cause damage. Students may be familiar with radon detection devices, similar to smoke detectors, found in many homes. Discussion of biological and health effects of ionizing radiation can inform students about the risks and benefits of nuclear reactions. Videos can be used in the classroom to show demonstrations of the penetrating ability of alpha, beta, and gamma radiation through paper, aluminum, and lead or through other dense substances of varying thicknesses. Geiger counter measurements can be used to record radiation data. The order of penetrating ability, from greatest to least, is gamma > beta > alpha, and this order is the basis for assessing proper shielding of radiation sources for safety.

There are a number of naturally occurring sources of ionizing radiation. One is potassium-40, which can be detected easily in potash fertilizer by using a Geiger counter. The other is background cosmic and alpha radiation from radon. This radiation can be seen in cloud chambers improvised in the classroom.

II. f.* *Students know how to calculate the amount of a radioactive substance remaining after an integral number of half-lives have passed.*

Radioactive decay transforms the initial (parent) nuclei into more stable (daughter) nuclei with a characteristic half-life. The *half-life* is the time it takes for one-half of a given number of parent atoms to decay to daughter atoms. One-half of the remaining parent atoms will then decay to produce more daughter atoms in the next half-life period. It is possible to predict only the proportion, not the individual number, of parent atoms that will undergo decay. Therefore, after one half-life, 50 percent of the initial parent nuclei remain; after two half-lives, 25 percent; and so forth. The intensity of radiation from a radioactive source is related to the half-life and to the original number of radioactive atoms present.

II. g.* *Students know protons and neutrons have substructures and consist of particles called quarks.*

Just as atoms consist of subatomic nuclear particles (protons and neutrons), so do protons and neutrons have constituent particles called *quarks*. Quarks come in six different types, but only two types are involved in ordinary matter: the *up quark* and the *down quark*.

For enrichment beyond the content in the standard, the following description is included: Protons and neutrons each contain three quarks. A proton consists of two up quarks and one down quark. A neutron consists of two down quarks and one up quark. Quarks have fractional electric charges; therefore, the charge of an

up quark is $+\frac{2}{3}$ units, and the charge of a down quark is $-\frac{1}{3}$ units. It is believed that it is not possible to isolate a free quark. All the common matter in the material world is made up of just three fundamental particles: the up quark, the down quark, and the electron.

Chapter 5
The Science
Content
Standards for
Grades Nine
Through
Twelve

Chemistry

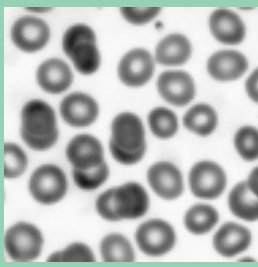
Biology/Life Sciences

Living organisms appear in many variations, yet there are basic similarities among their forms and functions. For example, all organisms require an outside source of energy to sustain life processes; all organisms demonstrate patterns of growth and, in many cases, senescence, the process of becoming old; and the continuity of all species requires reproduction. All organisms are constructed from the same types of macromolecules (proteins, nucleic acids, lipids) and inherit a deoxyribonucleic acid (DNA) genome from a parent or parents. DNA is always transcribed to yield ribonucleic acid (RNA), which is translated through the use of a nearly universal genetic code. Environmental factors frequently regulate and influence the expression of specific genes.

Biologists study life at many levels, and the biology standards for grades nine through twelve reflect these studies. *Organisms* are part of an ecosystem and have complex relationships with other organisms and the physical environment. Ecologists study these populations and communities, and many are deeply interested in the physical and behavioral adaptations of organisms. Evolutionary biologists share these interests because the fitness of an organism is a manifestation of these adaptations. *Adaptations* are traits subject to the rules of inheritance; therefore, genetics and evolutionary biology are closely allied fields.

Physiologists study whole body systems or organs. For example, a neurophysiologist focuses primarily on the nervous system. Cell biologists study the details of how cells and organelles work, considering such weighty matters as how cytoskeletal elements segregate chromosomes during mitosis, how proteins are sorted to different compartments of the cell, and how receptors in the cell membrane communicate with factors that regulate gene expression. Many cell biologists also consider themselves to be developmental biologists, molecular geneticists, or biochemists. There are many connections between all the fields and different ways of viewing life.

Biology textbooks typically start with a review of chemistry and energetics; therefore, California students will be able to make good use of their study of the content standards for “Chemistry of Living Systems” in the eighth grade. The principles of cellular biology, including respiration and photosynthesis, are usually taught next, followed by instruction in molecular and Mendelian genetics. Population genetics and evolution follow naturally from the study of genetics and lead to a discussion of diversity of form and physiology. The teaching culminates with ecology, a subject that draws on each of the preceding topics. The teaching comes full circle because ecology is also a starting point for students in lower elementary school grade levels.



STANDARD SET I. Cell Biology

The first knowledge of cells came from the work of an English scientist, Robert Hooke, who in 1665 used a primitive microscope to study thin sections of cork and called the boxlike cavities he saw “cells.” Antony van Leeuwenhoek later observed one-celled “animalcules” in pond water, but not until the 1830s did Theodor Schwann view cartilage tissue in which he discovered cells resembling plant cells. He published the theory that cells are the basic unit of life. Rudolf Virchow used the work of Schwann and Matthias Schleiden to advance the cell theory, presenting the concept that plants and animals are made of cells that contain fluid and nuclei and arise from preexisting cells.

After the cell theory was established, detailed study of cell structure and function depended on the improvement of microscopes and on techniques for preparing specimens for observation. It is now understood that cells in plants and animals contain genes to control chemical reactions needed for survival and organelles to perform those reactions. Living organisms may consist of one cell, as in bacteria, or of many cells acting in a coordinated and cooperative manner, as in plants, animals, and fungi. All cells have at least three structures in common: genetic material, a cell or plasma membrane, and cytoplasm.

I. The fundamental life processes of plants and animals depend on a variety of chemical reactions that occur in specialized areas of the organism’s cells. As a basis for understanding this concept:

- a.** *Students know* cells are enclosed within semipermeable membranes that regulate their interaction with their surroundings.

The plasma membrane consists of two layers of lipid molecules organized with the polar (globular) heads of the molecules forming the outside of the membrane and the nonpolar (straight) tails forming the interior of the membrane. Protein molecules embedded within the membrane move about relative to one another in a fluid fashion. Because of its dynamic nature the membrane is sometimes referred to as *the fluid mosaic model* of membrane structure.

Cell membranes have three major ways of taking in or of regulating the passage of materials into and out of the cell: simple diffusion, carrier-facilitated diffusion, and active transport. Osmosis of water is a form of diffusion. Simple diffusion and carrier-facilitated diffusion do not require the expenditure of chemical bond energy, and the net movement of materials reflects a concentration gradient or a voltage gradient or both. Active transport requires free energy, in the form of either chemical bond energy or a coupled concentration gradient, and permits the net transport or “pumping” of materials against a concentration gradient.

- I. b.** *Students know* enzymes are proteins that catalyze biochemical reactions without altering the reaction equilibrium and the activities of enzymes depend on the temperature, ionic conditions, and the pH of the surroundings.

Almost all *enzymes* are protein catalysts made by living organisms. Enzymes speed up favorable (spontaneous) reactions by reducing the activation energy required for the reaction, but they are not consumed in the reactions they promote. To demonstrate the action of enzymes on a substrate, the teacher can use liver homogenate or yeast as a source of the enzyme catalase and hydrogen peroxide as the substrate. The effect of various environmental factors, such as pH, temperature, and substrate concentration, on the rate of reaction can be investigated. These investigations should encourage student observation, recording of qualitative and quantitative data, and graphing and interpretation of data.

- I. c.** *Students know* how prokaryotic cells, eukaryotic cells (including those from plants and animals), and viruses differ in complexity and general structure.

All living cells are divided into one of two groups according to their cellular structure. *Prokaryotes* have no membrane-bound organelles and are represented by the Kingdom Monera, which in modern nomenclature is subdivided into the Eubacteria and Archaea. *Eukaryotes* have a complex internal structure that allows thousands of chemical reactions to proceed simultaneously in various organelles. *Viruses* are not cells; they consist of only a protein coat surrounding a strand of genetic material, either RNA or DNA.

- I. d.** *Students know* the central dogma of molecular biology outlines the flow of information from transcription of ribonucleic acid (RNA) in the nucleus to translation of proteins on ribosomes in the cytoplasm.

DNA, which is found in the nucleus of eukaryotes, contains the genetic information for encoding proteins. The DNA sequence specifying a specific protein is copied (transcribed) into messenger RNA (mRNA), which then carries this message out of the nucleus to the ribosomes located in the cytoplasm. The mRNA message is then translated, or converted, into the protein originally coded for by the DNA.

- I. e.** *Students know* the role of the endoplasmic reticulum and Golgi apparatus in the secretion of proteins.

There are two types—rough and smooth—of endoplasmic reticulum (ER), both of which are systems of folded sacs and interconnected channels. *Rough ER* synthesizes proteins, and *smooth ER* modifies or detoxifies lipids. Rough ER produces new proteins, including membrane proteins. The proteins to be exported from the cell are moved to the Golgi apparatus for modification, packaged in vesicles, and transported to the plasma membrane for secretion.

I. f. Students know usable energy is captured from sunlight by chloroplasts and is stored through the synthesis of sugar from carbon dioxide.

Photosynthesis is a complex process in which visible sunlight is converted into chemical energy in carbohydrate molecules. This process occurs within chloroplasts and specifically within the thylakoid membrane (light-dependent reaction) and the stroma (light-independent reaction). During the light-dependent reaction, water is oxidized and light energy is converted into chemical bond energy generating ATP, NADPH + H⁺, and oxygen gas.[†] During the light-independent reaction (Calvin cycle), carbon dioxide, ATP, and NADPH + H⁺ react, forming phosphoglyceraldehyde, which is then converted into sugars. By using a microscope with appropriate magnification, students can see the chloroplasts in plant cells (e.g., lettuce, onion) and photosynthetic protists (e.g., euglena).

Students can prepare slides of these cells themselves, an activity that provides a good opportunity to see the necessity for well-made thin sections of specimens and for correct staining procedures. Commercially prepared slides are also available. By observing prepared cross sections of a leaf under a microscope, students can see how a leaf is organized structurally and think about the access of cells to light and carbon dioxide during photosynthesis. The production of oxygen from photosynthesis can be demonstrated and measured quantitatively with a volumeter, which can collect oxygen gas from the illuminated leaves of an aquatic plant, such as elodea. By varying the distance between the light source and the plant, teachers can demonstrate intensities of the effects of various illumination. To eliminate heat as a factor, the teacher can place a heat sink, such as a flat-sided bottle of water, between the plant and light source to absorb or dissipate unwanted heat.

I. g. Students know the role of the mitochondria in making stored chemical-bond energy available to cells by completing the breakdown of glucose to carbon dioxide.

Mitochondria consist of a matrix where three-carbon fragments originating from carbohydrates are broken down (to CO₂ and water) and of the cristae where ATP is produced. Cell respiration occurs in a series of reactions in which fats, proteins, and carbohydrates, mostly glucose, are broken down to produce carbon dioxide, water, and energy. Most of the energy from cell respiration is converted into ATP, a substance that powers most cell activities.

I. h. Students know most macromolecules (polysaccharides, nucleic acids, proteins, lipids) in cells and organisms are synthesized from a small collection of simple precursors.

Many of the large carbon compound molecules necessary for life (e.g., polysaccharides, nucleic acids, proteins, and lipids) are polymers of smaller monomers. Polysaccharides are composed of monosaccharides; proteins are composed of amino

[†]ATP is adenosine triphosphate, and NADPH is reduced nicotinamide adenine dinucleotide phosphate.

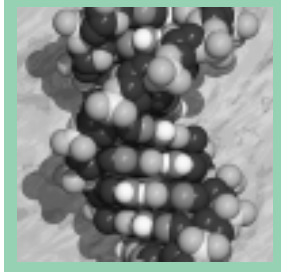
acids; lipids are composed of fatty acids, glycerol, and other components; and nucleic acids are composed of nucleotides.

I. i.* Students know how chemiosmotic gradients in the mitochondria and chloroplast store energy for ATP production.

Enzymes called *ATP synthase*, located within the thylakoid membranes in chloroplasts and cristae membranes in mitochondria, synthesize most ATP within cells. The thylakoid and cristae membranes are impermeable to protons except at pores that are coupled with the ATP synthase. The potential energy of the proton concentration gradient drives ATP synthesis as the protons move through the ATP synthase pores. The proton gradient is established by energy furnished by a flow of electrons passing through the electron transport system located within these membranes.

I. j.* Students know how eukaryotic cells are given shape and internal organization by a cytoskeleton or cell wall or both.

The *cytoskeleton*, which gives shape to and organizes eukaryotic cells, is composed of fine protein threads called *microfilaments* and thin protein tubes called *microtubules*. *Cilia* and *flagella* are composed of microtubules arranged in the 9 + 2 arrangement, in which nine pairs of microtubules surround two single microtubules. The rapid assembly and disassembly of microtubules and microfilaments and their capacity to slide past one another enable cells to move, as observed in white blood cells and amoebae, and also account for movement of organelles within the cell. Students can observe prepared slides of plant mitosis in an onion root tip to see the microtubules that make up the spindle apparatus. Prepared slides of white fish blastula reveal animal spindle apparatus and centrioles, both of which are composed of microtubules.



STANDARD SET 2. Genetics (Meiosis and Fertilization)

Students should know that organisms reproduce offspring of their own kind and that organisms of the same species resemble each other. Students have been introduced to the idea that some characteristics can be passed from parents to offspring and that individual variations appear among offspring and in the broader population. Understanding genetic variation requires mastery of the fundamentals of sex cell formation and the steps to reorganize and redistribute genetic material during defined stages in the cell cycle.

Students should understand the difference between asexual cell reproduction (*mitosis*) and the formation of male or female gamete cells (*meiosis*). Sexual reproduction initially requires the production of haploid eggs and haploid sperm, a process occurring in humans within the female ovary and the male testis. These haploid cells unite in fertilization and produce the *diploid zygote*, or fertilized cell.

The mechanisms involved in synapsis and movement of chromosomes during meiosis bring about the halving of the chromosome numbers for the production of the haploid male or female gamete cells from the original diploid parent cell and different combinations of parental genes. The exchange of chromosomal segments between homologous chromosomes (crossing over) revises the association of genes on the chromosomes and contributes to increased diversity. Any change in genetic constitution through mutation, crossing over, or chromosome assortment during meiosis promotes genetic variation in a population.

2. Mutation and sexual reproduction lead to genetic variation in a population. As a basis for understanding this concept:

- a. *Students know* meiosis is an early step in sexual reproduction in which the pairs of chromosomes separate and segregate randomly during cell division to produce gametes containing one chromosome of each type.

Haploid gamete production through meiosis involves two cell divisions. During meiosis prophase I, the homologous chromosomes are paired, a process that abets the exchange of chromosome parts through breakage and reunion. The second meiotic division parallels the mechanics of mitosis except that this division is not preceded by a round of DNA replication; therefore, the cells end up with the haploid number of chromosomes. (The nucleus in a haploid cell contains one set of chromosomes.) Four haploid nuclei are produced from the two divisions that characterize meiosis, and each of the four resulting cells has different chromosomal constituents (components). In the male all four become sperm cells. In the female only one becomes an egg, while the other three remain small degenerate polar bodies and cannot be fertilized.

Chromosome models can be constructed and used to illustrate the segregation taking place during the phases of mitosis (covered initially in Standard 1.e for grade seven in Chapter 4) and meiosis. Commercially available optical microscope slides also show cells captured in mitosis (onion root tip) or meiosis (*Ascaris* blastocyst cells), and computer and video animations are also available.

- 2. b.** *Students know* only certain cells in a multicellular organism undergo meiosis.

Only special diploid cells, called *spermatogonia* in the testis of the male and *oogonia* in the female ovary, undergo meiotic divisions to produce the haploid sperm and haploid eggs.

- 2. c.** *Students know* how random chromosome segregation explains the probability that a particular allele will be in a gamete.

The steps in meiosis involve random chromosome segregation, a process that accounts for the probability that a particular allele will be packaged in any given gamete. This process allows for genetic predictions based on laws of probability

that pertain to genetic sortings. Students can create a genetic chart and mark alternate traits on chromosomes, one expression coming from the mother and another expression coming from the father. Students can be shown that partitions of the chromosomes are controlled by chance (are random) and that separation (segregation) of chromosomes during *karyokinesis* (division of the nucleus) leads to the random sequestering of different combinations of chromosomes.

2. d. *Students know new combinations of alleles may be generated in a zygote through the fusion of male and female gametes (fertilization).*

Once gametes are formed, the second half of sexual reproduction can take place. In this process a diploid organism is reconstituted from two haploid parts. When a sperm is coupled with an egg, a fertilized egg (zygote) is produced that contains the combined genotypes of the parents to produce a new allelic composition for the progeny. Genetic charts can be used to illustrate how new combinations of alleles may be present in a zygote through the events of meiosis and the chance union of gametes. Students should be able to read the genetic diploid karyotype, or chromosomal makeup, of a fertilized egg and compare the allelic composition of progeny with the genotypes and phenotypes of the parents.

2. e. *Students know why approximately half of an individual's DNA sequence comes from each parent.*

Chromosomes are composed of a single, very long molecule of double-stranded DNA and proteins. Genes are defined as segments of DNA that code for polypeptides (proteins). During fertilization half the DNA of the progeny comes from the gamete of one parent, and the other half comes from the gamete of the other parent.

2. f. *Students know the role of chromosomes in determining an individual's sex.*

The normal human somatic cell contains 46 chromosomes, of which 44 are pairs of homologous chromosomes and 2 are sex chromosomes. Females usually carry two X chromosomes, and males possess one X and a smaller Y chromosome. Combinations of these two sex chromosomes determine the sex of the progeny.

2. g. *Students know how to predict possible combinations of alleles in a zygote from the genetic makeup of the parents.*

When the genetic makeups of potential parents are known, the possible assortments of alleles in their gametes can be determined for each genetic locus. Two parental gametes will fuse during fertilization, and with all pair-wise combinations of their gametes considered, the possible genetic makeups of progeny can then be predicted.



STANDARD SET 3. Genetics (Mendel's Laws)

Breeding of plants and animals has been an active technology for thousands of years, but the science of heredity is linked to the genetics pioneer Gregor Mendel. He studied phenotypic traits of various plants, especially those of peas.

(A *phenotypic trait* is the physical appearance of a trait in an organism). From the appearance of these traits in different generations of growth, he was able to infer their *genotypes* (the genetic makeup of an organism with respect to a trait) and to speculate about the genetic makeup and method of transfer of the hereditary units from one generation to the next. (Probability analysis is now used to predict probable progeny phenotypes from various parental genetic crosses.) The genetic basis for Mendel's laws of segregation and independent assortment is apparent from genetic outcomes of crosses.

3. A multicellular organism develops from a single zygote, and its phenotype depends on its genotype, which is established at fertilization. As a basis for understanding this concept:

- a. *Students know* how to predict the probable outcome of phenotypes in a genetic cross from the genotypes of the parents and mode of inheritance (autosomal or X-linked, dominant or recessive).

Monohybrid crosses, including autosomal dominant alleles, autosomal recessive alleles, incomplete dominant alleles, and X-linked alleles, can be used to indicate the parental genotypes and phenotypes. The possible gametes derived from each parent are based on genotypic ratios and can be used to predict possible progeny. The predictive (probabilistic) methods for determining the outcome of genotypes and phenotypes in a genetic cross can be introduced by using Punnett Squares and probability mathematics.

Teachers should review the process of writing genotypes and help students translate genotypes into phenotypes. Teachers should emphasize dominant, recessive, and incomplete dominance as the students advance to an explanation of monohybrid crosses illustrating human conditions characterized by autosomal recessive alleles, such as albinism, cystic fibrosis, Tay-Sachs, and phenylketonuria (PKU). These disorders can be contrasted with those produced by possession of just one autosomal dominant allele, conditions such as Huntington disease, dwarfism, and neurofibromatosis. This basic introduction can be followed with examples of incomplete dominance, such as seen in the comparisons of straight, curly, and wavy hair or in the expression of intermediate flower colors in snapdragon plants.

Sex-linked characteristics that are found only on the X chromosome should also be considered, and students should reflect on how this mode of transmission can cause the exclusive or near-exclusive appearance in males of color blindness, hemophilia, fragile-X syndrome, and sex-linked muscular dystrophy.

3. b. *Students know the genetic basis for Mendel’s laws of segregation and independent assortment.*

Mendel deduced that for each characteristic, an organism inherits two genes, one from each parent. When the two alleles differ, the dominant allele is expressed, and the recessive allele remains hidden. Two genes or alleles separate (segregate) during gamete production in meiosis, resulting in the sorting of alleles into separate gametes (the law of segregation). Students can be shown how to diagram Mendel’s explanation for how a trait present in the parental generation can appear to vanish in the first filial (F1) generation of a monohybrid cross and then reappear in the following second filial (F2) generation.

Students should be told that alternate versions of a gene at a single locus are called *alleles*. Students should understand Mendel’s deduction that for each character, an organism inherits two genes, one from each parent. From this point students should realize that if the two alleles differ, the dominant allele, if there is one, is expressed, and the recessive allele remains hidden. Students should recall that the two genes, or alleles, separate (segregate) during gamete production in meiosis and that this sorting of alleles into separate gametes is the basis for the law of segregation. This law applies most accurately when genes reside on separate chromosomes that segregate out at random, and it often does not apply or is a poor predictor for combinations and frequencies of genes that reside on the same chromosome. Students can study various resources that describe Mendel’s logic and build models to illustrate the laws of segregation and independent assortment.

3. c.* *Students know how to predict the probable mode of inheritance from a pedigree diagram showing phenotypes.*

Students should be taught how to use a pedigree diagram showing phenotypes to predict the mode of inheritance.

3. d.* *Students know how to use data on frequency of recombination at meiosis to estimate genetic distances between loci and to interpret genetic maps of chromosomes.*

Students should be able to interpret genetic maps of chromosomes and manipulate genetic data by using standard techniques to relate recombination at meiosis to estimate genetic distances between loci.



**STANDARD SET 4. Genetics
(Molecular Biology)**

All cells contain DNA as their genetic material. The role of DNA in organisms is twofold: first, to store and transfer genetic information from one generation to the next, and second, to express that genetic information in the synthesis

of proteins. By controlling protein synthesis, DNA controls the structure and function of all cells. The complexity of an organism determines whether it may have several hundred to more than twenty thousand proteins as a part of its makeup.

Proteins are composed of a sequence of amino acids linked by peptide bonds (see Standard 10.c for chemistry in this chapter). The identity, number, and sequence of the amino acids in a protein give each protein its unique structure and function. Twenty types of amino acids are commonly employed in proteins, and each can appear many times in a single protein molecule. The proper sequence of amino acids in a protein is translated from an RNA sequence that is itself encoded in the DNA.

4. Genes are a set of instructions encoded in the DNA sequence of each organism that specify the sequence of amino acids in proteins characteristic of that organism. As a basis for understanding this concept:

- a. *Students know* the general pathway by which ribosomes synthesize proteins, using tRNAs to translate genetic information in mRNA.

DNA does not leave the cell nucleus, but messenger RNA (mRNA), complementary to DNA, carries encoded information from DNA to the ribosomes (transcription) in the cytoplasm. (The *ribosomes* translate mRNAs to make protein.) Freely floating amino acids within the cytoplasm are bonded to specific transfer RNAs (tRNAs) that then transport the amino acid to the mRNA now located on the ribosome. As a ribosome moves along the mRNA strand, each mRNA codon, or sequence of three nucleotides specifying the insertion of a particular amino acid, is paired in sequence with the anticodon of the tRNA that recognizes the sequence. Each amino acid is added, in turn, to the growing polypeptide at the specified position.

After learning about transcription and translation through careful study of expository texts, students can simulate the processes on paper or with representative models. Computer software and commercial videos are available that illustrate animated sequences of transcription and translation.

- 4. b.** *Students know* how to apply the genetic coding rules to predict the sequence of amino acids from a sequence of codons in RNA.

The sequence of amino acids in protein is provided by the genetic information found in DNA. In prokaryotes, mRNA transcripts of a coding sequence are copied from the DNA as a single contiguous sequence. In eukaryotes, the initial RNA transcript, while in the nucleus, is composed of *exons*, sequences of nucleotides that carry useful information for protein synthesis, and *introns*, sequences that do not. Before leaving the nucleus, the initial transcript is processed to remove introns and splice exons together. The processed transcript, then properly called mRNA and carrying the appropriate codon sequence for a protein, is transported from the nucleus to the ribosome for translation.

Each mRNA has sequences, called *codons*, that are decoded three nucleotides at a time. Each codon specifies the addition of a single amino acid to a growing polypeptide chain. A *start codon* signals the beginning of the sequence of codons to be translated, and a *stop codon* ends the sequence to be translated into protein. Students can write out mRNA sequences with start and stop codons from a given DNA sequence and use a table of the genetic code to predict the primary sequences of proteins.

4. c. *Students know how mutations in the DNA sequence of a gene may or may not affect the expression of the gene or the sequence of amino acids in the encoded protein.*

Mutations are permanent changes in the sequence of nitrogen-containing bases in DNA (see Standard 5.a in this section for details on DNA structure and nitrogen bases). Mutations occur when base pairs are incorrectly matched (e.g., *A* bonded to *C* rather than *A* bonded to *T*) and can, but usually do not, improve the product coded by the gene. Inserting or deleting base pairs in an existing gene can cause a mutation by changing the codon reading frame used by a ribosome. Mutations that occur in somatic, or nongerm, cells are often not detected because they cannot be passed on to offspring. They may, however, give rise to cancer or other undesirable cellular changes. Mutations in the germline can produce functionally different proteins that cause such genetic diseases as Tay-Sachs, sickle cell anemia, and Duchenne muscular dystrophy.

4. d. *Students know specialization of cells in multicellular organisms is usually due to different patterns of gene expression rather than to differences of the genes themselves.*

Gene expression is a process in which a gene codes for a product, usually a protein, through transcription and translation. Nearly all cells in an organism contain the same DNA, but each cell transcribes only that portion of DNA containing the genetic information for proteins required at that specific time by that specific cell. The remainder of the DNA is not expressed. Specific types of cells may produce specific proteins unique to that type of cell.

4. e. *Students know proteins can differ from one another in the number and sequence of amino acids.*

Protein molecules vary from about 50 to 3,000 amino acids in length. The types, sequences, and numbers of amino acids used determine the type of protein produced.

4. f.* *Students know why proteins having different amino acid sequences typically have different shapes and chemical properties.*

The 20 different protein-making amino acids have the same basic structure: an amino group; an acidic (carboxyl) group; and an R, or radical group (see Standard

Set 10, “Organic and Biochemistry,” in the chemistry section of this chapter). The protein is formed by the amino group of one amino acid linking to the carboxyl group of another amino acid. This bond, called the *peptide bond*, is repeated to form long molecular chains with the R groups attached along the polymer backbone.

The properties of these amino acids vary from one another because of both the order and the chemical properties of these R groups. Typically, the long protein molecule folds on itself, creating a three-dimensional structure related to its function. Structure, for example, may allow a protein to be a highly specific catalyst, or enzyme, able to position and hold other molecules. The R group of an amino acid consists of atoms that may include carbon, hydrogen, nitrogen, oxygen, and sulfur, depending on the amino acid. Amino acids containing sulfur sometimes play an important role of cross-linking and stabilizing polymer chains. Because of their various R groups, different amino acids vary in their chemical and physical properties, such as solubility in water, electrical charge, and size. These differences are reflected in the unique structure and function of each type of protein.



STANDARD SET 5. Genetics (Biotechnology)

Long before scientists identified DNA as the genetic material of cells, much was known about inheritance and the relationships between various characteristics likely to appear from one generation to the next. However, to comprehend clearly how the genetic composition of cells changes, students need to understand the structure and activity of nucleic acids.

Genetic recombination occurs naturally in sexual reproduction, viral infection, and bacterial transformation. These natural events change the genetic makeup of organisms and provide the raw materials for evolution. Natural selection determines the usefulness of the recombinants. In recombinant DNA technology specific pieces of DNA are recombined in the laboratory to achieve a specific goal. The scientist, rather than natural selection, then determines the usefulness of the recombinant DNA created.

5. The genetic composition of cells can be altered by incorporation of exogenous DNA into the cells. As a basis for understanding this concept:

- a.** Students know the general structures and functions of DNA, RNA, and protein.

Nucleic acids are polymers composed of monomers called *nucleotides*. Each nucleotide consists of three subunits: a five-carbon pentose sugar, a phosphoric acid group, and one of four nitrogen bases. (For DNA these nitrogen bases are adenine, guanine, cytosine, or thymine.) DNA and RNA differ in a number of major ways. A DNA nucleotide contains a deoxyribose sugar, but RNA contains ribose sugar.

The nitrogen bases in RNA are the same as those in DNA except that thymine is replaced by uracil. RNA consists of only one strand of nucleotides instead of two as in DNA.

The DNA molecule consists of two strands twisted around each other into a double helix resembling a ladder twisted around its long axis. The outside, or uprights, of the ladder are formed by the two sugar-phosphate backbones. The rungs of the ladder are composed of pairs of nitrogen bases, one extending from each upright. In DNA these nitrogen bases always pair so that *T* pairs with *A*, and *G* pairs with *C*. This pairing is the reason DNA acts as a template for its own replication. RNA exists in many structural forms, many of which play different roles in protein synthesis. The mRNA form serves as a template during protein synthesis, and its codons are recognized by aminoacylated tRNAs. Protein and rRNA make up the structure of the ribosome.

Proteins are polymers composed of amino acid monomers (see Standard Set 10 for chemistry in this chapter). Different types of proteins function as enzymes and transport molecules, hormones, structural components of cells, and antibodies that fight infection. Most cells in an individual organism carry the same set of DNA instructions but do not use the entire DNA set all the time. Only a small amount of the DNA appropriate to the function of that cell is expressed. Genes are, therefore, turned on or turned off as needed by the cell, and the products coded by these genes are produced only when required.

5. b. *Students know how to apply base-pairing rules to explain precise copying of DNA during semiconservative replication and transcription of information from DNA into mRNA.*

Enzymes initiate DNA replication by unzipping, or unwinding, the double helix to separate the two parental strands. Each strand acts as a template to form a complementary daughter strand of DNA. The new daughter strands are formed when complementary new nucleotides are added to the bases of the nucleotides on the parental strands. The nucleotide sequence of the parental strand dictates the order of the nucleotides in the daughter strands. One parental strand is conserved and joins a newly synthesized complementary strand to form the new double helix; this process is called *semiconservative replication*.

DNA replication is usually initiated by the separation of DNA strands in a small region to make a “replication bubble” in which DNA synthesis is primed. The DNA strands progressively unwind and are replicated as the replication bubble expands, and the two forks of replication move in opposite directions along the chromosome. At each of the diverging replication forks, the strand that is conserved remains a single, continuous “leading” strand, and the other “lagging” complementary strand is made as a series of short fragments that are subsequently repaired and ligated together.

Students may visualize DNA by constructing models, and they can simulate semiconservative replication by tracing the synthesis of the leading and lagging

strands. The critical principles to teach with this activity are that two double-stranded DNA strands are the product of synthesis, that the process is semiconservative, that the antiparallel orientation of the strands requires repeated reinitiation on the lagging strand, and that the only information used during synthesis is specified by the base-pairing rules.

RNA is produced from DNA when a section of DNA (containing the nucleotide sequence required for the production of a specific protein) is transcribed. Only the template side of the DNA is copied. RNA then leaves the nucleus and travels to the cytoplasm, where protein synthesis takes place.

5. c. *Students know how genetic engineering (biotechnology) is used to produce novel biomedical and agricultural products.*

Recombinant DNA contains DNA from two or more different sources. Bacterial plasmids and viruses are the two most common vectors, or carriers, by which recombinant DNA is introduced into a host cell. Restriction enzymes provide the means by which researchers cut DNA at desired locations to provide DNA fragments with “sticky ends.” Genes, once identified, can be amplified either by cloning or by polymerase chain reactions, both of which produce large numbers of copies. The recombinant cells are then grown in large fermentation vessels, and their products are extracted from the cells (or from the medium if the products are secreted) and purified. Genes for human insulin, human growth hormone, blood clotting factors, and many other products have been identified and introduced into bacteria or other microorganisms that are then cultured for commercial production. Some agricultural applications of this technology are the identification and insertion of genes to increase the productivity of food crops and animals and to promote resistance to certain pests and herbicides, robustness in the face of harsh environmental conditions, and resistance to various viruses.

Students can model the recombinant DNA process by using paper models to represent eukaryotic complementary DNA (cDNA), the activity of different restriction enzymes, and ligation into plasmid DNA containing an antibiotic resistance gene and origin of DNA replication. To manipulate the modeled DNA sequences, students can use scissors (representing the activity of restriction enzymes) and tape (representing DNA ligase). If both strands are modeled on a paper tape, students can visualize how, in many cases, restriction enzymes make staggered cuts that generate “sticky ends” and how the ends must be matched during ligation.

5. d.* *Students know how basic DNA technology (restriction digestion by endonucleases, gel electrophoresis, ligation, and transformation) is used to construct recombinant DNA molecules.*

In recombinant DNA technology DNA is isolated and exchanged between organisms to fulfill a specific human purpose. The desired gene is usually identified and extracted by using restriction enzymes, or *endonucleases*, to cut the DNA into fragments. Restriction enzymes typically cut *palindromic* portions of DNA, which

read the same forward and backward, in ways that form sticky complementary ends. DNA from different sources, but with complementary sticky ends, can be joined by the enzyme DNA ligase, thus forming recombinant DNA.

DNA fragments of varying lengths can be separated from one another by *gel electrophoresis*. In this process the particles, propelled by an electric current, are moved through an agarose gel. Depending on the size, shape, and electrical charge of the particles, they will move at different rates through the gel and thus form bands of particles of similar size and charge. With appropriate staining, the various DNA fragments can then be visualized and removed for further analysis or recombination.

5. e.* *Students know how exogenous DNA can be inserted into bacterial cells to alter their genetic makeup and support expression of new protein products.*

Bacteria can be induced to take up recombinant plasmids, a process called DNA transformation, and the plasmid is replicated as the bacteria reproduce. Recombinant bacteria can be grown to obtain billions of copies of the recombinant DNA. Commercially available kits containing all the necessary reagents, restriction enzymes, and bacteria are available for experiments in plasmid DNA transformation. Although the reagents and equipment can be expensive, various California corporations and universities have programs to make the cost more affordable, sometimes providing reagents and lending equipment.

Students should know that DNA transformation is a natural process and that horizontal DNA transfer is common in the wild. An example of how humans have manipulated genetic makeup is through the selective breeding of pets and of agricultural crops.



STANDARD SET 6. Ecology

Ecology is the study of relationships among living organisms and their interactions with the physical environment. These relationships are in a constant state of flux, and even small changes can cause effects throughout the ecosystem.

Students in grades nine through twelve can be taught to think of ecology as changing relationships among the components of an ecosystem. Students also need to recognize that humans are participants in these ecosystem relationships, not just observers. A goal of classroom teaching should be to develop a strong scientific understanding of ecology to establish the basis for making informed and valid decisions.

**6. Stability in an ecosystem is a balance between competing effects.
As a basis for understanding this concept:**

- a. *Students know* biodiversity is the sum total of different kinds of organisms and is affected by alterations of habitats.

Biodiversity refers to the collective variety of living organisms in an ecosystem. This structure is influenced by alterations in habitat, including but not limited to climatic changes, fire, flood, and invasion by organisms from another system. The more biodiversity in an ecosystem, the greater its stability and resiliency. The best way for students to learn about ecology is to master the principles of the subject through careful study and then to make firsthand observations of ecosystems in action over time.

Although field trips are the ideal way to implement this process and should be encouraged, even career scientists often use models to study ecology. Local ecologists from government, private industry, or university programs may also be willing to serve as guest speakers in the classroom. Viewing the Internet's many virtual windows that show actual ecological experiments can also help students understand the scientific basis of ecology.

- 6. b.** *Students know* how to analyze changes in an ecosystem resulting from changes in climate, human activity, introduction of nonnative species, or changes in population size.

Analysis of change can help people to describe and understand what is happening in a natural system and, to some extent, to control or influence that system. Understanding different kinds of change can help to improve predictions of what will happen next. Changes in ecosystems often manifest themselves in predictable patterns of climate, seasonal reproductive cycles, population cycles, and migrations. However, unexpected disturbances caused by human intervention or the introduction of a new species, for example, may destabilize the often complex and delicate balance in an ecosystem.

Analyzing changes in an ecosystem can require complex methods and techniques because variation is not necessarily simple and may be interrelated with changes or trends in other factors. Rates and patterns of change, including trends, cycles, and irregularities, are essential features of the living world and are useful indicators of change that can provide data for analysis. Often it is important to analyze change over time, a process called *longitudinal analysis*.

- 6. c.** *Students know* how fluctuations in population size in an ecosystem are determined by the relative rates of birth, immigration, emigration, and death.

Fluctuations in the size of a population are often difficult to measure directly but may be estimated by measuring the relative rates of birth, death, immigration, and emigration in a population. The number of deaths and emigrations over time

will decrease a population's size, and the number of births and immigrations over time will increase it. Comparing rates for death and emigration with those for birth and immigration will determine whether the population shows a net growth or a decline over time.

6. d. *Students know* how water, carbon, and nitrogen cycle between abiotic resources and organic matter in the ecosystem and how oxygen cycles through photosynthesis and respiration.

Living things depend on nonliving things for life. At the organism level living things depend on natural resources, and at the molecular level, they depend on chemical cycles. Water, carbon, nitrogen, phosphorus, and other elements are recycled back and forth between organisms and their environments. Water, carbon, and nitrogen are necessary for life to exist. These chemicals are incorporated into plants (producers) by photosynthesis and nitrogen fixation and used by animals (consumers) for food and protein synthesis. Chemical recycling occurs through respiration, the excretion of waste products and, of course, the death of organisms.

6. e. *Students know* a vital part of an ecosystem is the stability of its producers and decomposers.

An ecosystem's producers (plants and photosynthetic microorganisms) and decomposers (fungi and microorganisms) are primarily responsible for the productivity and recycling of organic matter, respectively. Conditions that threaten the stability of producer and decomposer populations in an ecosystem jeopardize the availability of energy and the capability of matter to recycle in the rest of the biological community. To study the interaction between producers and decomposers, students can set up a closed or restricted ecosystem, such as a worm farm, a composting system, a terrarium, or an aquarium.

6. f. *Students know* at each link in a food web some energy is stored in newly made structures but much energy is dissipated into the environment as heat. This dissipation may be represented in an energy pyramid.

The energy pyramid illustrates how stored energy is passed from one organism to another. At every level in a food web, an organism uses energy metabolically to survive and grow, but much is released as heat, usually about 90 percent. At every link in a food web, energy is transferred to the next level, but typically only 10 percent of the energy from the previous level is passed on to the consumer.

6. g.* *Students know* how to distinguish between the accommodation of an individual organism to its environment and the gradual adaptation of a lineage of organisms through genetic change.

Living organisms may adapt to changing environments through nongenetic changes in their structure, metabolism, or behavior or through natural selection of

favorable combinations of alleles governing any or all of these processes. Genetic and behavioral adaptations are sometimes difficult to identify or to distinguish without studying the organism over a long time. Physical changes are slow to develop in most organisms, requiring careful measurements over many years. Examining fossil ancestors of an organism may help provide clues for detecting adaptation through genetic change. Genetic change can institute behavioral changes, making it all the more complicated to determine whether a change is solely a behavioral accommodation to environmental change.

Through the use of print and online resources in library-media centers, students can research the effects of encroaching urbanization on undeveloped land and consider the effects on specific species, such as the coyote (not endangered) and the California condor (endangered). Such examples can illustrate how some organisms adapt to their environments through learned changes in behavior, and others are unsuccessful in learning survival skills. Over a long time, organisms can also adapt to changing environments through genetic changes, some of which may include genetically determined changes in behavior. Such changes may be difficult to recognize because a long time must elapse before the changes become evident. Studies of the origins of desert pup fish or blind cave fish may help students understand how gradual genetic changes in an organism lead to adaptations to changes in its habitat.



STANDARD SET 7. Evolution (Population Genetics)

This discussion applies to Standard Sets 7 and 8. Students in grades nine through twelve should be ready to explore and understand the concept of biological evolution from its basis in genetics. The synthesis of genetics, and later of molecular biology, with the Darwin-Wallace theory of natural selection validated the mechanism of evolution and extended its scientific impact. Students need to understand that the same evolutionary mechanisms that have affected the rest of the living world have also affected the human species.

Students need to understand that a theory in science is not merely a hypothesis or a guess, but a unifying explanation of observed phenomena. Charles Darwin's theory of the origin of species by natural selection is such an explanation. Even though biologists continue to test the boundaries of this theory today, their investigations have not found credible evidence to refute the theory. Scientists have also had many opportunities to demonstrate the gradual evolution of populations in the wild and in controlled laboratory settings. As more populations of organisms are studied at the level of DNA sequence and as the fossil record improves, the understanding of species divergence has become clearer.

7. The frequency of an allele in a gene pool of a population depends on many factors and may be stable or unstable over time. As a basis for understanding this concept:

- a.** *Students know why natural selection acts on the phenotype rather than the genotype of an organism.*

Natural selection works directly on the expression or appearance of an inherited trait, the *phenotype*, rather than on the gene combination that produces that trait, the *genotype*. The influence of a dominant allele for a trait over a recessive one in the genotype determines the resulting phenotype on which natural selection acts.

- 7. b.** *Students know why alleles that are lethal in a homozygous individual may be carried in a heterozygote and thus maintained in a gene pool.*

Two types of allele pairings can occur in the genotype: *homozygous* (pairing two of the same alleles, whether dominant, codominant, or recessive) and *heterozygous* (pairing of two different alleles). Recessive lethal alleles (e.g., Tay-Sachs disease) will, by definition, cause the death of only the homozygous recessive individual. Healthy heterozygous individuals will also contribute the masked recessive gene to the population's gene pool, allowing the gene to persist.

- 7. c.** *Students know new mutations are constantly being generated in a gene pool.*

Mutation is an important source of genetic variation within a gene pool. These random changes take the form of additions, deletions, and substitutions of nucleotides and of rearrangements of chromosomes. The effect of many mutations is minor and neutral, being neither favorable nor unfavorable to survival and reproduction. Other mutations may be beneficial or harmful. The important principle is that culling, or selective breeding, cannot eliminate genetic diseases or unwanted traits from a population. The trait constantly reappears in the population in the form of new, spontaneous mutations.

- 7. d.** *Students know variation within a species increases the likelihood that at least some members of a species will survive under changed environmental conditions.*

As environmental factors change, natural selection of adaptive traits must also be realigned. Variation within a species stemming either from mutation or from genetic recombination broadens the opportunity for that species to adapt to change, increasing the probability that at least some members of the species will be suitably adapted to the new conditions. Genetic diversity promotes survival of a species should the environment change significantly, and sameness can mean vulnerability that could lead to extinction.

7. e.* Students know the conditions for Hardy-Weinberg equilibrium in a population and why these conditions are not likely to appear in nature.

The principle of Hardy-Weinberg equilibrium, derived in 1908, asserts that the genetic structure of a nonevolving population remains constant over the generations. If mating in a large population occurs randomly without the influence of natural selection, the migration of genes from neighboring populations, or the occurrence of mutations, the frequency of alleles and of genotypes will remain constant over time. Such conditions are so restrictive that they are not likely to occur in nature precisely as predicted, but the Hardy-Weinberg equilibrium equation often gives an excellent approximation for a limited number of generations in sizeable, randomly mating populations. Even though genetic recombination is taken into account, mutations, gene flow between populations, and environmental changes influencing pressures of selection on a population do not cease to occur in the natural world.

7. f.* Students know how to solve the Hardy-Weinberg equation to predict the frequency of genotypes in a population, given the frequency of phenotypes.

The Hardy-Weinberg equilibrium equation can be used to calculate the frequency of alleles and genotypes in a population's gene pool. When only two alleles for a trait occur in a population, the letter p is used to represent the frequency of one allele, and the letter q is used to represent the frequency of the other. Students should agree first that the sum of the frequencies of the two alleles is 1, and this equation is written $p + q = 1$. That is, the combined frequencies of the alleles account for all the genes for a given trait.

Students should then consider the possible combinations of alleles in a *diploid organism* (the genome of a diploid organism consists of two copies of each chromosome). An individual could be homozygous for one allele (pp) or homozygous for the other (qq) or heterozygous (either pq or qp). These diploid genotypes will appear at frequencies that are the product of the allele frequencies (e.g., the frequency of a diploid pp individual is p^2 , and the frequency of a diploid qq individual is q^2).

The heterozygotes are of two varieties, pq and qp (because the p allele might have been inherited from either parent), but the products of frequency pq and qp are the same. Therefore, the frequency of heterozygotes can simply be expressed as $2pq$. The sum of the frequencies of the homozygous and heterozygous individuals must equal 1, since all individuals have been accounted for. These principles are usually expressed as the equation $p^2 + 2pq + q^2 = 1$. Both equations represent different statements. The first ($p + q = 1$) is an accounting of the two types of alleles in the population, and the second ($p^2 + 2pq + q^2 = 1$) is an accounting of the three distinguishable genotypes.

If the allele frequencies are known (e.g., if $p = 0.1$ and $q = 0.9$) and Hardy-Weinberg equilibrium is assumed, then the frequencies p^2 , $2pq$, and q^2 are

respectively 0.01, 0.18, and 0.81. That is, 81 percent of individuals would be homozygous qq . If p were a dominant (but nonselective) allele, then $p^2 + 2pq$, or 19 percent of the population, would express the dominant phenotype of the p allele.

The calculation can be used in reverse as well. If Hardy-Weinberg equilibrium conditions exist and 81 percent of the population expresses the qq recessive phenotype, then the allele frequency q is the square root of 0.81, and the rest of the terms can be calculated in a straightforward fashion.

Students can convince themselves of the state of equilibrium by constructing a Punnett Square that assumes random mating. The scenario might be a mass spawning of fish, in which 100,000 eggs and sperm are mixed in a stream and meet with each other randomly to form zygotes. Students can calculate the fraction of p and q type gametes in the stream by thinking through the types of gametes produced by heterozygous and homozygous adult fish. (For this exercise to work, the genotype distribution of adults must agree with Hardy-Weinberg equilibrium.) With the frequencies or numbers of each type of zygote calculated in the cells of a Punnett Square, students will see that equilibrium is preserved. Frequencies of alleles and genotypes, which are the genetic structure of the study population, would remain constant for generations under the premise of Hardy-Weinberg equilibrium.



STANDARD SET 8. Evolution (Speciation)

See the discussion introducing the concept of biological evolution that appears under Standard Set 7, “Evolution (Population Genetics),” on page 237.

8. Evolution is the result of genetic changes that occur in constantly changing environments. As a basis for understanding this concept:

- a. Students know how natural selection determines the differential survival of groups of organisms.

Genetic changes can result from gene recombination during gamete formation and from mutations. These events are responsible for variety and diversity within each species. Natural selection favors the organisms that are better suited to survive in a given environment. Those not well suited to the environment may die before they can pass on their traits to the next generation. As the environment changes, selection for adaptive traits is realigned with the change. Traits that were once adaptive may become disadvantageous because of change.

Students can explore the process of natural selection further with an activity based on predator-prey relationships. The main purpose of these activities is to simulate survival in predator or prey species as they struggle to find food or to escape being consumed themselves. The traits of predator and prey individuals can be varied to test their selective fitness in different environmental settings.

An example of natural selection is the effect of industrial “melanism,” or darkness of pigmentation, on the peppered moths of Manchester, England. These moths come in two varieties, one darker than the other. Before the industrial revolution, the dark moth was rare; however, during the industrial revolution the light moth seldom appeared. Throughout the industrial revolution, much coal was burned in the region, emitting soot and sulfur dioxide. For reasons not completely understood, the light-colored moth had successfully adapted to the cleaner air conditions that existed in preindustrial times and that exist in the region today.

However, the light-colored moth appears to have lost its survival advantage during times of heavy industrial air pollution. One early explanation is that when soot covered tree bark, light moths became highly visible to predatory birds. Once this change happened, the dark-peppered moth had an inherited survival advantage because it was harder to see against the sooty background. This explanation may not have been the cause, and an alternative one is that the white-peppered moth was more susceptible to the sulfur dioxide emissions of the industrial revolution. In any case, in the evolution of the moth, mutations of the genes produced light and dark moths. Through natural selection the light moth had an adaptive advantage until environmental conditions changed, increasing the population of the dark moths and depleting that of the light moths.

8. b. *Students know a great diversity of species increases the chance that at least some organisms survive major changes in the environment.*

This standard is similar to the previous standard set on diversity within a species but takes student understanding one step further by addressing diversity among and between species. For the same reasons pertinent to those for intraspecies diversity, increased diversity among species increases the chances that some species will adapt to survive future environmental changes.

8. c. *Students know the effects of genetic drift on the diversity of organisms in a population.*

If a small random sample of individuals is separated from a larger population, the gene frequencies in the sample may differ significantly from those in the population as a whole. The shifts in frequency depend only on which individuals fall in the sample (and so are themselves random). Because a random shift in gene frequency is not guaranteed to make the next generation better adapted, the shift—or genetic drift—with respect to the original gene pool is not necessarily an adaptive change. The *bottleneck effect* (i.e., nonselective population reductions due to disasters) and the *founder effect* (i.e., the colonization of a new habitat by a few individuals) describe situations that can lead to genetic drift of small populations.

8. d. *Students know reproductive or geographic isolation affects speciation.*

Events that lead to reproductive isolation of populations of the same species cause new species to appear. Barriers to reproduction that prevent mating between

populations are called *prezygotic* (before fertilization) if they involve such factors as the isolation of habitats, a difference in breeding season or mating behavior, or an incompatibility of genitalia or gametes. *Postzygotic* (after fertilization) barriers that prevent the development of viable, fertile hybrids exist because of genetic incompatibility between the populations, hybrid sterility, and hybrid breakdown.

These isolation events can occur within the geographic range of a parent population (*sympatric speciation*) or through the geographic isolation of a small population from its parent population (*allopatric speciation*). Sympatric speciation is much more common in plants than in animals. Extra sets of chromosomes, or *polypoidy*, that result from mistakes in cell division produce plants still capable of long-term reproduction but animals that are incapable of that process because polypoidy interferes with sex determination and because animals, unlike most plants, are usually of one sex or the other. Allopatric speciation occurs in animal evolution when geographically isolated populations adapt to different environmental conditions. In addition, the rate of allopatric speciation is faster in small populations than in large ones because of greater genetic drift.

8. e. *Students know how to analyze fossil evidence with regard to biological diversity, episodic speciation, and mass extinction.*

Analysis of the fossil record reveals the story of major events in the history of life on earth, sometimes called *macroevolution*, as opposed to the small changes in genes and chromosomes that occur within a single population, or *microevolution*. Explosive radiations of life following mass extinctions are marked by the four eras in the geologic time scale: the Precambrian, Paleozoic, Mesozoic, and Cenozoic. The study of biological diversity from the fossil record is generally limited to the study of the differences among species instead of the differences within a species. Biological diversity within a species is difficult to study because preserved organic material is rare as a source of DNA in fossils.

Episodes of speciation are the most dramatic after the appearance of novel characteristics, such as feathers and wings, or in the aftermath of a mass extinction that has cleared the way for new species to inhabit recently vacated adaptive zones. Extinction is inevitable in a changing world, but examples of mass extinction from the fossil record coincide with rapid global environmental changes. During the formation of the supercontinent Pangaea during the Permian period, most marine invertebrate species disappeared with the loss of their coastal habitats. During the Cretaceous period a climatic shift to cooler temperatures because of diminished solar energy coincided with the extinction of dinosaurs.

8. f.* *Students know how to use comparative embryology, DNA or protein sequence comparisons, and other independent sources of data to create a branching diagram (cladogram) that shows probable evolutionary relationships.*

The area of study that connects biological diversity to *phylogeny*, or the evolutionary history of a species, is called *systematics*. Systematic classification is based on

the degree of similarity between species. Thus, comparisons of embryology, anatomy, proteins, and DNA are used to establish the extent of similarities. Embryological studies reveal that *ontogeny*, development of the embryo, provides clues to phylogeny. In contrast to the old assertion that “ontogeny recapitulates phylogeny” (i.e., that it replays the entire evolutionary history of a species), new findings indicate that structures, such as gill pouches, that appear during embryonic development but are less obvious in many adult life forms may establish *homologies* between species (similarities attributable to a common origin). These homologies are evidence of common ancestry. Likewise, homologous anatomical structures, such as the forelimbs of humans, cats, whales, and bats, are also evidence of a common ancestor. Similarity between species can be evaluated at the molecular level by comparing the amino acid sequences of proteins or the nucleotide sequences of DNA strands. DNA-DNA hybridization, restriction mapping, and DNA sequencing are powerful new tools in systematics.

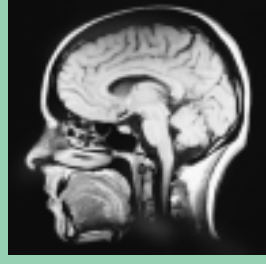
Approaches for using comparison information to classify organisms on the basis of evolutionary history differ greatly. *Cladistics* uses a branching pattern, or *cladogram*, based on shared derived characteristics to map the sequence of evolutionary change. The cladogram is a dichotomous tree that branches to separate those species that share a derived characteristic, such as hair or fur, from those species that lack the characteristic. Each new branch of the cladogram helps to establish a sequence of evolutionary history; however, the extent of divergence between species is unclear from the sequence alone.

Phenetics classifies species entirely on the basis of measurable similarities and differences with no attempt to sort homology from analogy. In recent years phenetic studies have been helped by the use of computer programs to compare species automatically across large numbers of traits. Striking a balance between these two approaches to classification has often involved subjective judgments in the final decision of taxonomic placement. Students can study examples of cladograms and create new ones to understand how a sequence of evolutionary change based on shared derived characteristics is developed.

8. g.* *Students know* how several independent molecular clocks, calibrated against each other and combined with evidence from the fossil record, can help to estimate how long ago various groups of organisms diverged evolutionarily from one other.

Molecular clocks are another tool to establish phylogenetic sequences and the relative dates of phylogenetic branching. Homologous proteins, such as cytochrome c, of different *taxa* (plants and animals classified according to their presumed natural relationships) and the genes that produce those proteins are assumed to evolve at relatively constant rates. On the basis of that assumption, the number of amino acid or nucleotide substitutions provides a record of change proportional to the time between evolutionary branches. The estimates of rate of change derived from these molecular clocks generally agree with parallel data from the fossil record; however, the branching orders and times between branches are more reliably determined by

measuring the degree of molecular change than by comparing qualitative features of morphology. When gaps in the fossil record exist, phylogenetic branching dates can be estimated by calibrating molecular change against the timeline determined from the fossil record.



STANDARD SET 9. Physiology (Homeostasis)

From the individual cell to the total organism, each functioning unit is organized according to *homeostasis*, or how the body and its parts deal with changing demands while maintaining a constant internal environment. In 1859 noted French physiologist Claude Bernard described the difference between the internal environment of the cells and the external environment in which the organism lives. Organisms are shielded from the variations of the external environment by the “constancy of the internal milieu.” This “steady state” refers to the dynamic equilibrium achieved by the integrated functioning of all the parts of the organism.

American physiologist Walter Cannon called this phenomenon *homeostasis*, which means “standing still.” All organ systems of the human body contribute to homeostasis so that blood and tissue constituents and values stay within a normal range. Students will need supportive review of the major systems of the body and of the organ components of those systems (see Standard Set 2, “Life Sciences,” for grade five in Chapter 3 and Standard Set 5, “Structure and Function in Living Systems,” for grade seven in Chapter 4). As the prime coordinators of the body’s activities, the nervous and endocrine systems must be examined and their interactive roles clearly defined.

9. As a result of the coordinated structures and functions of organ systems, the internal environment of the human body remains relatively stable (homeostatic) despite changes in the outside environment. As a basis for understanding this concept:

- a. *Students know* how the complementary activity of major body systems provides cells with oxygen and nutrients and removes toxic waste products such as carbon dioxide.

The digestive system delivers nutrients (e.g., glucose) to the circulatory system. Oxygen molecules move from the air to the alveoli of the lungs and then to the circulatory system. From the circulatory system glucose and oxygen molecules move from the capillaries into the cells of the body where cellular respiration occurs. During cellular respiration these molecules are oxidized into carbon dioxide and water, and energy is trapped in the form of ATP. The gas exchange process is reversed for the removal of carbon dioxide from its higher concentration in the cells to the circulatory system and, finally, to its elimination by exhalation from the lungs.

The concentration of sugar in the blood is monitored, and students should know that sugar can be stored or pulled from reserves (glycogen) in the liver and

muscles to maintain a constant blood sugar level. Amino acids contained in proteins can also serve as an energy source, but first the amino acids must be deaminated, or chemically converted, in the liver, producing ammonia (a toxic product), which is converted to water-soluble urea and excreted by the kidneys. Teachers should emphasize that all these chemicals are transported by the circulatory system and the cells. Organs at the final destination direct these chemicals to their exit from the circulatory system.

9. b. *Students know how the nervous system mediates communication between different parts of the body and the body's interactions with the environment.*

An individual becomes aware of the environment through the sense organs and other body receptors (e.g., by allowing for touch, taste, and smell and by collecting information about temperature, light, and sound). The body reflexively responds to external stimuli through a reflex arc (see Standard 9.e in this section). (*A reflex arc* is the pathway along the central nervous system where an impulse must travel to bring about a reflex; e.g., sneezing or coughing.) Students can examine the sense organs, identify other body receptors that make them aware of their environment, and see ways in which the body reflexively responds to an external stimulus through a reflex arc.

Hormones work in conjunction with the nervous system, as shown, for example, in the digestive system, where insulin released from the pancreas into the blood regulates the uptake of glucose by muscle cells. The pituitary master gland produces growth hormone for controlling height. Other pituitary hormones have specialized roles (e.g., follicle-stimulating hormone [FSH] and luteinizing hormone [LH] control the gonads, thyroid-stimulating hormone [TSH] controls the thyroid, and adrenocorticotrophic hormone [ACTH] regulates the formation of glucocorticoids by the adrenal cortex). This master gland is itself controlled by the hypothalamus of the brain.

9. c. *Students know how feedback loops in the nervous and endocrine systems regulate conditions in the body.*

Feedback loops are the means through which the nervous system uses the endocrine system to regulate body conditions. The presence or absence of hormones in blood brought to the brain by the circulatory system will trigger an attempt to regulate conditions in the body. To make feedback loops relevant to students, teachers can discuss the hormone leptin, which fat cells produce as they become filled with storage reserves. Leptin is carried by the blood to the brain, where it normally acts to inhibit the appetite center, an example of negative feedback. When fat reserves diminish, the concentration of leptin decreases, a phenomenon that in turn causes the appetite center in the brain to start the hunger stimulus and activate the urge to eat.

9. d. *Students know the functions of the nervous system and the role of neurons in transmitting electrochemical impulses.*

Transmission of nerve impulses involves an electrochemical “action potential” generated by gated ion channels in the membrane that make use of the counter-vailing gradients of sodium and potassium ions across the membrane. Potassium ion concentration is high inside cells and low outside; sodium ion concentration is the opposite. The sodium and potassium ion concentration gradients are restored by an active transport system, a pump that exchanges sodium and potassium ions across the membrane and uses ATP hydrolysis as a source of free energy. The release of neurotransmitter chemicals from the axon terminal at the synapse may initiate an action potential in an adjacent neuron, propagating the impulse to a new cell.

9. e. *Students know the roles of sensory neurons, interneurons, and motor neurons in sensation, thought, and response.*

The pathways of impulses from dendrite to cell body to axon of sensory neurons, interneurons, and motor neurons link the chains of events that occur in a reflex action. Students should be able to diagram this pathway. Similar paths of neural connections lead to the brain, where the sensations become conscious and conscious actions are initiated in response to external stimuli. Students might also trace the path of the neural connections as the sensation becomes conscious and a response to the external stimulus is initiated. Students should also be able to identify gray and white matter in the central nervous system.

9. f.* *Students know the individual functions and sites of secretion of digestive enzymes (amylases, proteases, nucleases, lipases), stomach acid, and bile salts.*

To bring about digestion, secretions of enzymes are mixed with food (in the mouth and as the food proceeds from the mouth through the stomach and through the small intestines). For example, salivary glands and the pancreas secrete amylase enzymes that change starch into sugar. Stomach acid and gastric enzymes begin the breakdown of protein, a process that intestinal and pancreatic secretions continue.

Lipase enzymes secreted by the pancreas break down fat molecules (which contain three fatty acids) to free fatty acids plus diglycerides (which contain two fatty acids) and monoglycerides (which contain one fatty acid). Bile secreted by the liver furthers the process of digestion, emulsifying fats and facilitating digestion of lipids. Students might diagram the digestive tract, labeling important points of secretion and tracing the pathways from digestion of starches, proteins, and other foods. They can then outline the role of the kidney nephron in the formation of urine and the role of the liver in glucogenesis and glycogenolysis (glucose balance) and in blood detoxification.

9. g.* *Students know the homeostatic role of the kidneys in the removal of nitrogenous wastes and the role of the liver in blood detoxification and glucose balance.*

Microscopic nephrons within the kidney filter out body wastes, regulate water, and stabilize electrolyte levels in blood. The liver removes toxic materials from the blood, stores them, and excretes them into the bile. The liver also regulates blood glucose.

9. h.* *Students know the cellular and molecular basis of muscle contraction, including the roles of actin, myosin, Ca^{+2} , and ATP.*

Controlled by calcium ions and powered by hydrolysis of ATP, actin and myosin filaments in a sarcomere generate movement in stomach muscles. Striated muscle fibers reflect the filamentous makeup and contraction state evidenced by the banding patterns of those fibers. A sketch of the sarcomere can be used to indicate the functions of the actin and myosin filaments and the role of calcium ions and ATP in muscle contraction.

9. i.* *Students know how hormones (including digestive, reproductive, osmoregulatory) provide internal feedback mechanisms for homeostasis at the cellular level and in whole organisms.*

Hormones act as chemical messengers, affecting the activity of neighboring cells or other target organs. Their movement can be traced from their point of origin to the target site. The feedback mechanism works to regulate the activity of hormones and promotes homeostasis.



STANDARD SET 10. Physiology (Infection and Immunity)

Some bacteria, parasites, and viruses cause human diseases because they either rob the body of necessary sustenance or secrete toxins that cause injury. The human body has a variety of mechanisms to interfere with or destroy invading pathogens. Besides protection afforded by the skin, one of the most effective means of defending against agents that harm the body is the immune system with its cellular and chemical defenses. Students should develop a clear understanding of the components of the immune system and know how vaccines and antibiotics are used to combat disease. They should also know that acquired immune deficiency syndrome (AIDS) compromises the immune system, causing affected persons to succumb to other AIDS-associated infections that are harmless to people with an intact immune system.

10. Organisms have a variety of mechanisms to combat disease. As a basis for understanding the human immune response:

- a. *Students know* the role of the skin in providing nonspecific defenses against infection.

The skin serves as a physical barrier to prevent the passage of many disease-causing microorganisms. Cuts and abrasions compromise the skin's ability to act as a barrier. Teachers can use charts and overhead projections to show the dangers and physiologic responses of a break in the skin.

- 10. b.** *Students know* the role of antibodies in the body's response to infection.

Cells produce antibodies to oppose antigens, substances that are foreign to the body. An example of an antigen is a surface protein of a flu virus, a protein with a shape and structure unlike those of any human proteins. The immune system recognizes that the flu virus structure is different and generates proteins called *antibodies* that bind to the flu virus. Antibodies can inactivate pathogens directly or signal immune cells that pathogens are present.

- 10. c.** *Students know* how vaccination protects an individual from infectious diseases.

Several weeks are required before the immune system develops immunity to a new antigen. To overcome this problem, vaccinations safely give the body a look in advance at the foreign structures. Vaccines usually contain either weakened or killed pathogens that are responsible for a specific infectious disease, or they may contain a purified protein or subunit from the pathogen. Although the vaccine does not cause an infectious disease, the antigens in the mixture prompt the body to generate antibodies to oppose the pathogen. When the individual is exposed to the pathogenic agent, perhaps years later, the body still remembers having seen the antigens in the vaccine dose and can respond quickly. Students have been exposed to the practical aspects of immunization through their knowledge of the vaccinations they must receive before they can enter school. They have all experienced getting shots and may have seen their personal vaccination record in which dates and kinds of inoculations are recorded. The review of a typical vaccination record, focusing on the reason for the shots and ways in which they work, may serve as an effective entry to the subject.

Students should review the history of vaccine use. Early literature provides descriptions of vaccine use from pragmatic exposure, but the term *vaccine* is derived from the cowpox exudate that Edward Jenner used during the 1700s to inoculate villagers against the more pathogenic smallpox. Louis Pasteur, noted for his discovery of the rabies treatment, also developed several vaccines. Poliovirus, the cause of infantile paralysis (poliomyelitis), was finally conquered in the 1950s through vaccines that Jonas Salk and Albert B. Sabin refined.

10. d. *Students know there are important differences between bacteria and viruses with respect to their requirements for growth and replication, the body's primary defenses against bacterial and viral infections, and effective treatments of these infections.*

A *virus*, which is the simplest form of a genetic entity, is incapable of metabolic life and reproduction outside the cells of other living organisms. A virus contains genetic material but has no ribosomes. Although some viruses are benign, many harm their host organism by destroying or altering its cell structures. Generally, the body perceives viruses as antigens and produces antibodies to counteract the virus. *Bacteria* are organisms with a full cellular structure. They, too, can be benign or harmful. Harmful bacteria and their toxins are perceived as antigens by the body, which in turn produces antibodies. In some cases infectious diseases may be treated effectively with *antiseptics*, which are chemicals that oxidize or in other ways inactivate the infecting organism. Antiseptics are also useful in decontaminating surfaces with which the body may come in contact (e.g., countertops). *Antibiotics* are effective in treating bacterial infections, sometimes working by destroying or interfering with the growth of bacterial cell walls or the functioning of cell wall physiology or by inhibiting bacterial synthesis of DNA, RNA, or proteins. Antibiotics are ineffective in treating viral infections.

Students might research infections caused by protists (malaria, amoebic dysentery), bacteria (blood poisoning, botulism, food poisoning, tuberculosis), and viruses (rabies, colds, influenza, AIDS). They might also investigate the pathogens currently being discussed in the media and study each infectious organism's requirements for growth and reproduction. Teachers should review the dangers of common bacteria becoming resistant to antibiotics through long-standing over-application, as shown by the increasing incidence of drug-resistant tuberculosis and other bacteria. Using a commercially available kit, teachers can demonstrate how antibiotics may act generally or specifically against bacteria. Agar plates may be inoculated with different bacteria, and different antibiotic discs may be placed on these plates to create a clear zone in which growth around the antibiotic discs is inhibited.

10. e. *Students know why an individual with a compromised immune system (for example, a person with AIDS) may be unable to fight off and survive infections by microorganisms that are usually benign.*

When an immune system is compromised (e.g., through infection by the human immunodeficiency virus [HIV]), it becomes either unable to recognize a dangerous antigen or incapable of mounting an appropriate defense. This situation happens when the virus infects and destroys key cells in the immune system.

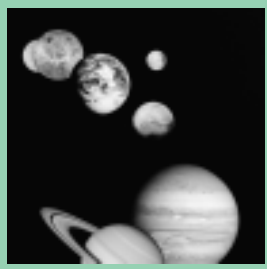
10. f.* *Students know the roles of phagocytes, B-lymphocytes, and T-lymphocytes in the immune system.*

Phagocytes move, amoebalike, through the circulatory system, consuming waste and foreign material, such as aged or damaged blood cells and some infectious bacteria and viruses. Two broad types of lymphocytes (a class of white blood cells) originate in the bone marrow during embryonic life. One type (the B-lymphocyte) matures in the bone marrow and gives rise to antibody-producing plasma cells that are responsible for humoral immunity. Each mature B-lymphocyte can give rise to only a single type of antibody, which itself may recognize only a single foreign antigen. The other type (the T-lymphocyte) matures in the thymus gland during embryogenesis and gives rise to “cytotoxic” (cell killing) and “helper” T-lymphocytes. The cytotoxic T-cells are particularly useful for surveillance of intra-cellular pathogens. Antibodies cannot reach the intracellular pathogen because of the cell membrane, but the infected cell can be identified and killed. Helper T-cells assist in organizing both the humoral and cellular immune responses.

Earth Sciences

By looking outward and deep into space and time, astronomers have discovered a vast and ancient universe. The study of earth sciences helps students find their place in this universe by showing where their unique world fits in with the grand scheme of the cosmos. Students of the earth sciences gain an understanding of the physical and chemical processes that formed Earth and continue to operate on this planet. As students study these science standards, they will also learn more about the geologic factors that help to make California special.

The Sun, a rather ordinary star, provides virtually all the surface energy required for life on Earth. Its energy also drives convection in Earth's atmosphere and oceans, a process that in turn drives global climate conditions and local weather patterns. In addition, heat energy moves slowly below Earth's surface through the planet's interior. Some of this internal heat originated with the formation of the planet, and some is generated by the decay of radioactive nuclides. This geothermal heat slowly escapes to the hydrosphere and atmosphere. The quantity of geothermal heat is tiny compared with the quantity of incoming solar energy. However, over the long term, geothermal heat is responsible for plate tectonic processes—moving continents, building mountains, and causing volcanism and earthquakes.



STANDARD SET I. Earth's Place in the Universe (Solar System)

Students should previously have studied the star patterns in the night sky and the changes in those patterns with the seasons and lunar cycles. They should also have been introduced to the solar system; and they can be expected to

know that the Sun, which is composed primarily of hydrogen and helium, is the center of the solar system. They should also know that the solar system includes Earth and eight other planets, their moons, and a large number of comets and asteroids and that gravitational interaction with the Sun primarily determines the orbits of all these objects. In the eighth grade students should have learned about the composition, relative sizes, positions, and motions of objects in the solar system.

Students should become familiar with evidence that dates Earth at 4.6 billion years old, and they should know that extraterrestrial objects hit the planet occasionally and that such impacts were more frequent in the past. They have also learned that the Moon, planets, and comets shine by reflected light. To study this standard set, students will need to understand electromagnetism and gravity. Students should know and understand the Doppler effect and the inverse square law of light (see Standard 4.f in the physics section of this chapter). Familiarity with the acquisition and analysis of spectral data will also be helpful. The content in this standard set may cause students difficulty in grasping the vastness of geologic time and

astronomical distances. Teachers should provide opportunities for students to think about space and time in different scales, from the macroscopic to the microscopic, such as practice in working with relevant numbers and in visualizing the solar system in the appropriate scale.

I. Astronomy and planetary exploration reveal the solar system's structure, scale, and change over time. As a basis for understanding this concept:

- a. *Students know* how the differences and similarities among the Sun, the terrestrial planets, and the gas planets may have been established during the formation of the solar system.

Students studying this standard will learn how the Sun and planets formed and developed their present characteristics. The solar nebula, a slowly rotating massive cloud of gas and dust, is believed to have contracted under the influence of gravitational forces and eventually formed the Sun, the rocky inner planets, the gaseous outer planets, and the moons, asteroids, and comets. The exact mechanism that caused this event is unknown. The outer planets are condensations of lighter gases that solar winds blew to the outer solar system when the Sun's fusion reaction ignited. Observations supporting this theory are that the orbital planes of the planets are nearly the same and that the planets revolve around the Sun in the same direction.

To comprehend the vast size of the solar system, students will need to understand scale, know the speed of light, and be familiar with units typically used for denoting astronomical distances. For example, Pluto's orbital radius can be expressed as 39.72 AU or 5.96×10^{12} meters or 5.5 light-hours. An astronomical unit (AU) is a unit of length equal to the mean distance of Earth from the Sun, approximately 93 million miles. A light-year, which is approximately 5.88 trillion miles, or 9.46 trillion kilometers, is the distance light can travel through a vacuum in one year. Students can make a scale model to help them visualize the vast distances in the solar system and the relative size of the planets and their orbit around the Sun. Calculator tape may be used to plot these distances to scale.

- I. b.** *Students know* the evidence from Earth and moon rocks indicates that the solar system was formed from a nebular cloud of dust and gas approximately 4.6 billion years ago.

Since the nineteenth century, geologists, through the use of relative dating techniques, have known that Earth is very old. Relative dating methods, however, are insufficient to identify actual dates for events in the deep past. The discovery of radioactivity provided science with a "clock." Radioactive dating of terrestrial samples, lunar samples, and meteorites indicates that the Earth and Moon system and meteorites are approximately 4.6 billion years old.

The solar system formed from a *nebula*, a cloud of gas and debris. Most of this material consisted of hydrogen and helium created during the big bang, but the material also included heavier elements formed by nucleosynthesis in massive stars

that lived and died before the Sun was formed. The death of a star can produce a spectacular explosion called a *supernova*, in which debris rich in heavy elements is ejected into space as stardust. Strong evidence exists that the impact of stardust from a nearby supernova triggered the collapse of the nebula that formed the solar system. The collapse of a nebula leads to heating, an increase in rotation rate, and flattening. From this hot, rapidly spinning nebula emerged the Sun and solid grains of various sizes that later accreted to form objects that evolved through collisions into planets, moons, and meteorites. The nebula from which the Sun and planets formed was composed primarily of hydrogen and helium, and the solar composition reflects this starting mixture. The nebula also contained some heavy elements. As the nebula cooled, condensation of the heavy elements and the loss of volatile elements from the hot, inner nebula led to formation of rocky inner planets. To varying extents, the whole of the solar system was fractionated; but the portion of the solar nebula now occupied by the inner planets was highly fractionated, losing most of its volatile material, while the outer portion (beyond Mars) was less fractionated and is consequently richer in the lighter, more volatile elements.

I. c. *Students know the evidence from geological studies of Earth and other planets suggests that the early Earth was very different from Earth today.*

The prevailing theory is that Earth formed around 4.6 billion years ago by the contraction under gravity of gases and dust grains found in a part of the solar nebula. As Earth accreted, it was heated by the compressing of its material by gravity and by the kinetic energy released when moving bits of debris and even planetoids struck and joined. Eventually, the interior of the planet heated sufficiently for iron, an abundant element in the earth, to melt. Iron's high density caused that element to sink toward the center of Earth. The entire planet differentiated, creating layers with the lower-density materials rising toward the top and the higher-density materials sinking toward the center. The volatile gases were the least dense and were "burped out" to form an atmosphere. The result is Earth's characteristic core, mantle, and crust and its oceans and atmosphere. Overall, Earth has slowly cooled since its formation, although radioactive decay has generated some additional heat.

Evidence from drill core samples and surface exposures of very old rocks reveals that early Earth differed from its present form in the distribution of water, the composition of the atmosphere, and the shapes, sizes, and positions of landmasses. Knowing about the evolution of these systems will help students understand the structure of Earth's lithosphere, hydrosphere, and atmosphere.

The composition of the earliest atmosphere was probably similar to that of present-day volcanic gases, consisting mostly of water vapor, hydrogen, hydrogen chloride, carbon monoxide, carbon dioxide, and nitrogen but lacking in free oxygen. Therefore, no ozone layer existed in the stratosphere to absorb ultraviolet rays, and ultraviolet radiation from the Sun would have kept the surface of the planet sterile. The oldest fossils, which are of anaerobic organisms, indicate that life on

Earth was established sometime before 3.5 billion years ago. Conditions on Earth were suitable for life to originate here, but the possibility that life hitched a ride to this planet on a meteorite cannot be excluded.

The continents have slowly differentiated through the partial melting of rocks, with the lightest portions floating to the top. The absence of atmospheric oxygen permitted substantial quantities of iron (ferrous) to dissolve, and some of this iron later precipitated as iron oxide (ferric oxide or rust) when early photosynthesizers added oxygen to the atmosphere. This precipitation of iron produced “banded iron formations,” an important geologic resource for contemporary use. These deposits were formed only during distinct time periods, generally from one to three billion years ago. Subsequently, atmospheric oxygen rose sufficiently to permit multicellular, aerobic organisms to flourish.

I. d. *Students know the evidence indicating that the planets are much closer to Earth than the stars are.*

Observations of planetary motions relative to the seemingly fixed stars indicate that planets are much closer to Earth than are the stars. Direct techniques for measuring distances to planets include radar, which makes use of the Doppler effect. Distances to some nearby stars can be measured by parallax: if a star appears to move slightly with respect to more distant stars as Earth orbits from one side of the Sun to the other, then the angle through which the star appears to move and the diameter of Earth’s orbit determine, by the use of simple trigonometry, the distance to the star. For more distant stars and extragalactic objects, indirect methods of estimating distances have to be used, all of which depend on the inverse square law of light. This principle states that the intensity of light observed falls off as the square of the distance from the source.

Student learning activities may include daily observations of the position of the Sun relative to a known horizon, observations of the Moon against the same horizon and also relative to the stars, and observations of planets against the background of stars. Other activities might take advantage of current data on the positions of the planets, computer-based lab exercises, and simulations that incorporate the use of library-media center resources.

I. e. *Students know the Sun is a typical star and is powered by nuclear reactions, primarily the fusion of hydrogen to form helium.*

Comparing the solar spectrum with the spectra of other stars shows that the Sun is a typical star. Analysis of the spectral features of a star provides information on a star’s chemical composition and relative abundance of elements. The most abundant element in the Sun is hydrogen. The Sun’s enormous energy output is evidence that the Sun is powered by nuclear fusion, the only source of energy that can produce the calculated total luminosity of the Sun over its lifetime. Fusion reactions in the Sun convert hydrogen to helium and to some heavier elements. This conversion is one example of nucleosynthesis, in which the fusion process forms helium and other elements (see Standard 11.c for chemistry in this chapter).

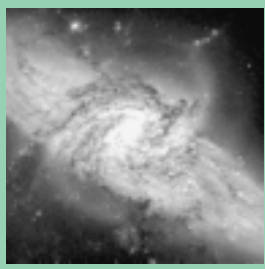
I. f. *Students know the evidence for the dramatic effects that asteroid impacts have had in shaping the surface of planets and their moons and in mass extinctions of life on Earth.*

Impacts of asteroids have created extensive cratering on the Moon, on Mercury, and on other bodies in the solar system. Some craters can also be found on Earth, but most have been destroyed by the active recycling of Earth's planetary surface. Some large impacts have had dramatic effects on Earth and on other planets and their moons. Many believe that the impact of an asteroid produced the unusual iridium-rich layer at the boundary between the rocks of the Cretaceous and the Tertiary periods. This event may have been ultimately responsible for the mass extinction of dinosaurs and many other species 65 million years ago.

Through videos or classroom demonstrations, teachers can introduce simulations of impacts of asteroids. Teachers can model cratering by carefully throwing marbles of different masses (weights) into soft clay or flour at different velocities. Students can observe the patterns of impact and shapes of the craters to help in understanding the physical evidence for impact cratering gathered on Earth and the Moon. Using the mass and velocity of the striking object, students can estimate the energy released from impacts of craters.

I. g.* *Students know the evidence for the existence of planets orbiting other stars.*

Spectral observations and direct imaging of nearby stars show that other stars have planetary systems. In fact, the number of planets that have been discovered to orbit nearby stars is increasing constantly; during 2002 that number exceeded 100. Methods used in these planetary discoveries rely on observing slight oscillations in the star's velocity as revealed by shifts in the frequency of spectral lines. Students can search school and public library collections and appropriate Internet sites for current information about planetary exploration and discoveries of planetary systems.



STANDARD SET 2. Earth's Place in the Universe (Stars, Galaxies, and the Universe)

High school courses in earth sciences will be the first experience for many students in using physical evidence to consider models of stellar life cycles and the history of the universe. Students in earlier grades should have observed the patterns of stars in the sky and learned that the Sun is an average star located in the Milky Way galaxy. Students should also have been introduced to astronomical units (AUs), which measure distances between solar system objects such as Earth and Jupiter. Students should know that distances between stars, and also between galaxies, are measured

in parsecs. The *parsec* is the distance at which one astronomical unit subtends one second of arc. This distance is about 3.26 light-years.

The concepts dealt with in this standard set are not a part of students' daily experience. As in the previous standard set, students may need help to internalize the distance and time scales used to describe the universe. In addition, misconceptions derived from outdated hypotheses or from science fiction movies, books, and videos may interfere with developing an understanding of accepted scientific evidence. To promote scientific literacy, school libraries should try to keep their collections up to date. Students can benefit from the significant amount of new data gained from space exploration during the past 20 years.

2. Earth-based and space-based astronomy reveal the structure, scale, and changes in stars, galaxies, and the universe over time. As a basis for understanding this concept:

- a.** *Students know* the solar system is located in an outer edge of the disc-shaped Milky Way galaxy, which spans 100,000 light years.

The solar system is a tiny part of the Milky Way galaxy, which is a vastly larger system held together by gravity and containing gas, dust, and billions of stars. Determining the shape of this galaxy is like reconstructing the shape of a building from the inside. The conception that the Milky Way galaxy is a disc-shaped spiral galaxy with a bulging spherical center of stars is obtained from the location of stars in the galaxy. If viewed under a low-powered telescope from a planet in another galaxy, the Milky Way would look like a fuzzy patch of light. If viewed with more powerful telescopes from that far planet, the Milky Way would look like a typical spiral galaxy. One would need to travel at the speed of light for about 100,000 years to go from one edge of the Milky Way to the galaxy's opposite edge.

- 2. b.** *Students know* galaxies are made of billions of stars and comprise most of the visible mass of the universe.

The large-scale structure of the visible, or luminous, universe consists of stars found by the billions in galaxies. In turn, there are billions of galaxies in the universe separated from each other by great distances and found in groups ranging from a few galaxies to large galaxy clusters with thousands of members. Superclusters are composed of agglomerations of many thousands of galaxy clusters.

Students should know that scientists catalog galaxies and stars according to the coordinates of their positions in the sky, their brightness, and their other physical characteristics. Spectroscopic analysis of the light from distant stars indicates that the same elements that make up nearby stars are present in the Sun, although the percentages of heavy elements may differ.

Matter found in stars makes up most of the mass of the universe's visible matter; that is, matter that emits or reflects light or some other electromagnetic radiation that is detectable on Earth. The presence of otherwise invisible matter can be inferred from the effect of its gravity on visible matter, and the mass of the invisible

matter in the universe appears to be even greater than the mass of the visible. To discover what form this invisible (or “dark”) matter takes is one of the great goals of astrophysics.

2. c. *Students know the evidence indicating that all elements with an atomic number greater than that of lithium have been formed by nuclear fusion in stars.*

Formation of the elements that compose the universe is called *nucleosynthesis*. Calculations based on nuclear physics suggest that nucleosynthesis occurred through the fusing of light elements to make heavier elements. The composition of distant stars, revealed by their spectra, and the relative abundance of the different elements provide strong evidence that these calculations are correct.

Theoretical models predict that the only elements that should have formed during the big bang are hydrogen, helium, and lithium. All other elements should have formed in the cores of stars through fusion reactions. Fusion requires that one nucleus approach another so closely that they touch and bind together. This process is difficult to accomplish because all nuclei are positively charged and repel their neighbors, creating a barrier that inhibits close approach. However, the barrier can be bypassed if the nuclei have high velocities because of high temperature. Once the process begins, fusion of lightweight nuclei leads to a net release of energy, facilitating further fusion. This mechanism can form elements with nuclei as large as (but no larger than) those of iron, atomic number 26. Temperatures sufficient to initiate fusion are attained in the cores of stars.

In the Sun, and in most stars, hydrogen fusion to form helium is the primary fusion reaction. Elements heavier than carbon are formed only in more massive stars and only during a brief period near the end of their lifetime. A different type of fusion is necessary to form elements heavier than iron. This type can be carried out only by adding neutrons to a preexisting heavy element that forms a “seed.” Neutrons are available only during a limited portion of a star’s lifetime, particularly during the brief supernova that occurs when a massive star dies.

2. d. *Students know that stars differ in their life cycles and that visual, radio, and X-ray telescopes may be used to collect data that reveal those differences.*

Stars differ in size, color, chemical composition, surface gravity, and temperature, all of which affect the spectrum of the radiation the stars emit and the total energy. It is primarily the electromagnetic radiation emitted from the surface of the Sun and stars that can be detected and studied. Radiation in wavelengths that run from those of X-rays to those of radio waves can be collected by modern telescopes. The data obtained enable astronomers to classify stars, determine their chemical composition, identify the stages of their life cycles, and understand their structures. No one has ever watched a star evolve from birth to death, but astronomers can predict the ultimate fate of a given star by observing many stars at different points

in their cycles. The primary characteristics that astronomers use to classify stars are surface temperature and luminosity (the total energy emitted).

2. e.* *Students know* accelerators boost subatomic particles to energy levels that simulate conditions in the stars and in the early history of the universe before stars formed.

Scientists' understanding of processes occurring in stars has been enhanced by experiments in particle physics, nuclear physics, and plasma physics. Particle accelerators create particle velocities great enough for the nuclei of elements to overcome electrostatic repulsion and to approach close enough for nuclear interactions to take place, mimicking stellar nuclear fusion processes. The first accelerator was developed in the 1950s in Berkeley, California. It allowed the energy of protons to be raised high enough to create antimatter particles, thereby making it possible to explore the substructure of what had been considered the most elementary form of matter.

Scientists used the results from these experiments to create models of the processes and conditions under which matter is created. Developed at the turn of the twentieth century, Einstein's special theory of relativity showed that matter and energy are interchangeable. Particle accelerators made it possible to produce, in the laboratory, matter-energy transformations previously possible only in stars. Scientists and engineers continue to look for ways to control and sustain fusion reactions, a potential source for a nearly inexhaustible supply of energy.

2. f.* *Students know* the evidence indicating that the color, brightness, and evolution of a star are determined by a balance between gravitational collapse and nuclear fusion.

A major concept in science is that temperature is a measure of the underlying energy of motion of a system. Furthermore, thermal energy can be radiated away into space as electromagnetic radiation. This process produces the light that Earth receives from the Sun. As the temperature of a star's surface increases, the intensity of radiation produced also increases, and the spectrum of radiation shifts toward a shorter wavelength. Consequently, a blue-white star is hotter than a red star and emits more energy than does a red star of equal size.

A star's surface temperature is a guide to the internal processes occurring within the star. Stars are so hot that they are a form of matter known as a *plasma*, in which atoms move so fast that electrons cannot keep up, leaving the nuclei free as ions. Gravity acts to collapse the ions in the hot plasma. The high density and high temperature of the plasma allow the barrier caused by the mutual repulsion of positive nuclei to be overcome, permitting fusion, or nucleosynthesis, to occur in the stellar core. The energy released from this reaction helps maintain a pressure that resists further compaction by the gravitational force and prevents collapse of the stellar core. The stellar dynamics evolve to a structure that reflects the thermal energy flow from the hot core, where energy is created, to the cooler surface, where it is radiated away to space as starlight. The star will attain an energy balance so that the

production of energy by fusion equals the upward heat flow, which in turn equals the energy emitted into space. The size and color of the star reflect the balances needed.

2. g.* *Students know how the red-shift from distant galaxies and the cosmic background radiation provide evidence for the “big bang” model that suggests that the universe has been expanding for 10 to 20 billion years.*

During the 1920s Edwin Hubble observed the *red shift* (the apparent increase in wavelength of emitted radiation) of distant galaxies. The red shift is due to a Doppler effect and indicates that distant galaxies are rapidly receding from ours. He noted that their speed of recession is proportional to their distance and suggested that the universe is expanding. More recent verification from radio waves and other data that a 3K background radiation, or low-level microwave background “noise,” exists throughout the universe has led to the acceptance of the big bang model of an expanding universe that is 10 to 20 billion years old. According to this theory, this radiation began as high-energy short-wavelength radiation created by the explosion when the universe was born. As space expanded and the universe cooled down, the wavelengths were essentially stretched out.

A major breakthrough in astrophysics occurred during the 1990s, when scientists at the Lawrence Berkeley National Laboratory in California saw evidence for variation in the intensity of this background radiation. This finding is consistent with the idea that matter in the early universe was already starting to condense in some areas, a necessary first step toward the clumping together that led to the formation of stars and galaxies.



STANDARD SET 3. Dynamic Earth Processes

The earth sciences use concepts, principles, and theories from the physical sciences and mathematics and often draw on facts and information from the biological sciences. To understand Earth’s magnetic field and magnetic patterns of the sea floor, students will need to recall, or in some cases learn, the basics of magnetism. To understand circulation in the atmosphere, hydrosphere, and lithosphere, students should know about convection, density and buoyancy, and the Coriolis effect. Earthquake epicenters are located by using geometry. To understand the formation of igneous and sedimentary minerals, students must master concepts related to crystallization and solution chemistry.

Because students in grades nine through twelve may take earth science before they study chemistry or physics, some background information from the physical sciences needs to be introduced in sufficient detail. From standards presented earlier, students should know about plate tectonics as a driving force that shapes Earth’s surface. They should know that evidence supporting plate tectonics includes

the shape of the continents, the global distribution of fossils and rock types, and the location of earthquakes and volcanoes. They should also understand that plates float on a hot, though mostly solid, slowly convecting mantle. They should be familiar with basic characteristics of volcanoes and earthquakes and the resulting changes in features of Earth's surface from volcanic and earthquake activity.

3. Plate tectonics operating over geologic time has changed the patterns of land, sea, and mountains on Earth's surface. As the basis for understanding this concept:

- a. *Students know features of the ocean floor (magnetic patterns, age, and sea-floor topography) provide evidence of plate tectonics.*

Much of the evidence for continental drift came from the seafloor rather than from the continents themselves. The longest topographic feature in the world is the midoceanic ridge system—a chain of volcanoes and rift valleys about 40,000 miles long that rings the planet like the seams of a giant baseball. A portion of this system is the Mid-Atlantic Ridge, which runs parallel to the coasts of Europe and Africa and of North and South America and is located halfway between them. The ridge system is made from the youngest rock on the ocean floor, and the floor gets progressively older, symmetrically, on both sides of the ridge. No portion of the ocean floor is more than about 200 million years old. Sediment is thin on and near the ridge. Sediment found away from the ridge thickens and contains progressively older fossils, a phenomenon that also occurs symmetrically.

Mapping the magnetic field anywhere across the ridge system produces a striking pattern of high and low fields in almost perfect symmetrical stripes. A brilliant piece of scientific detective work inferred that these “zebra stripes” arose because lava had erupted and cooled, locking into the rocks a residual magnetic field whose direction matched that of Earth's field when cooling took place. The magnetic field near the rocks is the sum of the residual field and Earth's present-day field. Near the lavas that cooled during times of normal polarity, the residual field points along Earth's field; therefore, the total field is high. Near the lavas that cooled during times of reversed polarity, the residual field points counter to Earth's field; therefore, the total field is low.

The “stripes” provide strong support for the idea of seafloor spreading because the lava in these stripes can be dated independently and because regions of reversed polarity correspond with times of known geomagnetic field reversals. This theory states that new seafloor is created by volcanic eruptions at the midoceanic ridge and that this erupted material continuously spreads out convectively and opens and creates the ocean basin. At some continental margins deep ocean trenches mark the places where the oldest ocean floor sinks back into the mantle to complete the convective cycle. Continental drift and seafloor spreading form the modern theory of plate tectonics.

3. b. Students know the principal structures that form at the three different kinds of plate boundaries.

There are three different types of plate boundaries, classified according to their relative motions: divergent boundaries; convergent boundaries; and transform, or parallel slip, boundaries. *Divergent boundaries* occur where plates are spreading apart. Young divergence is characterized by thin or thinning crust and rift valleys; if divergence goes on long enough, midocean ridges eventually develop, such as the Mid-Atlantic Ridge and the East Pacific Rise.

Convergent boundaries occur where plates are moving toward each other. At a convergent boundary, material that is dense enough, such as oceanic crust, may sink back into the mantle and produce a deep ocean trench. This process is known as *subduction*. The sinking material may partially melt, producing volcanic island arcs, such as the Aleutian Islands and Japan. If the subduction of denser oceanic crust occurs underneath a continent, a volcanic mountain chain, such as the Andes or the Cascades, is formed. When two plates collide and both are too light to subduct, as when one continent crashes into another, the crust is crumpled and uplifted to produce great mountain chains, such as the relatively young Himalayas or the more ancient Appalachians.

The third type of plate boundary, called a *transform*, or *parallel slip, boundary*, comes into existence where two plates move laterally by each other, parallel to the boundary. The San Andreas fault in California is an important example. Marking the boundary between the North American and Pacific plates, the fault runs from the Gulf of California northwest to Mendocino County in northern California.

3. c. Students know how to explain the properties of rocks based on the physical and chemical conditions in which they formed, including plate tectonic processes.

Rocks are classified according to their chemical compositions and textures. The composition reflects the chemical constituents available when the rock was formed. The texture is an indication of the conditions of temperature and pressure under which the rock formed. For example, many igneous rocks, which cooled from molten material, have interlocking crystalline textures. Many sedimentary rocks have fragmental textures. Whether formed from cooling magma, created by deposits of sediment grains in varying sizes, or transformed by heat and pressure, each rock possesses identifying properties that reflect its origin.

Plate tectonic processes directly or indirectly control the distribution of different rock types. Subduction, for example, takes rocks from close to the surface and drags them down to depths where they are subjected to increased pressures and temperatures. Tectonic processes also uplift rocks so that they are exposed to lower temperatures and pressures and to the weathering effects of the atmosphere.

3. d. *Students know why and how earthquakes occur and the scales used to measure their intensity and magnitude.*

Most earthquakes are caused by lithospheric plates moving against each other. Earth's brittle crust breaks episodically in a stick-and-slip manner. Plate tectonic stresses build up until enough energy is stored to overcome the frictional forces at plate boundaries. The *magnitude* of an earthquake (e.g., as shown on the Richter scale) is a measure of the amplitude of an earthquake's waves. The magnitude depends on the amount of energy that is stored as elastic strain and then released. Magnitude scales are logarithmic, meaning that each increase of one point on the scale represents a factor of ten increase in wave amplitude and a factor of about thirty increase in energy. An earthquake's intensity (as measured on a modified Mercalli scale) is a subjective, but still valuable, measure of how strong an earthquake felt and how much damage it did at any given location.

3. e. *Students know there are two kinds of volcanoes: one kind with violent eruptions producing steep slopes and the other kind with voluminous lava flows producing gentle slopes.*

The violence of volcanic eruptions is a function of the viscosity of the lava that erupted. All magmas contain dissolved volatiles (or gases) that expand and rise buoyantly as the magma rises to the surface—much like the bubbles in a bottle of soda. Fluid lavas allow gases to bubble away relatively harmlessly, but viscous lavas trap the gases until large pressures build up and the system explodes. Temperature and composition determine the viscosity of magma. Magma at cool temperatures and with a high silica content is very viscous. Rhyolitic and andesitic lavas are examples of lavas with high viscosity. They erupt violently, scattering volcanic fragments and ash widely. Viscous lava, which does not flow very far, builds steep-sided volcanoes. Other lavas, such as basaltic, are relatively fluid and erupt quietly, producing great flows of lava that gradually build gently sloping deposits (called *shield volcanoes*).

3. f.* *Students know the explanation for the location and properties of volcanoes that are due to hot spots and the explanation for those that are due to subduction.*

The melting of silica-rich (granitic) upper-crustal rock produces viscous lavas. The melting of iron-rich (basaltic) lower-crustal, or upper-mantle, rock produces fluid lavas. Upper-crustal rock may melt at subduction zones, and violent volcanic eruptions are common there. Lower-crustal rock may melt at the midocean spreading centers, where quiet, fluid eruptions are common.

Volcanoes may also arise from the activity of mantle plumes, which are long-lived hot spots deep in the mantle. Rock locally melted within the hot spot rises through buoyancy through the crust, sometimes forming volcanoes. As the magma rises, it melts other rocks in its path and incorporates them into the magma. The incorporation of enough upper-crustal rocks, as at the Yellowstone Caldera

Complex at Yellowstone National Park, produces explosive volcanoes. If only lower-crustal rocks are incorporated, as in Hawaii, nonexplosive, gently sloped shield volcanoes form. The Hawaiian Islands are an example of hot spot volcanism, which occurs in chains with the volcanoes systematically aging downward away from the heat source. This type of volcanism is extra evidence supporting the theory of plate tectonics. Volcanoes form when a particular piece of the crust is over the hot spot and then die out as that part of the plate moves off.



STANDARD SET 4. Energy in the Earth System (Solar Energy Enters, Heat Escapes)

Students know that energy is transferred from warmer to cooler objects. They are expected to know that energy is transported by moving material or in heat flow or as waves.

They have learned that when fuel is consumed, energy is released as heat, which can be transferred by conduction, convection, or radiation. They have also learned that the Sun is the major source of energy for Earth. They have studied ways in which heat from Earth's interior influences conditions in the atmosphere and oceans and have considered the changes in weather caused by differences in pressure, temperature, air movement, and humidity.

Photosynthesis may have been covered in detail if the students have completed high school biology. Students who have completed high school physics and chemistry will also be better prepared to deal with transfer and absorption of energy. To complete this standard set, students should review the characteristics of the electromagnetic spectrum. Students should also review information presented in the sixth grade science standards related to dynamic Earth processes to increase their awareness of the enormous amount of energy stored in the planet, both as original heat and as a product of radioactive decay. Students should also have studied the mechanisms, primarily mantle convection and some conduction, that bring heat to Earth's surface. Students should know that heat from Earth's interior escapes into the atmosphere through volcanic eruptions, hot spring activity, geysers, and similar means. Although spectacular and energetic, these phenomena are localized and occur over a tiny percentage of Earth's surface. Beyond these readily noticeable losses of interior heat, internal heat disperses into the atmosphere slowly and relatively uniformly across the entire surface of the planet.

4. Energy enters the Earth system primarily as solar radiation and eventually escapes as heat. As a basis for understanding this concept:

- a.** *Students know the relative amount of incoming solar energy compared with Earth's internal energy and the energy used by society.*

Most of the energy that reaches Earth's surface comes from the Sun as electromagnetic radiation concentrated in infrared, visible, and ultraviolet wavelengths.

The energy available from the Sun's radiation exceeds all other sources of energy available at Earth's surface. There is energy within Earth, some of which is primitive, or original, heat from the planet's formation and some that is generated by the continuing decay of radioactive elements. Over short periods of time, however, only a small amount of that energy reaches Earth's surface. The enormous amount of energy remaining within Earth powers plate tectonics.

Human societies use energy for heating, lighting, transportation, and many other modern conveniences. Most of this energy came to Earth as solar energy. Some has been stored as fossil fuels, plants that stored energy through photosynthesis. Fossil fuels, including oil, natural gas, and coal, provide the majority of energy used by contemporary economies. This energy, which has been stored in crustal rocks during hundreds of millions of years, is ultimately limited. On average a U.S. household consumes energy at the rate of about 1 kilowatt, or 1,000 joules of energy, per second. The Sun delivers almost this much power to every square meter of the illuminated side of Earth. For this reason total energy use by humans is small relative to the total solar energy incident on Earth every day, but harvesting this energy economically poses a challenge to modern engineering.

4. b. *Students know the fate of incoming solar radiation in terms of reflection, absorption, and photosynthesis.*

The fate of incoming solar radiation, which is concentrated in the visible region of the electromagnetic spectrum, is determined by its wavelength. Longer wavelength radiation (e.g., infrared) is absorbed by atmospheric gases. Shorter wavelengths of solar electromagnetic energy, particularly in the visible range, are not absorbed by the atmosphere, except for the absorption of ultraviolet radiation by the ozone layer of the upper atmosphere. Some of the incident visible solar radiation is reflected back into space by clouds, dust, and Earth's surface, and the rest is absorbed.

Plants and other photosynthetic organisms contain chlorophyll that absorbs light in the orange, short-red, blue, and ultraviolet portions of the solar radiation spectrum. The absorption of visible light is less for green and yellow wavelengths, the reflection of which accounts for the color of leaves. The plant uses the absorbed light energy for photosynthesis, in which carbon dioxide and water are converted to sugar, a process that is used to support plant growth and cell metabolism. A by-product of photosynthesis is oxygen. The amount of carbon dioxide in the atmosphere declines slightly during the summer growing season and increases again in the winter. The solar energy stored in plants is the primary energy source for life on Earth.

4. c. *Students know the different atmospheric gases that absorb the Earth's thermal radiation and the mechanism and significance of the greenhouse effect.*

Every object emits electromagnetic radiation that is characteristic of the temperature of the object. This phenomenon is called "blackbody" radiation. For example,

an iron bar heated in a fire glows red. At room temperatures the radiation emitted by the bar is in the far infrared region of the electromagnetic spectrum and cannot be seen except with cameras with infrared imaging capability.

The Sun is much hotter than Earth; therefore, energy reaching Earth from the Sun has, on average, much shorter wavelengths than the infrared wavelengths that Earth emits back into space. Energy reaching Earth is mostly in the visible range, and a portion of this energy is absorbed. However, for the planet to achieve energy balance, all the incoming solar energy must be either reflected or reradiated to space. Earth cools itself as the Sun does, by emitting blackbody radiation; but because Earth is cooler than the Sun, Earth's radiation peaks in the infrared instead of in the visible wavelengths.

Certain gases, particularly water vapor, carbon dioxide, methane, and some nitrogen oxide pollutants, transmit visible light but absorb infrared light. These atmospheric constituents, therefore, admit energy from the Sun but inhibit the loss of that energy back into space. This phenomenon is known as the greenhouse effect, and these constituents are called greenhouse gases. Without them Earth would be a colder place in which to live. Human activity, such as the burning of fossil fuels, is increasing the concentration of greenhouse gases in the atmosphere. This buildup can potentially cause a significant increase in global temperatures and affect global and regional weather patterns. Predicting the precise long-term impact is difficult, however, because the influence of cloud cover and other factors is poorly understood.

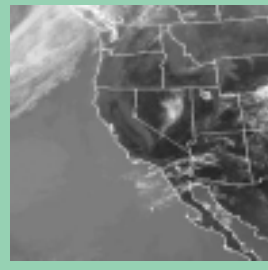
4. d.* *Students know the differing greenhouse conditions on Earth, Mars, and Venus; the origins of those conditions; and the climatic consequences of each.*

Atmospheric conditions on Earth, Mars, and Venus are different. With a thick atmosphere rich in greenhouse gases, Venus exhibits a much higher planetary surface temperature than does Earth. Mars has a very thin atmosphere depleted in greenhouse gases and therefore has little greenhouse warming. And because Mars lacks oceans and the thin atmosphere does not effectively store heat, the planet experiences large temperature swings: high during the daytime and low at night.

The greenhouse effect is important to Earth's climate because without that effect the planet would be much colder and more like Mars. But if the concentration of absorbing gases is too high, trapping too much heat in the atmosphere, excessive heating could occur on Earth, producing global warming and a climate closer to that of Venus.

The concentration of greenhouse gases, principally that of carbon dioxide, is increasing in Earth's atmosphere, a phenomenon caused primarily by the burning of fossil fuels for electricity and heat. Computer models of the greenhouse effect (a projected buildup of greenhouse gases) predict an increase in average global temperatures. If these models are accurate, the change predicted could have significant consequences on weather patterns and ocean levels. However, Earth's climate system consists of a complex set of positive and negative feedback mechanisms that are

not fully understood, and therefore predictions of changes in global temperatures contain some uncertainty.



STANDARD SET 5. Energy in the Earth System (Ocean and Atmospheric Convection)

Students know that the uneven heating of Earth causes air movements and that oceans and the water cycle influence weather. They also know that heat energy is transferred by radiation, conduction, and convection and that radiation from the Sun is responsible for winds and ocean currents, which in turn influence the weather and climate. They should have learned the concept of density and that warm, less-dense fluids rise and cooler, denser fluids sink (see Standard Set 8, “Density and Buoyancy,” for grade eight in Chapter 4). Students who have completed courses in chemistry and physics know that water has high heats of crystallization and evaporation and high specific heat (see Standard 7.d for chemistry in this chapter). Others will have to be introduced to these concepts. This knowledge provides a foundation of physical principles for a fuller understanding of energy flow through Earth’s system.

5. Heating of Earth’s surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents. As a basis for understanding this concept:

- a. *Students know* how differential heating of Earth results in circulation patterns in the atmosphere and oceans that globally distribute the heat.

The Sun’s rays spread unequally across Earth’s surface, heating it more at the equator and less at the poles. As heat at the surface transfers to the atmosphere, circulation cells are created. At the equator, for example, hot, moist air rises, expands under lower atmospheric pressure, and cools, causing the air to release its water as precipitation. The air then moves either north or south away from the equator. In its eventual descent the air is compressed by higher atmospheric pressure and warms. Therefore, the air arrives at Earth’s surface in a state of low relative humidity. The air then flows back to the equator, completing the cycle. There are three such cycles (or cells) between the equator and the pole. The circulation in these cells regulates the general pattern of rainfall on Earth’s surface, with wet climates to be found under ascending air and dry climates under descending air. Therefore, wet climates are generally found at the equator, dry climates in bands at around 30 degrees north and south, wet climates in bands at around 60 degrees, and dry climates again at still higher latitudes.

The same unequal heating of Earth’s surface that drives the global atmospheric circulation also causes large thermally driven currents in the oceans. These currents are important in global redistribution of heat. Air currents also distribute heat. Some of the atmospheric heat transport is carried out by exchanging warm and cold air, but water vapor is also a major transport mechanism. Heat is stored in water

that evaporates at low latitudes and then is released when the water recondenses (as precipitation) at higher latitudes. For all these reasons combined, the equatorial regions are somewhat cooler, and the poles somewhat warmer, than might otherwise be expected.

Earth's axis is tilted with respect to the plane of its orbit around the Sun. As a result, different amounts of solar energy reach the two hemispheres at different times, thus causing the seasons.

The ocean and atmosphere are a linked system as energy is exchanged between them. Ocean currents rise in part because cool or more saline waters descend, setting circulation patterns in motion. These currents also distribute heat from the equator toward the pole.

5. b. *Students know the relationship between the rotation of Earth and the circular motions of ocean currents and air in pressure centers.*

Earth rotates on an axis, and all flow of fluids on or below the surface appears to be deflected by the Coriolis effect, making right turns in the Northern Hemisphere and left turns in the south. This is a complicated phenomenon to explain to students, but it can be illustrated with a rotatable globe and chalk. Students can hold the globe still and draw a chalk line from the North Pole to the equator and another from the South Pole to the equator. The result will be a part of a great circle. Next the students draw the same line while, at the same time, slowly rotating the globe. A curved line will appear. The faster the globe turns, the more profound the turning of the chalk line. Teachers may find it helpful to compare this effect with centrifugal force, another apparent force arising from an accelerating reference frame. Many good demonstrations of this phenomenon are possible. Teachers can also point out to students that the airflow past a bicycle rider feels the same if the bicycle is still and the air is moving or vice versa. An observer standing on Earth feels that the air is moving, even if the relative motion arises because he or she and Earth are moving through the air.

Combining convective air or water flows with Coriolis turning produces circular currents. For example, when a region, or cell, of lower-pressure (less dense) air exists in the Northern Hemisphere, higher-pressure air tries to flow toward it from all sides by convection. However, the Coriolis effect deflects these flows to the right, leading to a circular airflow, which appears counterclockwise when viewed from above.

5. c. *Students know the origin and effects of temperature inversions.*

Normally, the atmosphere is heated from below by the transfer of energy from Earth's surface. This activity produces *convection*, the transfer of heat by the vertical movements of air masses. However, in certain geographical settings, local sources or sinks for heat can interact with topography to create circumstances in which lower-density warm air, flowing from one direction, is emplaced over higher-density cool air that has come from another direction. This situation, called a *temperature*

inversion, effectively stops convection, causing stagnant air. In areas with high population density (or with other sources of pollution) atmospheric pollutants, known as smog, may be trapped by the inversion.

In southern California inverted air occurs normally during the late spring and summer, when the land's temperature is significantly warmer than the ocean's. Air that has been cooled over the ocean flows inland but is stopped by the mountains. Airflow from the deserts, which are at higher elevations, provides warm air that caps this cool marine layer, producing an inversion. This low-elevation, cooler air is held in place by mountains ringing the Los Angeles Basin and is rapidly filled with pollutants.

5. d. *Students know properties of ocean water, such as temperature and salinity, can be used to explain the layered structure of the oceans, the generation of horizontal and vertical ocean currents, and the geographic distribution of marine organisms.*

In low latitudes water is warmed at the surface by the Sun. Differences in the density of water force this water to flow to high latitudes, where it cools as it transfers thermal energy into the atmosphere. Because cooling increases water's density (down to a temperature of 4 degrees Celsius in the case of fresh water and down to the freezing point in the case of sea water), water sinks at high latitudes, flows back toward the equator at depth, and upwells toward the surface as it is warmed by the Sun. This density-driven circulation creates a layered ocean structure at low and midlatitudes, with warm low-density water at the surface and cool high-density water at depth. Salinity also plays a role because rapid evaporation in dry-latitude belts concentrates the salt. Fresh water inflowing from rainfall in wet climatic belts, from rivers, and from melting ice formed at high latitudes decreases salinity.

Because water has a high specific heat, it effectively transports heat from the equator to the poles. Furthermore, the high specific heat helps to buffer Earth's surface against significant daily or seasonal temperature changes. Ice, the solid phase of water, is less dense than the liquid phase and thus floats. (This unique property of water is important to life on Earth.) Icebergs float long distances from their places of origin before they melt and add fresh water to the surface of the ocean.

Water is an excellent solvent for many ions and dissolved gases necessary to sustain marine life. The ocean's chemistry reflects the combined influences of ocean circulation and of marine organisms on biologically active compounds. Water near the surface is oxygenated by photosynthesis, and dissolved nutrients required by phytoplankton are depleted. Zooplankton eat phytoplankton, and the remains of both sink into deeper waters where they decompose. The decomposition enriches deep water in nutrients and depletes it in oxygen, leading to a chemically stratified ocean. Deep water upwelled into the surface zone carries abundant nutrients needed to sustain the growth of phytoplankton. These patterns influence the distribution of marine life because organisms tend to follow and stay within zones that best meet their requirements for survival.

In addition to the density factors that drive ocean circulation, a wind-driven circulation exists in surface waters. These surface and deep currents mix the oceans continuously, particularly at the surface. Ocean currents influence regional climates. For example, the Gulf Stream brings warm water offshore to northwest Europe, warming the climate in such countries as Great Britain. Without these currents the climate would be very different.

To demonstrate the density of currents, teachers can use containers of water heated to different temperatures. Food coloring may be used to dye hot water one color and cold water another. The students observe as the hot water is poured into the cold water and vice versa. To extend the demonstration further, the teacher can add table salt to make different concentrations of salt in same- and different-colored water samples. As the teacher pours saline water into fresh water, and vice versa, students can observe and report what happens.

5. e. *Students know rain forests and deserts on Earth are distributed in bands at specific latitudes.*

Latitudinal bands, or zones, of similar climatic conditions circle Earth. These bands are produced by the large-scale convective air patterns described earlier, known as “Hadley cells.” Basically, air rises at the equator and at near 60 degrees north and south latitudes and sinks near 30 degrees north and south latitudes and at both poles. Students will learn these concepts more easily if they understand the ideal gas law and also the notion of relative humidity—that cooler air evaporates less water than does warmer air. If students have not studied these topics, the teacher can explain that sinking air is compressed because of gravity’s pull on the overlying air.

Rising air expands and cools, and sinking air is compressed and heated (e.g., compressing air into a bicycle tire warms the air). Because more water can evaporate at warmer temperatures, the air seems drier as it is compressed and heated. Therefore, deserts are common in bands of sinking air and, conversely, high precipitation in zones of rising air supports lush vegetation (e.g., rainforests).

5. f.* *Students know the interaction of wind patterns, ocean currents, and mountain ranges results in the global pattern of latitudinal bands of rain forests and deserts.*

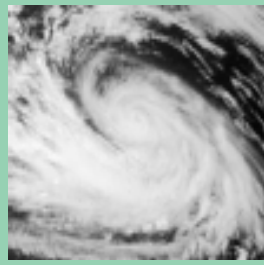
As air is warmed in the tropics, water is evaporated, and the resulting warm, moist air rises and cools. When this moist tropical air cools enough, it becomes saturated and precipitates water as rain. The once warm, moist air is now dryer and cold and heavy. This air is then displaced to the north or south by rising currents of warm, moist air. The cold, dry air begins to descend and is again compressed and heated. At last reaching the ground, at about 30 degrees latitude, the now warm, dry air evaporates water from the ground, producing a desert. A similar pattern is seen farther north and south, where temperate rainforests exist at about 60 degrees latitude, reflecting the rising air in that region. The air sinks at the poles and is warmed somewhat but is still very cold and dry.

Deserts, called *rain shadow deserts*, are also found outside the latitudinal band of deserts. An example is the desert in much of Nevada east of the Sierra Nevada. Warm, moist winds blowing off the Pacific Ocean rise up over the Sierra Nevada, cooling and dropping rain on the forested westward side of the mountains. East of the mountains the air, which is dry, drops down to lower elevations, heats up, and evaporates surface water, producing a desert.

Global weather and atmospheric circulation maps from the weather bureau are helpful for studying this process. Such maps can be downloaded from appropriate Internet sites. Students may search an atlas for maps that show the distribution of deserts and rain forests and compare those maps with global weather maps. Students can plot atmospheric and oceanic currents on a world map and identify regions that are warm and wet and those that are cold and dry.

5. g.* Students know features of the ENSO (El Niño southern oscillation) cycle in terms of sea-surface and air temperature variations across the Pacific and some climatic results of this cycle.

The *El Niño* southern oscillation (ENSO) cycle refers to the observed relationships between periodic changes in the patterns of temperature and air pressure of the equatorial surface of the Pacific Ocean and overlying air masses. These relationships change on a time scale of several years and correlate with characteristic variability in global weather climate. Data on sea surface temperatures gathered during several decades can be compared with other records for weather and related topics to see patterns develop (e.g., temperatures near the coast of southern California can be compared with rainfall totals in various places in the world or with various agricultural indicators).



STANDARD SET 6. Energy in the Earth System (Climate and Weather)

This standard set is designed to help students focus on the various factors that produce climate and weather. Since the study of the water (hydrologic) cycle is fundamental to understanding weather, teachers should review that cycle during the study of Standard Set 6. In standard sets taught previously in the lower grade levels, weather was introduced, as a phenomenon, followed by a discussion of the procedures in which weather is observed, measured, and described. Subsequently, weather maps were introduced, and students should have learned to read and interpret topographic maps. The Investigation and Experimentation standards for grades six and seven also called for students to construct scale models and make predictions from accumulated evidence. Teachers should review the concept of pressure with the students.

6. Climate is the long-term average of a region's weather and depends on many factors. As a basis for understanding this concept:

- a.** *Students know* weather (in the short run) and climate (in the long run) involve the transfer of energy into and out of the atmosphere.

Unequal transmission and absorption of solar energy cause differences in air temperature and therefore differences in pressure; winds are generated as a result. Solar-influenced evaporation and precipitation of water determine the humidity of the atmosphere. Evaporation and precipitation also transfer energy between the atmosphere and oceans because energy is absorbed when water evaporates and is released when water condenses. Climate is the long-term average of weather. According to an old saying, “Climate is what you expect, and weather is what you get.”

- 6. b.** *Students know* the effects on climate of latitude, elevation, topography, and proximity to large bodies of water and cold or warm ocean currents.

Previous earth science standards covered how and why the locations of rainforests and deserts depend on latitude. But other variables can modify the climate in a particular region. For example, since air expands and cools when it rises, expected temperatures at high elevations are considerably lower than they are at sea level or below. Mountains also affect local climate because of the rain-shadow effect, described in Standard Set 5, “Energy in the Earth System,” in this section, and the direction of prevailing winds. The Indian monsoon cycle and the smaller-scale Santa Ana winds are other examples of how mountains may influence weather and climate.

The proximity of land to large bodies of water can also strongly influence climate. Large-scale warm and cold oceanic currents (e.g., the cold Japanese current off the coast of California and the warm Gulf Stream off the East Coast of the United States) exert regional controls on the climate of adjoining landmasses. Even more important, water has a very high specific heat, which causes water to remain within a relatively narrow temperature range between day and night and from season to season. Because of this phenomenon, regions near bodies of water have a tempered climate generally cooler than inland regions during hot weather and warmer than inland regions during cold weather.

- 6. c.** *Students know* how Earth's climate has changed over time, corresponding to changes in Earth's geography, atmospheric composition, and other factors, such as solar radiation and plate movement.

Because Earth is dynamic, particularly with regard to long-term changes in the distribution of continents caused by plate tectonic movements, the planet's climate has changed over time. Some geologic eras were much warmer than the present Cenozoic era. At other times much of the land was covered in giant ice sheets.

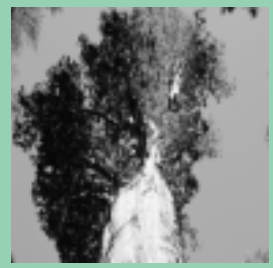
Astronomical factors that vary significantly only over millenia and such factors as changes in the tilt of Earth's axis of rotation and changes in the shape of Earth's orbit also influence climate. The configuration of continental landmasses affects ocean currents. Climate is affected, episodically, by volcanic eruptions and impacts of meteorites that inject dust into the atmosphere. Dust and volcanic ash reduce the amount of energy penetrating the atmosphere, thereby changing atmospheric circulation, rainfall patterns, and Earth's surface temperatures.

Variations in life in general, and human activity in particular, affect the amounts of carbon dioxide and other gases that enter the atmosphere. The effect of carbon dioxide and other greenhouse gases is discussed in Standard 4.d in this section.

6. d.* *Students know* how computer models are used to predict the effects of the increase in greenhouse gases on climate for the planet as a whole and for specific regions.

Scientists now know enough about what controls complex climatic variations to construct computer-generated models on global and regional scales. Such models can now make useful predictions about the consequences of greenhouse gases, including the potential for changes in global and regional mean temperatures. Computer-generated weather models have been improved and broadened sufficiently to be useful in exploring long-term changes in weather that border on climatic predictors. Specific models have been constructed to predict effects of ozone depletion and an increase in greenhouse gases.

Students can download current and historical data on weather from the Internet and use this information to explore whether a correlation exists between data on weather and on greenhouse gas production. Students' conclusions may be compared with results from computer-generated greenhouse models and interpretations published in scientific papers or posted on the Internet. However, students should be advised to expect contrary opinions because interpretations of the same climatic data can vary widely.



STANDARD SET 7. Biogeochemical Cycles

Students who complete high school biology/life sciences before they take earth sciences will already have learned about biogeochemical cycles. Through standards presented in lower grade levels, other students should have been exposed to life cycles, food chains, and the movement of chemical elements through biological and physical systems. Students should also have studied chemical changes in organisms and should know that through photosynthesis solar energy is used to create the molecules needed by plants. In this standard set students will learn that within the biogeochemical cycles, matter is transferred between organisms through food webs or chains. Matter can also be transferred from these cycles into physical

environments where the cycling elements are held in reservoirs. Matter can be transferred back into biological cycles through physical processes, such as volcanic eruptions and products of the rock cycle, particularly those from weathering.

7. Each element on Earth moves among reservoirs, which exist in the solid earth, in oceans, in the atmosphere, and within and among organisms as part of biogeochemical cycles. As a basis for understanding this concept:

- a. *Students know* the carbon cycle of photosynthesis and respiration and the nitrogen cycle.

Carbon and nitrogen move through biogeochemical cycles. The recycling of these components in the environment is crucial to the maintenance of life. Through photosynthesis, carbon is incorporated into the biosphere from the atmosphere. It is then released back into the atmosphere through respiration. Carbon dioxide in the atmosphere is dissolved and stored in the ocean as carbonate and bicarbonate ions, which organisms take in to make their shells. When these organisms die, their shells rain down to the ocean floor, where they may be dissolved if the water is not saturated in carbonate. Otherwise, the shells are deposited on the ocean floor and become incorporated into the sediment, eventually turning into a bed of carbonate rock, such as limestone.

Uplifted limestone may dissolve in acidic rain to return carbon to the atmosphere as carbon dioxide, sending calcium ions back into the ocean where they will precipitate with carbon dioxide to form new carbonate material. Carbonate rocks may also be subducted, heated to high temperatures, and decomposed, returning carbon to the atmosphere as volcanic carbon dioxide gas. Carbon is also stored in the solid earth as graphite, methane gas, petroleum, or coal.

Nitrogen, another element important to life, also cycles through the biosphere and environment. Nitrogen gas makes up most of the atmosphere, but elemental nitrogen is relatively inert, and multicellular plants and animals cannot use it directly. Nitrogen must be “fixed,” or converted to ammonia, by specialized bacteria. Other bacteria change ammonia to nitrite and then to nitrate, which plants can use as a nutrient. Eventually, decomposer bacteria return nitrogen to the atmosphere by reversing this process.

- 7. b.** *Students know* the global carbon cycle: the different physical and chemical forms of carbon in the atmosphere, oceans, biomass, fossil fuels, and the movement of carbon among these reservoirs.

The global carbon cycle extends across physical and biological Earth systems. Carbon is held temporarily in a number of reservoirs, such as in biomass, the atmosphere, oceans, and in fossil fuels. Carbon appears primarily as carbon dioxide in the atmosphere. In oceans carbon takes the form of dissolved carbon dioxide and of bicarbonate and carbonate ions. In the biosphere carbon takes the form of sugar and of many other organic molecules in living organisms. Some movement

of carbon between reservoirs takes place through biological means, such as respiration and photosynthesis, or through physical means, such as those related to plate tectonics and the geologic cycle. Carbon fixed into the biosphere and then transformed into coal, oil, and gas deposits within the solid earth has in recent years been returning to the atmosphere through the burning of fossil fuels to generate energy. This release of carbon has increased the concentration of carbon dioxide in the atmosphere. Carbon dioxide is a primary greenhouse gas, and its concentration in the atmosphere is tied to climatic conditions.

7. c. *Students know the movement of matter among reservoirs is driven by Earth’s internal and external sources of energy.*

The energy to move carbon from one reservoir to another originates either from solar energy or as heat from Earth’s interior. For example, the energy that plants use for photosynthesis comes directly from the Sun, and the heat that drives subduction comes from the solid earth.

7. d.* *Students know the relative residence times and flow characteristics of carbon in and out of its different reservoirs.*

Carbon moves at different rates from one reservoir to another, measured by its residence time in any particular reservoir. For example, carbon may move quickly from the biomass to the atmosphere and back because its residence time in organisms is relatively short and the processes of photosynthesis and respiration are relatively fast. Carbon may move very slowly from a coal deposit or a fossil fuel to the atmosphere because its residence time in the coal bed is long and oxidation of coal by weathering processes is relatively slow.



STANDARD SET 8. Structure and Composition of the Atmosphere

Students have little direct background on the structure and composition of the atmosphere beyond what they have learned from Standard Set 7, “Biogeochemical Cycles.” If they have taken high school biology/life sciences before studying earth sciences, they will know how organisms exert chemical influences on the air around them through photosynthesis and respiration.

8. Life has changed Earth’s atmosphere, and changes in the atmosphere affect conditions for life. As a basis for understanding this concept:

a. *Students know the thermal structure and chemical composition of the atmosphere.*

The atmosphere is a mixture of gases: nitrogen (78 percent), oxygen (21 percent), argon (1 percent), and trace gases, such as water vapor and carbon

dioxide. Gravity pulls air toward Earth, and the atmosphere gradually becomes less dense as elevation increases. The atmosphere is classified into four layers according to the temperature gradient. The temperature decreases with altitude in the troposphere, the first layer; then similarly increases in the stratosphere, the second layer; decreases in the mesosphere, the third layer; and increases in the thermosphere (ionosphere), the fourth layer.

The *troposphere*, the layer in which weather occurs, supports life on Earth. The *stratosphere* is less dense than the troposphere but has a similar composition except that this second layer is nearly devoid of water. The other difference is that solar radiation ionizes atoms in the stratosphere and dissociates oxygen to form ozone, O_3 . This process is important to life on Earth because ozone absorbs harmful ultraviolet radiation that would otherwise cause health problems. Air in the *mesosphere* has very low density and is ionized by solar radiation. The *thermosphere*, the outermost layer of the atmosphere, is almost devoid of air and receives the direct rays of the Sun. The thermosphere provides a good illustration of the difference between temperature and heat. Temperature is high there because the little heat absorbed is distributed among very few molecules, keeping the average energy of each molecule high.

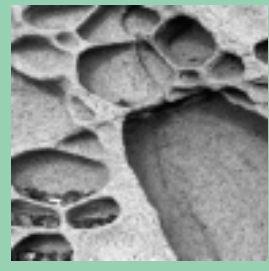
8. b. *Students know* how the composition of the Earth's atmosphere has evolved over geologic time and know the effect of outgassing, the variations of carbon dioxide concentration, and the origin of atmospheric oxygen.

During the early history of the solar system, strong solar winds drove the primordial atmosphere away. This atmosphere was then replaced by a combination of gases released from Earth (outgassing), mostly through volcanic action, and by bombardment of materials from comets and asteroids. Chemical reactions through time, in the presence of water, changed the atmosphere's original methane and ammonia into nitrogen, hydrogen, and carbon dioxide. Lightweight hydrogen escaped, leaving a predominance of nitrogen. As life capable of photosynthesis developed on Earth, carbon dioxide was taken up by plants, and oxygen was released. The present balance of gases in the atmosphere was achieved at least 600 million years ago. Small but important variations in the amount of carbon dioxide in the atmosphere have occurred naturally since then. Significant increases have been measured in modern times and attributed in large part to human activities, such as the burning of fossil fuels.

8. c. *Students know* the location of the ozone layer in the upper atmosphere, its role in absorbing ultraviolet radiation, and the way in which this layer varies both naturally and in response to human activities.

The ozone layer in the stratosphere is formed when high-energy solar radiation interacts with diatomic oxygen molecules (O_2) to produce ozone, a triatomic oxygen molecule (O_3). By absorbing ultraviolet radiation, the ozone eventually converts

back to diatomic oxygen. This absorption of ultraviolet radiation in the stratosphere reduces radiation levels at Earth's surface and mitigates harmful effects on plants and animals. The formation and destruction of ozone creates an equilibrium concentration of ozone in the stratosphere. A reduction in stratospheric ozone near the poles has been detected, believed to be caused by the release of chlorofluorocarbons (CFCs), such as those used as working fluids in air conditioners. The halogens in these CFCs interfere with the formation of ozone by acting as catalysts—substances that modify the rate of a reaction without being consumed in the process. As catalysts, a few molecules of CFCs can help to eliminate hundreds of ozone molecules in the stratosphere. While ozone is beneficial in the stratosphere, it is also a manufactured photochemical pollutant in the lower atmosphere. Students should be taught the importance of reducing the level of ozone in the troposphere and of maintaining the concentration of that gas in the stratosphere.



STANDARD SET 9. California Geology

Students should already know that mountains, faults, and volcanoes in California result from plate tectonic activity and that flowing surface water is the most important agent in shaping the California landscape. The topics in this standard set can be covered as a separate unit or as a part of a unit included in other topics addressed by the standards. A specific discussion of California earthquakes can be introduced in the teaching of Standard Set 3, “Dynamic Earth Processes,” in this section.

9. The geology of California underlies the state's wealth of natural resources as well as its natural hazards. As a basis for understanding this concept:

- a.** *Students know* the resources of major economic importance in California and their relation to California's geology.

Many of the important natural resources of California are related to geology. The Central Valley is a major agricultural area and a source of oil and natural gas because of deposition of sediments in the valley, which was created by faulting that occurred simultaneously as the Sierra Nevada was elevated tectonically. California's valuable ore deposits (e.g., gold) came into existence during the formation of large igneous intrusions, when molten igneous rock was injected into older rocks. Geothermal energy resources are related to mountain building and to plate tectonic spreading, or rifting, of the continent.

- 9. b.** *Students know* the principal natural hazards in different California regions and the geologic basis of those hazards.

California is subject to a variety of natural hazards. Active fault zones generate earthquakes, such as those of the San Andreas fault system. Uplifted areas with

weak underlying rocks and sediments are prone to landslides, and the California Cascade mountains contain both active and dormant volcanoes. The erosion of coastal cliffs is expected, caused in part by the energy of waves eroding them at their bases. When earthquakes occur along the Pacific Rim, seismic sea waves, or tsunamis, may be generated.

9. c. *Students know the importance of water to society, the origins of California's fresh water, and the relationship between supply and need.*

Water is especially important in California because its economy is based on agriculture and industry, both of which require large quantities of water. California is blessed with an abundance of fresh water, which is supplied by precipitation and collected from the melting of the snowpack in watersheds located in the Sierra Nevada and in other mountain ranges. This process ensures a slow runoff of water following the winter rains and snowfall. But the water is not distributed evenly. Northern California receives most of the rain and snowfall, and southern California is arid to semiarid. The natural distribution of water is adjusted through engineered projects that transport water in canals from the northern to the southern part of the state.

9. d.* *Students know how to analyze published geologic hazard maps of California and know how to use the map's information to identify evidence of geologic events of the past and predict geologic changes in the future.*

Students who learn to read and analyze published geological hazard maps will be able to make better personal decisions about the safety of business and residential locations. They will also be able to make intelligent voting decisions relative to public land use and remediation of hazards.

A wealth of information pertaining to these content standards for earth science is readily available, much of it on the Internet. County governments have agencies that dispense information about resources and hazards, often related to issuing permits and collecting taxes. The California Division of Mines and Geology is an excellent state-level resource. Federal agencies that supply useful information about California resources and hazards are the U.S. Geological Survey, the Federal Emergency Management Agency, and the U.S. Army Corps of Engineers.

Investigation and Experimentation

Teachers must convey the skills and knowledge that students need to perform investigations and experiments, the foundation of scientific knowledge. The Investigation and Experimentation standards allow students to make concrete associations between science and the study of nature and to provide many opportunities to take measurements and use basic mathematics. In the sequence for grades nine through twelve, teachers implement these standards in the context of physics, chemistry, biology/life sciences, and earth sciences.

Investigations and experiments engage scientists, catalyzing their highest levels of creativity and producing their most satisfying rewards. The possibility of discovery or of adding new scientific knowledge in the form of facts, concepts, principles, or theories offers a great sense of accomplishment and wonder. Investigation and experimentation can be just as engaging to high school students as they study science. Although students may not discover knowledge new to the scientific community, they may find pleasure in discovering something new to themselves or in seeing the content from their science text illuminated through demonstrations of the concepts. Accordingly, they can experience the pride of creating experimental protocols and realize the joy of discovery and learning.

Teachers need to know and teach the details of the scientific processes addressed by the Investigation and Experimentation standards. To be valid, an experiment needs controls that minimize sources of error and that provide reproducible results. Teachers should select standards-based, well-tested experiments and demonstrations instead of unguided or disorganized “expeditions.” Taught effectively, science courses may be engaging for high school students. Some principles are best pretaught explicitly through direct instruction, then demonstrated with a hands-on activity that reinforces the teaching. Students may easily discover other principles by themselves, and teachers should not rob them of that pleasure. The teacher must be certain that every investigative activity reinforces content and sound thinking.

I. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content of the other four strands, students should develop their own questions and perform investigations. Students will:

- a. Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.
- b. Identify and communicate sources of unavoidable experimental error.

- c. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- d. Formulate explanations by using logic and evidence.
- e. Solve scientific problems by using quadratic equations and simple trigonometric, exponential, and logarithmic functions.
- f. Distinguish between hypothesis and theory as scientific terms.
- g. Recognize the usefulness and limitations of models and theories as scientific representations of reality.
- h. Read and interpret topographic and geologic maps.
- i. Analyze the locations, sequences, or time intervals that are characteristic of natural phenomena (e.g., relative ages of rocks, locations of planets over time, and succession of species in an ecosystem).
- j. Recognize the issues of statistical variability and the need for controlled tests.
- k. Recognize the cumulative nature of scientific evidence.
- l. Analyze situations and solve problems that require combining and applying concepts from more than one area of science.
- m. Investigate a science-based societal issue by researching the literature, analyzing data, and communicating the findings. Examples of issues include irradiation of food, cloning of animals by somatic cell nuclear transfer, choice of energy sources, and land and water use decisions in California.
- n. Know that when an observation does not agree with an accepted scientific theory, the observation is sometimes mistaken or fraudulent (e.g., the Piltdown Man fossil or unidentified flying objects) and that the theory is sometimes wrong (e.g., the Ptolemaic model of the movement of the Sun, Moon, and planets).

Chapter 5

The Science
Content
Standards for
Grades Nine
Through
Twelve

**Investigation and
Experimentation**