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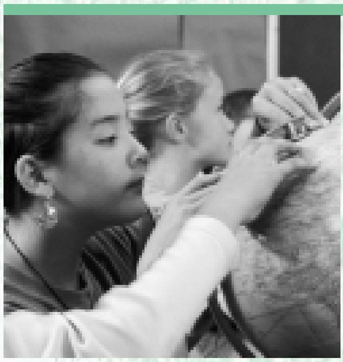

The Science Content Standards for Grades Six Through Eight

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In each grade, kindergarten through grade five, the science content standards cover the areas of physical, life, and earth sciences in approximately equal measures. In each of the middle grades, however, the content standards emphasize an individual area. This organization permits students to probe each area in greater depth.

- In grade six the content standards focus on earth sciences. Students often become environmentally aware at this grade level, and this focus is meant to stimulate intellectual curiosity in that area.
- In grade seven the content standards focus on life sciences. Students at this grade level typically receive a semester of health education, and this focus is designed both to complement that instruction and to prepare students for the biology/life sciences course work that is often taken in the early high school years.
- In grade eight the content standards focus on physical sciences. This focus is designed to prepare students for the physics and chemistry course work that is often taken in the later high school years.

In all three of the middle grades, science instruction is intended to provide students with a solid foundation for the more formal treatment of concepts, principles, and theories called for at the high school level.

Not all students will enter middle school prepared for the rigorous science curriculum called for in the middle grades standards. Teachers should use "catch up" strategies to ensure that students are prepared for high school science. One of the key requirements is for students to have foundational reading and mathematics skills, as outlined in the State Board of Education's *Reading/Language Arts Framework for California Public Schools* and the *Mathematics Framework for California Public Schools.*[1] Those frameworks provide specific strategies for teachers to help students who are below grade level in reading and mathematics.

Students who are prepared to undertake the study of algebra (either as a separate course or as part of an integrated mathematics course) in grade eight, as called for in the *Mathematics Content Standards for California Public Schools*, will be on the pathway for success in high school science.[2] Those who are not as well prepared will struggle and may even fail in their science classes to the great frustration of their teachers and parents/guardians. For example, students who have not mastered arithmetic and algebra skills will find chemistry difficult, if not impossible. Science instruction should provide opportunities for students to use mathematics by solving problems. Teachers may use science to both reinforce mathematical abilities and deepen students' understanding of key mathematical concepts.

Safety is always the foremost consideration in the design of demonstrations, hands-on activities, laboratories, and science projects on site or away from school. Teachers must become familiar with the *Science Safety Handbook for California Public Schools.*[3] It contains specific and useful information relevant to classroom teachers of science. School administrators, teachers, parents/guardians, and students have a legal and moral obligation to promote safety in science education. Safety should be taught. Scientists and engineers in universities and industries are required to follow strict environmental health and safety regulations. Knowing and following safe practices in science are a part of understanding the nature of science and scientific enterprise.

Grade Eight Focus on Physical Sciences

Students in grade eight study topics in physical sciences, such as motion, forces, and the structure of matter, by using a quantitative, mathematically based approach similar to the procedures they will use in high school. Earth, the solar system, chemical reactions, the chemistry of biological processes, the periodic table, and density and buoyancy are additional topics that will be treated with increased mathematical rigor, again in anticipation of high school courses. Students should begin to grasp four concepts that help to unify physical sciences: force and energy; the laws of conservation; atoms, molecules, and the atomic theory; and kinetic theory. Those concepts serve as important organizers that will be required as students continue to learn science. Although much of the science called for in the standards is considered "classical" physics and chemistry, it should provide a powerful basis for understanding modern science and serve students as well as adults.

Mastery of the eighth-grade physical sciences content will greatly enhance the ability of students to succeed in high school science classes. Modern molecular biology and earth sciences, as well as chemistry and physics, require that students have a good understanding of the basics of physical sciences.

STANDARD SET 1. Motion

Aristotle wrote that a force is required to keep a body moving. Everyday experience seems to confirm this misconception. For two thousand years Aristotle's description of motion was accepted without question. Then an experiment by Galileo resulted in the discovery of friction. Galileo's experimental approach to investigating Nature helped to establish modern science and led to the invention of calculus and Newton's laws of motion. Four centuries after Galileo the knowledge of motion enables scientists to predict and control the paths of distant spacecraft with great accuracy.

There are many types of motion: straight line, circular, back and forth, free-fall, projectile, orbital, and so on. This standard set concerns itself with the motion of a body traveling either at a constant speed or with a varying speed that is represented by an average value.

1. The velocity of an object is the rate of change of its position. As a basis for understanding this concept:

a. *Students know* position is defined in relation to some choice of a standard reference point and a set of reference directions.

The position of a person or object must be described in relation to a standard reference point. For example, the position of a bicycle may be in front of the flagpole or behind the flagpole. The flagpole is the reference point, and *in front of* and *behind* are the reference directions. A reference point is usually called the *origin,* and position can be expressed as a distance from the reference point together with a plus (+) or minus (–) sign that may stand for *in front of* and *behind, away from* and *toward, right* and *left,* or one of any other pair of convenient, opposing directions from the reference point.

The idea of measuring positions, distances, and directions in relation to a standard reference point may be introduced by using metersticks (or rulers). The students are directed to call the 50 cm mark (or some other convenient mark) the reference point. A position of –10 cm would be 10 cm to the left of the standard reference point; a position of +5 cm would be 5 cm to the right of the standard reference point. The teacher may call out various positive and negative position values, and the students should point to that location on the ruler. In particular, students can experience the fact that although moving in a positive direction (to the right) when going from –10 cm to –6 cm, they still end up pointing to a spot that is to the left of the origin. Students in grade eight should be able to track the motion of objects in a two-dimensional (x, y) coordinate system. For example, both x and y may represent distances along the coordinate axes, or the value of y might represent the distance traveled and x might represent elapsed time.

1. b. *Students know* that average speed is the total distance traveled divided by the total time elapsed and that the speed of an object along the path traveled can vary.

Speed is how fast something is moving in relation to some reference point without regard to the direction. It is calculated by dividing the distance traveled by the elapsed time. In the next standard students should learn to use the International System of Units (a modernized version of the metric system) to measure distance in meters (m) and time intervals in seconds (s). Thus a car traveling 120 kilometers in two hours is traveling at a speed of 60 km/hr. (In everyday units speed is measured in miles per hour. In the school laboratory it may be more convenient to use centimeters instead of meters for measuring distances and seconds for measuring time; therefore, speed would be expressed in centimeters per second [cm/s].) The speed of a spacecraft may be measured by how long it takes to orbit Earth and the length of that orbit. Sometimes the speed of an object remains constant while it is being observed, but usually the speed of a vehicle changes during a trip. Students should be taught to recognize that the average speed of a vehicle is calculated by dividing the total distance traveled by the length of time to complete the entire trip. With several stops a trip of 100 miles from town A to town B may take four hours. The average speed is 100 miles ÷ 4 hours = 25 miles per hour (mph) even though at times the car may have had a speedometer reading of 55 mph.

Students can measure the entire distance that a toy vehicle or ball travels across the floor or tabletop after it is released from the top of an inclined ramp (the standard reference point). They can also measure the time elapsed during the trip. The average speed can then be calculated by dividing the distance traveled (from the standard reference point) by the elapsed time. More than one student may be assigned to measure the times and distances so that duplicate data sets are created. The teacher may explore with the students why the data sets are not exactly the same and help them evaluate the accuracy and reproducibility of the experiment. The object's speed may be observed to change during the trip: it travels faster down the ramp because of gravity and slows down as it travels across the floor or tabletop because of friction. What is being calculated by $v = d/t$ (where v is the average speed, d is the total distance traveled, and t is the elapsed time) is the average speed for the entire trip as though the object were to travel at a constant speed. Students may change one of the conditions, such as the height of the ramp, to see how that affects the average speed. Or students do not have to wait for the object to stop; they may measure the elapsed time for the object to roll from the top of the ramp to any point along the path, before the object stops, to obtain the average speed between the measurement points.

1. c. *Students know* how to solve problems involving distance, time, and average speed.

Problems related to this standard may be solved by using the traditional mathematics formula: $d = rt$. The d represents the total distance traveled, r stands for rate (or speed) and represents either the constant speed (if the speed is constant) or average speed (if it varies), and t represents the time taken for the trip. Given any two of these quantities, students can calculate the third quantity: $d = rt$, $t = d/r$, $r = d/t$. Students may be given information involving d, r, or t for different segments of a real or hypothetical trip and asked to use the formula $d = rt$ to solve for the missing information. To avoid confusion later, teachers may introduce the symbol v for speed instead of r once students are familiar with this type of problem. (When the vector nature of *velocity* needs to be introduced, the v will be written in boldfaced type, $\mathbf{v}$, as will other vector quantities in the framework.)

1. d. *Students know* the velocity of an object must be described by specifying both the direction and the speed of the object.

The word *velocity* has a special meaning in science. An air traffic controller needs to know both the speed and the direction of an aircraft (as well as its position), not just the speed. Measurable quantities that require both the magnitude (sometimes the term *size* is used) and direction are called *vector quantities.* Displacement, velocity, acceleration, and force are all vector quantities and will be introduced in grade eight by using only one dimension or specified pathway. An arrow pointing in the direction of motion usually represents the velocity of an object. The length of the arrow is proportional to how fast the object is going (the speed). Students demonstrate mastery of this standard by knowing, without prompting, that they must specify both speed and direction when asked to describe an object's velocity.

1. e. *Students know* changes in velocity may be due to changes in speed, direction, or both.

Since velocity is a vector quantity, the velocity of an object is determined by both the speed and direction in which the object is traveling. Changing the speed of an object changes its velocity; changing the direction in which an object is traveling also changes the velocity. A change in either speed or direction (or both) will, by definition, change the velocity. (Although the term is not included in this standard set, the rate at which velocity changes with time is called *acceleration.* When a car speeds up or slows down, it undergoes acceleration. When a car rounds a curve maintaining the same speed, it also undergoes acceleration because it changes direction.)

The important idea is that a change in the speed of the object, the direction of the moving object, or both is a change in velocity. Students may easily understand that a change in the speed of an object causes a change in the velocity; it may be less obvious to students that a change in the direction of an object, with no change in the speed, also changes the velocity of the object. Students need to recognize that spinning, curving soccer balls, baseballs, or Ping-Pong balls may maintain a nearly constant speed through the air but change velocity because they change direction. Of course, an object may undergo a change in velocity in which both the direction and the speed change; for example, when a driver applies the brakes while going around a curve.

In the next standard set, students will learn that changes in velocity are always related to one or more forces acting on the object. Students learn to find and identify forces and to determine the direction of each force's action. Being able to recognize velocity changes of magnitude and direction is key to observing and characterizing forces.

1. f. *Students know* how to interpret graphs of position versus time and graphs of speed versus time for motion in a single direction.

Students are required to apply the graphing skills they learned in lower grades to the plotting and interpretation of graphs of distance, location, and position (d) versus time (t) and of speed (v) versus time (t) for motion in a single direction. A major conceptual difference from the graphing skills learned in mathematics is that the two axes will no longer be number lines with no units. What must be explicitly addressed in dealing with motion graphs is the plotting of locations in distance units (e.g., meters, centimeters, miles) on the vertical axis and plotting of time in time units (seconds, minutes, hours) on the horizontal axis.

In plotting position versus time, students should learn that the vertical axis represents distances away from an origin either in the positive (+) or negative (–) direction. The horizontal axis represents time. Every data point lying on the horizontal axis is "at the origin" because its distance value is zero. Given a graph of position versus time, students should be able to generate a table and calculate average speeds for any time interval ($v = d/t$). If the graph of position versus time is a straight line, the speed is constant; students should be able to find the slope and know that the slope of the line is numerically equal to the value of the speed in units corresponding to the labels of the axes.

Students should know that a graph of speed versus time consisting of a horizontal line represents an object traveling at a constant speed, and they should be able to use $d = rt$ to calculate the distance (d) traveled during a time interval (t). Students should know that a graph of speed versus time that is not a horizontal line indicates the speed is changing.

STANDARD SET 2. Forces

The concept of force is central to the study of all natural phenomena that involve some kind of interaction between two or more objects regardless of whether visible motion occurs. For example, architects and civil engineers want their structures to stand firm against the forces of gravity, wind, and earthquakes. On the other hand, automotive engineers need to know how best to accelerate a car, brake it to a safe stop, and smoothly change its direction. Students need to know that balanced forces keep an object from changing its velocity and that changes in the velocities of objects are caused by unbalanced forces.

There are only four known fundamental forces: gravitational forces, electromagnetic forces, and two nuclear forces known as the strong and the weak forces. Gravitational force is the attraction all objects with mass have for one another. The common experience of gravity on Earth is only one example; the other forces of pushing and pulling are elastic forces caused by electromagnetic interactions between atoms and molecules being pushed together or pulled apart. The large, repulsive electrical forces between the positively charged protons in the nucleus of an atom are balanced against the stronger, attractive nuclear forces that hold the atom together.

Students learned in grade two that the way to change how something is moving is to give it a push or a pull (e.g., apply a force). In grade four the study of magnets, compasses, and static electricity gave students experience with electromagnetic forces. In grade seven students learned about motion and forces, which involved comparing bones, muscles, and joints in the body to machines.

2. Unbalanced forces cause changes in velocity. As a basis for understanding this concept:

a. *Students know* a force has both direction and magnitude.

Forces are pushes or pulls and, like velocity, are vector quantities described by the magnitude and the direction of a force. As noted in Standard 1.d, the direction and strength of a force may be indicated graphically by using an arrow. The length of the arrow is proportional to the strength of the force, and the arrow points in the direction of the force's application.

The simplest case to consider is that of forces acting along one line, such as to the left or to the right. These colinear forces act either in the positive direction and are represented as positive quantities or in the negative direction and are represented as negative quantities.

A worthwhile activity is to have the students pull objects across level surfaces to measure the forces of friction. Different surfaces, because of varying roughness or different types of material, will exert different forces of friction on an object being dragged across them. If an object is pulled at a constant speed across a level surface, the force applied is just equal and opposite to the force of friction. If the force applied is greater than the force of friction, the object will slide easily. If the force applied is less than the force of friction, the object will drag. If the force applied is zero, the object will slow down and stop more quickly under the influence of the force of friction alone. Students can obtain data by using a spring scale to measure the force and compare different objects on different surfaces.

2. b. *Students know* when an object is subject to two or more forces at once, the result is the cumulative effect of all the forces.

Forces acting on an object along the same line at the same time are calculated by using algebra. For example, a force of 5 newtons acting in the positive direction (+5 N) and a force of 7 newtons acting in the negative direction (–7 N) will result in an unbalanced force of 2 newtons acting in the negative direction (–2 N). A force of one newton is close to the weight of half a stick of butter or of a small apple. (In high school physics, students will learn that forces acting at different angles on an object can be broken down into components along the *x* axis, *y* axis, and *z* axis and that these components can also be calculated algebraically.)

2. c. *Students know* when the forces on an object are balanced, the motion of the object does not change.

When several forces act simultaneously on an object, they may amount to zero, meaning there is no net force on the object and the motion of the object does not change. For example, a force of 10 newtons acting to the right (+10 N) and a second force of 10 newtons acting to the left (–10 N) amount to zero, meaning there will be no change in the velocity of the object. Sometimes an object acted on by balanced forces is at rest and remains at rest. In a tug of war in which opposing sides are pulling a rope with equal force, the rope does not move.

Sometimes a moving object is acted on by balanced forces and continues to move at the same velocity. For example, pushing a book straight across a table at a constant velocity requires force. The book does not speed up, slow down, or change direction; therefore, one must conclude a frictional force is pushing back on the book. Many people have the misconception that a force is necessary for an object to maintain a constant velocity; they overlook the opposing force of friction. Identifying and analyzing the forces acting on a sliding object by observing its velocity can help students develop their observation and analysis of frictional forces.

If the motion (or velocity) of an object is not changing, one may conclude that all the forces must be balanced. There are two equal and opposing vertical forces (weight down and table up) acting on the book as well as two equal and opposing horizontal forces (sliding push and friction): a total of four forces.

2. d. *Students know* how to identify separately the two or more forces that are acting on a single static object, including gravity, elastic forces due to tension or compression in matter, and friction.

The force of gravity pulls objects toward the center of the earth. This force of gravity is commonly called the *weight* of the object. If an object is dropped, the force of gravity alone causes the velocity of the object to increase rapidly in the down direction. But when a single object is at rest, such as a book on a table, the table must be supplying a balancing upward force (an elastic force of compression caused by the compacting of the molecules of the table). When an object, such as a yo-yo, is observed hanging motionless from a string, the string must be supplying a balancing upward force—an elastic force of tension as its molecules are stretched apart. A student may push gently on a book to move it horizontally across the table, but the book does not move. The horizontal push cannot be the only acting force. A second force pushes back to keep the book at rest. This opposing force is the friction between the molecules in the surface of the book and the surface of the table.

Resting a book on a meterstick spanning the gap between two student desks usually causes the meterstick to sag, showing that the meterstick flexes until the upward force from its elastic distortion is sufficient to support the book. Resting a book on a soft, dry sponge or spring might also show how elastic forces support the book against the downward pull of gravity.

2. e . *Students know* that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

When an unbalanced force acts on an object initially at rest, the object moves in the direction of the applied force. If an object is already in motion, for example, traveling to the right, and an unbalanced force acts to the right, the object will speed up. An object traveling to the right acted on by an unbalanced force to the left will slow down; if the unbalanced force continues to act, the object may slow to a stop and even begin to move faster in the opposite direction. If an unbalanced force acts in a direction perpendicular to the direction the object is moving, the force will deflect the object from its path, changing its direction but not its speed along the curved path. Any force that acts in such a direction (for example, the force of the road on the tires of a car) is called a *centripetal force.* This force is directed to the center of the orbit. Finally, an unbalanced force acting at an angle to the path may affect both the speed and the direction of the object.

Students should be able to predict changes in velocity if forces are shown to be acting on an object and be able to identify that an unbalanced force is acting on an object if they observe a change in its velocity. Students may not be able to explain fully the cause of the unbalanced forces acting on the baseball pitcher's curve ball or on the path of a spinning soccer ball, but they can state that there is a force acting perpendicular to the path of the ball.

2. f. *Students know* the greater the mass of an object, the more force is needed to achieve the same rate of change in motion.

When the forces acting on an object are unbalanced, the velocity of the object must change by increasing speed, decreasing speed, or altering direction. This principle also means that if an object is observed to speed up, slow down, or change direction, an unbalanced force must be acting on it. The rate of change of velocity is called *acceleration.* At the high school level, students will learn to solve problems by using Newton's second law of motion, which states that the acceleration of an object is directly proportional to the force applied to the object and inversely proportional to its mass. For now students should learn to recognize acceleration (or deceleration) and should be able to state the direction and relative magnitude of the force that is the cause of the acceleration.

When an unbalanced force acts on an object, the velocity of the object can change slowly or rapidly. How fast the velocity of the object changes, that is, the rate of change in velocity with time (called acceleration), depends on two things: the size of the unbalanced force acting on the object and the mass of the object. The larger the unbalanced force, the faster the velocity of the object changes, but the greater the mass of the object, the slower the velocity changes. Quantitatively, the acceleration of an object may be predicted by dividing the net force acting on the object by the mass of the object.

Often high school students learn to solve problems involving force without clearly relating the physical circumstances to the word problem presented. It is important to teach students in grade eight to identify mass, velocity, acceleration, and forces and to analyze how those factors relate to one another in the physical system being studied. The ability to make qualitative predictions about what will happen next in these situations is the key to successful problem solving that all scientists use before starting a calculation. Once the correct qualitative prediction is envisioned, a numerical solution is more likely to be correct. For example, students might be told that an opposing force is applied to an object being pushed along the ground. Given all the numbers needed to calculate the object's final velocity, the students should be able to predict correctly whether the object could slow down, come to a stop, or even start moving backward before they solve the problem numerically.

2. g. *Students know* the role of gravity in forming and maintaining the shapes of planets, stars, and the solar system.

Gravity, an attractive force between masses, is responsible for forming the Sun, the planets, and the moons in the solar system into their spherical shapes and for holding the system together. It is also responsible for internal pressures in the Sun, Earth and other planets, and the atmosphere. Newton asked himself whether the force that causes objects to fall to Earth could extend to the Moon. Newton knew that the Moon should travel in a straight line (getting farther and farther from Earth) unless a force was acting on it to change its direction into a circular path.

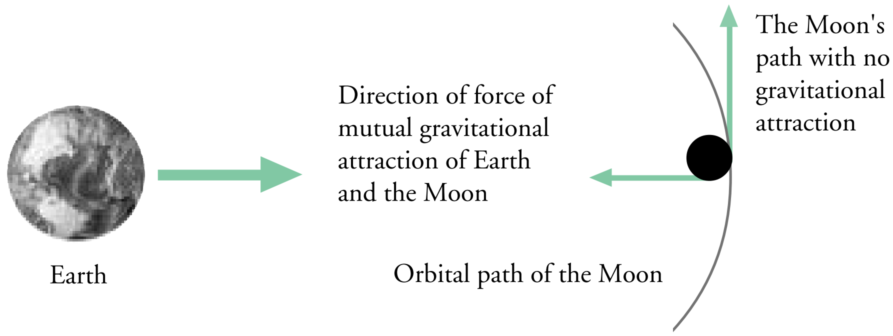

Fig. 1. Effect of Gravity on the Moon's Path

He worked out the mathematics that convinced him that the force between all massive objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers. This relationship was then extended to explain the motion of Earth and other planets about the Sun.

Initially, the universe consisted of light elements, such as hydrogen, helium, and lithium, distributed in space. The attraction of every particle of matter for every other particle of matter caused the stars to form, making possible the "stuff" of the universe. As gravity is the fundamental force responsible for the formation and motion of stars and of the clusters of stars called galaxies, it controls the size and shape of the universe.

STANDARD SET 3. Structure of Matter

There is no disagreement about the importance of understanding the structure of matter. Richard Feynman, a famous Nobel prize-winning physicist, has said:

> If, in some cataclysm, all scientific knowledge were to be destroyed and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or atomic fact, or whatever you wish to call it) that all things are made of atoms—little particles that move around in perpetual motion attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.[7]

Teachers should assess students' knowledge prior to instruction of this topic, as the atomic theory of matter may be very challenging to them. Students are expected to recall terms and definitions from earlier introductions to the concepts of atoms, molecules, and elements. Instruction should provide empirical evidence for the atomic theory, which will be useful for understanding science and crucial to the study of chemistry.

When students learn about the structure of matter, teachers should emphasize that the historical evidence for atoms was based largely on indirect measurements and inferences far removed from direct experience. Recently, instruments have been built that produce images of individual atoms, confirming what was inferred earlier as a result of overwhelming evidence from many scientific experiments. Most scientists come to know the atomic theory is true by repeatedly using the concepts and principles presented in the theory to explain observed properties and predict changes in matter.

3. Each of the more than 100 elements of matter has distinct properties and a distinct atomic structure. All forms of matter are composed of one or more of the elements. As a basis for understanding this concept:

a. *Students know* the structure of the atom and know it is composed of protons, neutrons, and electrons.

Shortly after British physicist Ernest Rutherford inferred the existence of atomic nuclei, the general idea emerged that atoms are mostly empty space with a tiny, massive nucleus at the center containing positively charged protons and neutral neutrons. This nucleus is surrounded by tiny, negatively charged electrons, each with about 1/2,000 the mass of a proton or neutron. Danish physicist Niels Bohr developed a model of the hydrogen atom to explain its visible spectrum. At the high school level, the chemistry standards require students to know the historical importance of this model. Bohr's model succeeded in predicting the spectrum of light emitted by hydrogen atoms and is therefore the acknowledged starting point for understanding atomic structure. However, Bohr's "solar" model of the atom, diagrammed in most textbooks as showing electrons in circular orbits about the nucleus, is oversimplified. Rather than try to describe how the electrons in an atom are moving, teachers are better advised to help students develop a model of the atom in which each electron has definite energy. Students should know that the energy of each electron in an atom keeps it in motion around the positive nucleus to which it is attracted. The structure of multielectron atoms is understood in terms of electrons filling energy levels that define *orbitals.*

3. b. *Students know* that compounds are formed by combining two or more different elements and that compounds have properties that are different from their constituent elements.

The word *combining* implies bonding. Understanding the concepts of ionic and covalent bonding helps explain why some elements combine to form compounds and some do not. Atoms of different elements combine to form compounds; a compound may, and usually does, have chemical characteristics and physical properties that are different from those of its constituent elements. Examples and generalizations may be drawn from ionic compounds formed of metals and nonmetals and covalently bonded, organic compounds formed from carbon and other elements.

Students often learn to manipulate chemical equations without having a picture in their minds of physical reality at the atomic level. The ability to create such a picture is a useful skill that helps students keep track of all the atoms in the process. For example, the reaction of methane and oxygen to form carbon dioxide and water can be visualized by using models or drawing pictures of the atoms and molecules in the reactants. These molecules can then be rearranged into new products. (Make sure that all the atoms in the starting reactants are accounted for in the new products.) Instruction in this standard will help students understand that compounds are collections of two or more different kinds of atoms that are bonded together. Knowing exactly how the atoms are organized to form a molecule is not essential.

3. c. *Students know* atoms and molecules form solids by building up repeating patterns, such as the crystal structure of NaCl or long-chain polymers.

Crystals of table salt, the compound NaCl, have a regular, cubic structure in which sodium (Na^+) ions alternate with chlorine (Cl^-) ions in three-dimensional array with the atoms at the corner of cubes forming the lattice. In organic polymers, the carbon, hydrogen, sometimes oxygen, and nitrogen atoms combine to form long, repetitive, stringlike molecules.

Inexpensive models of molecules may be made by using colored gumdrops (held together by toothpicks) to represent molecules. Students identify the atoms that constitute the molecules by using a color-coded key relating the color of the gumdrop to an atom of an element. They learn that the shape of a molecule is important to its chemical and physical properties. At the high school level, students will be introduced to the idea that shape is determined mainly by the electron configuration that provides the most energy-stable system.

Students can also grow crystals from a solution and should understand that this process leads to the building up of atoms into a lattice. Students may begin the process by dissolving an excess of sodium chloride, sugar, or Epsom salts in water. Then they hang a string in the water and store the container in a place where it will be undisturbed while the water evaporates. Crystals will form on the string. Putting a small (seed) crystal tied to a piece of thread in the solution will accelerate the growth process. Books and kits (including chemicals, glassware, and instructions) on crystal growing are available commercially. Students can watch crystals grow on slides under a microscope. Some crystals display vivid colors when viewed between crossed sheets of polarizing material.

3. d. *Students know* the states of matter (solid, liquid, gas) depend on molecular motion.

All atoms, and subsequently all molecules, are in constant motion. For any given substance the relative freedom of motion of its atoms or molecules increases from solids to liquids to gases. When a thermometer is inserted into a substance and the temperature is measured, the average atomic or molecular energy of motion is being measured. The state of matter of a given substance therefore depends on the balance between the internal forces that would restrain the motion of the atoms or molecules and the random motions that are in opposition to those restraints.

The change in phases is evidence of various degrees of atomic and molecular motion. The conditions of temperature and pressure under which most materials change from solid to liquid or liquid to vapor (gas) or gas to plasma have been measured. Those properties are difficult to predict but are highly reproducible for different samples of the same material and can be used to identify substances. Some substances will go from solid to gas directly at one atmosphere pressure. Dry ice, which is frozen carbon dioxide, is an example. Chemistry handbooks contain the melting points (or freezing points) and boiling points (or condensation temperatures) of most materials usually under one atmosphere pressure. If the pressure is not one atmosphere, those temperatures change. Some substances have more than one stable solid phase at room temperature. Graphite, with its soft black texture and its hard, clear crystalline diamond atomic structure, represents the two solid phases of elemental carbon.

Water is another example of a substance that undergoes a change in atomic and molecular motion under extreme conditions of temperature and pressure. At one atmosphere pressure, ice forms when water is cooled below zero degrees Celsius (or 32 degrees Fahrenheit). Above the freezing point the average molecular energy of motion of the water molecules is just enough to overcome the attractive forces between the molecules. The water molecules thereby avoid being locked in place and remain liquid. At and below the freezing point, the water molecules become the solid, crystalline material called ice. When liquid water is heated to temperatures of 100 degrees Celsius, molecular motion increases until large groups of water molecules overcome the attractive forces between the molecules. At this point those energetic molecules form bubbles of steam, which are bubbles of gas made not of air but of water. The process in which bubbles of water vapor escape from liquid water is called *boiling.* Continued heating will change the liquid water entirely into vapor instead of raising the temperature of the water above 100 degrees Celsius.

3. e. *Students know* that in solids the atoms are closely locked in position and can only vibrate; in liquids the atoms and molecules are more loosely connected and can collide with and move past one another; and in gases the atoms and molecules are free to move independently, colliding frequently.

The atoms or molecules of a solid form a pattern that minimizes the structural energy of the solid consistent with the way in which the atoms or molecules attract at long distances but repel at short distances. The atoms or molecules vibrate about their equilibrium positions in this pattern. When raised above the melting temperature, the atoms or molecules acquire enough energy to slide past one another so that the material, now a liquid, can flow; the density of the liquid remains very close to that of the solid, demonstrating that in a solid or a liquid the atoms stay at about the same average distance.

If a single atom or molecule acquires enough energy, however, it can pull away from its neighbors and escape to become a molecule of a gas. Gas molecules move about freely and collide randomly with the walls of a container and with each other. The distance between molecules in a gas is much larger than that in a solid or a liquid, and this point may be emphasized when students study density.

3. f. *Students know* how to use the periodic table to identify elements in simple compounds.

The periodic table of elements is arranged horizontally in order of increasing atomic number (number of protons) and vertically in columns of elements with similar chemical properties. Students should learn to use the periodic table as a quick reference for associating the name and symbol of an element in compounds and ions. They should be able to find the atomic number and atomic weight of the element listed on the table. The periodic table is both a tool and an organized arrangement of the elements that reveals the underlying atomic structure of the atoms. This standard focuses on the table as a tool.

Every field of science uses the periodic table, and various forms of it exist. Astrophysicists may have a table that includes elemental abundances in the solar system. Physicists and engineers may use tables that include boiling and melting points or thermal and electrical conductivity of the elements. Chemists have tables that show the electron structures of the element. Students should be encouraged to refer to the periodic table as they study the properties of matter and learn about the atomic model.

STANDARD SET 4. Earth in the Solar System (Earth Sciences)

Students in grade eight are ready to tackle the larger picture of galaxies and astronomical distances. They are ready to study stars compared with and contrasted to the Sun and to learn in greater detail about the planets and other objects in the solar system. High school studies of earth sciences will include the dimension of time along with three-dimensional space in the study of astronomy.

4. The structure and composition of the universe can be learned from studying stars and galaxies and their evolution. As a basis for understanding this concept:

a. *Students know* galaxies are clusters of billions of stars and may have different shapes.

Stars are not uniformly distributed throughout the universe but are clustered by the billions in galaxies. Some of the fuzzy points of light in the sky that were originally thought to be stars are now known to be distant galaxies. Galaxies themselves appear to form clusters that are separated by vast expanses of empty space. As galaxies are discovered they are classified by their differing sizes and shapes. The most common shapes are spiral, elliptical, and irregular. Beautiful, full-color photographs of astronomical objects are available on the Internet, in library books, and in popular and professional journals. It may also interest students to know that astronomers have inferred the existence of planets orbiting some stars.

4. b. *Students know* that the Sun is one of many stars in the Milky Way galaxy and that stars may differ in size, temperature, and color.

The Sun is a star located on the rim of a typical spiral galaxy called the Milky Way and orbits the galactic center. In similar spiral galaxies this galactic center appears as a bulge of stars in the heart of the disk. The bright band of stars cutting across the night sky is the edge of the Milky Way as seen from the perspective of Earth, which lies within the disk of the galaxy. Stars vary greatly in size, temperature, and color. For the most part those variations are related to the stars' life cycles. Light from the Sun and other stars indicates that the Sun is a fairly typical star. It has a mass of about 2×10^{30} kg and an energy output, or luminosity, of about 4×10^{26} joules/sec. The surface temperature of the Sun is approximately 5,500 degrees Celsius, and the radius of the Sun is about 700 million meters. The surface temperature determines the yellow color of the light shining from the Sun. Red stars have cooler surface temperatures, and blue stars have hotter surface temperatures. To connect the surface temperature to the color of the Sun or of other stars, teachers should obtain a "black-body" temperature spectrum chart, which is typically found in high school and college textbooks.

4. c. *Students know* how to use astronomical units and light years as measures of distance between the Sun, stars, and Earth.

Distances between astronomical objects are enormous. Measurement units such as centimeters, meters, and kilometers used in the laboratory or on field trips are not useful for expressing those distances. Consequently, astronomers use other units to describe large distances. The astronomical unit (AU) is defined to be equal to the average distance from Earth to the Sun: 1 AU = 1.496×10^{11} meters. Distances between planets of the solar system are usually expressed in AU. For distances between stars and galaxies, even that large unit of length is not sufficient. Interstellar and intergalactic distances are expressed in terms of how far light travels in one year, the light year (ly): 1 ly = 9.462×10^{15} meters, or approximately 6 trillion miles. The most distant objects observed in the universe are estimated to be 10 to 15 billion light years from the solar system. Teachers need to help students become familiar with AUs by expressing the distance from the Sun to the planets in AUs instead of meters or miles. A good way to become familiar with the relative distances of the planets from the Sun is to lay out the solar system to scale on a length of cash register tape.

4. d. *Students know* that stars are the source of light for all bright objects in outer space and that the Moon and planets shine by reflected sunlight, not by their own light.

The energy from the Sun and other stars, seen as visible light, is caused by nuclear fusion reactions that occur deep inside the stars' cores. By carefully analyzing the spectrum of light from stars, scientists know that most stars are composed primarily of hydrogen, a smaller amount of helium, and much smaller amounts of all the other chemical elements. Most stars are born from the gravitational compression and heating of hydrogen gas. A fusion reaction results when hydrogen nuclei combine to form helium nuclei. This event releases energy and establishes a balance between the inward pull of gravity and the outward pressure of the fusion reaction products.

Ancient peoples observed that some objects in the night sky wandered about while other objects maintained fixed positions in relation to one another (i.e., the constellations). Those "wanderers" are the planets. Through careful observations of the planets' movements, scientists found that planets travel in nearly circular (slightly elliptical) orbits about the Sun.

Planets (and the Moon) do not generate the light that makes them visible, a fact that is demonstrated during eclipses of the Moon or by observation of the phases of the Moon and planets when a portion is shaded from the direct light of the Sun.

Various types of exploratory missions have yielded much information about the reflectivity, structure, and composition of the Moon and the planets. Those missions have included spacecraft flying by and orbiting those bodies, the soft landing of spacecraft fitted with instruments, and, of course, the visits of astronauts to the Moon.

4. e. *Students know* the appearance, general composition, relative position and size, and motion of objects in the solar system, including planets, planetary satellites, comets, and asteroids.

Nine planets* are currently known in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. They vary greatly in size and appearance. For example, the mass of Earth is 6×10^{24} kg and the radius is 6.4×10^6 m. Jupiter has more than 300 times the mass of Earth, and the radius is ten times larger. The planets also drastically vary in their distance from the Sun, period of revolution about the Sun, period of rotation about their own axis, tilt of their axis, composition, and appearance. The inner planets (Mercury, Venus, Earth, and Mars) tend to be relatively small and are composed primarily of rock. The outer planets (Jupiter, Saturn, Uranus, and Neptune) are generally much larger and are composed primarily of gas. Pluto is composed primarily of rock and is the smallest planet in the solar system.

All the planets are much smaller than the Sun. All objects are attracted toward one another gravitationally, and the strength of the gravitational force between

* Under resolutions passed by the International Astronomical Union on August 26, 2006, there are eight planets. Pluto no longer meets the definition of a "planet" but is now classified under a new distinct class of objects called "dwarf planets."

them depends on their masses and the distance that separates them from one another and from the Sun. Before Newton formulated his laws of motion and the law of universal gravitational attraction, German astronomer Johannes Kepler deduced from astronomical observations three laws (Kepler's laws) that describe the motions of the planets.

Planets have smaller objects orbiting them called *satellites* or *moons.* Earth has one moon that completes an orbit once every 28 days (approximately). Mercury and Venus have no moons, but Jupiter and Saturn have many moons. Very small objects composed mostly of rock (asteroids) or the ice from condensed gases (comets) or both also orbit the Sun. The orbits of many asteroids are relatively circular and lie between the orbital paths of Mars and Jupiter (the asteroid belt). Some asteroids and all comets have highly elliptical orbits, causing them to range great distances from very close to the Sun to well beyond the orbit of Pluto.

Teachers should look for field trip opportunities for students to observe the night sky from an astronomical observatory or with the aid of a local astronomical society. A visit to a planetarium would be another way of observing the sky. If feasible, teachers should have students observe the motion of Jupiter's inner moons as well as the phases of Venus. Using resources in the library-media center, students can research related topics of interest.

STANDARD SET 5. Reactions

When substances react, the atoms involved in the reactants are rearranged, forming other products. Students have learned that the physical and chemical properties of the newly formed substances (products) are different from the physical and chemical properties of the original substances (reactants). Students in grade eight will learn that it is the underlying arrangement of the atoms in the reactants and products and the energy needed or released during the rearrangement process that explain chemical reactions. Understanding chemical reactions is essential because they constitute, directly or indirectly, a large portion of the discipline of chemistry.

Students need to be able to distinguish a chemical change from a physical change. In a physical change one or more physical properties of the material are altered, but the chemical composition (i.e., the arrangement of the atoms in molecules) remains the same. In a chemical change the atoms are rearranged to form new substances with different chemical and physical properties. Students must be familiar with the periodic table and the names and symbols of the chemical elements.

In grade one students are prepared for the idea of chemical reactions when they learn that the properties of substances can change when they are mixed, cooled, or heated. In grade three they learn that when two or more substances are combined, a new substance may be formed with properties that are different from those of the original materials. In grade five they learn that during chemical reactions, the atoms in the reactants rearrange to form products with different properties.

The study on reactions begun in grade eight will support future studies about conservation of matter and stoichiometry as well as work on acids, bases, and solutions. Students will go beyond studying reactions and their reactant/product relationships to work with the rates of reaction and chemical equilibrium. Students should be able to envision a chemical equation at the atomic and molecular levels. They should "see" the number of reactant atoms and molecules in the equation coming together and by some process rearranging into the correct number of atoms and molecules that form the products. This important conceptual skill helps students to keep track of all the atoms.

5. Chemical reactions are processes in which atoms are rearranged into different combinations of molecules. As a basis for understanding this concept:

a. *Students know* reactant atoms and molecules interact to form products with different chemical properties.

This standard focuses on changes that occur when atoms and molecules as reactants form product compounds with different chemical properties. Teachers may have students perform simple reactions or demonstrate the reactions for students. All students should be able to learn the more important chemical reactions and the elements involved in them, especially if common compounds such as vinegar (acetic acid), baking soda (sodium bicarbonate), table salt (sodium chloride), carbonated water, and nutritional minerals and foods are used in activities or demonstrations. An example might involve adding calcium chloride and baking soda to water. Such reactions demonstrate clearly the differences in properties between reactants (solids and liquid) and products (solid, liquid, and gas).

5. b. *Students know* the idea of atoms explains the conservation of matter: In chemical reactions the number of atoms stays the same no matter how they are arranged, so their total mass stays the same.

The conservation of matter is a classical concept, reinforcing the idea that atoms are the fundamental building blocks of matter. Atoms do not appear or disappear in traditional chemical reactions in which the constituent atoms and/or polyatomic ions are simply rearranged into new and different compounds. Conservation of atoms is fundamental to the idea of balancing chemical equations. The total number of atoms of each element in the reactants must equal the total number of atoms of each element in the products. The total number of atoms, hence the total mass, stays the same before and after the reaction.

There are several ways to teach and assess students' understanding of the concept of conservation of mass in chemical reactions. Weighing reactants before and products after a reaction shows that mass is neither gained nor lost. However, experimental errors are possible; the most common one is not sufficiently drying the products before weighing. One simple demonstration of the concept that atoms (or matter) are conserved in chemical reactions in which mass might appear to be lost is to determine the combined mass of a small, sealed container filled one-third with water, the screw-on cap, and one-quarter of an effervescent tablet. After the piece of tablet is dropped in the water, the container is immediately sealed. When the fizzing has stopped, the combined mass of the sealed container and the tablet should remain the same. After the seal is broken, much of the carbon dioxide gas formed by the reaction escapes, and the mass of the container and its contents decrease.

Students should also be taught to balance simple chemical equations. This step reinforces the idea that atoms do not appear or disappear in chemical reactions and, therefore, that matter is conserved.

5. c. *Students know* chemical reactions usually liberate heat or absorb heat.

In chemical reactions the atoms in the reactants rearrange to form products, and there is usually a net change in energy. Breaking bonds between atoms requires energy; making a bond releases energy. If the total making and breaking of all bonds for a particular chemical reaction results in a net release of energy, the reaction is said to be *exothermic.* The energy is typically released as heat into nearby matter. If the total making and breaking of bonds results in a net absorption of energy, the reaction is called *endothermic.* The energy is typically absorbed as heat from nearby matter, which therefore cools. A convenient way to demonstrate that chemical reactions release or absorb heat is the application of the hot packs or cold packs used for athletic injuries. The change in temperature produced by those packs may be the result of a chemical reaction, or it may be caused by a "heat of solution" and not by a chemical reaction. For example, dissolving is considered a physical and not a chemical change because the compound may be recovered, unchanged chemically, by evaporation.

5. d. *Students know* physical processes include freezing and boiling, in which a material changes form with no chemical reaction.

When heated, many solid materials undergo a reversible change of state into a liquid (melting). Under the standard condition of one atmosphere of pressure, the temperature at which such a solid material melts is the same as the temperature at which the liquid material freezes; this temperature, called the *melting point,* is characteristic of the material. Many liquid materials when heated also undergo a reversible change of state into a gas. Under one atmosphere of pressure, such a liquid material may boil; the temperature at which this occurs is also characteristic of the material and is called the *boiling point.* Such reversible changes—back and forth from solid to liquid or from liquid to gas—are called physical changes because no chemical change (a permanent reordering of the atoms into new molecules) occurs. Similarly, the dissolving of one substance into another, such as a solid or gas into a liquid, is often reversible (by evaporating the liquid to leave the solid or heating the liquid to drive out the gas) and is also called a physical rather than a chemical change. Physical changes can usually be undone to recover the original materials unchanged. Activities such as mixing iron filings with sand demonstrate a physical change. In this case a magnet can recover the iron filings from the mixture.

5. e. *Students know* how to determine whether a solution is acidic, basic, or neutral.

Indicators that change color are routinely used to determine whether a solution is acidic, basic, or neutral. A pH scale indicates with numbers the concentration of hydrogen ions in a solution and characterizes a solution as acidic (lower than 7), basic (higher than 7), or neutral (near 7). There are electrodes and electronic instruments that can measure directly the pH of a solution. Some acids and bases are defined other than by their hydrogen ion concentration, but they will be addressed in high school chemistry. Teachers may give students the opportunity to test solutions, including foods such as fruits and vegetables, with pH paper, litmus paper, indicator solutions, or pH meters to determine whether a solution or food is acidic, basic, or neutral. Students should be familiar with the pH scale to know what a given pH value indicates.

STANDARD SET 6. Chemistry of Living Systems (Life Sciences)

Because all living organisms are made up of atoms, chemical reactions take place continually in plants and animals, including humans. The uniqueness of organic chemistry stems from *chain polymers.* Life could not exist without the ability of some chemicals to join together, repetitively, to form large, complex molecules. Concepts learned in this standard set are critical for understanding fully the chemistry of the cells of organisms, genetics, ecology, and physiology that will be taught in the high school biology/life sciences standard sets.

6. Principles of chemistry underlie the functioning of biological systems. As a basis for understanding this concept:

a. *Students know* that carbon, because of its ability to combine in many ways with itself and other elements, has a central role in the chemistry of living organisms.

Carbon is unique among the elements because it can bond to itself and to many other elements. This attribute makes possible many different kinds of large, carbon-based molecules. Typically, carbon will make four separate covalent bonds (to other carbon atoms), but double and triple bonds are also possible. The variety of bonds allows carbon-based molecules to have a wide range of shapes and chemical properties. Key shapes include tetrahedral (e.g., methane and carbon tetrachloride), planar (e.g., formaldehyde and ethylene), and linear (e.g., acetylene and carbon dioxide). Students can research the nomenclature, composition, and structure of organic molecules by using textbooks and supplemental instructional materials. They can also construct models of carbon-based molecules by using commercial modeling kits or inexpensive alternatives (e.g., gumdrops and toothpicks).

6. b. *Students know* that living organisms are made of molecules consisting largely of carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur.

Living organisms are made up of a great variety of molecules consisting of many atoms (with carbon atoms playing the main roles), but the number of different elements involved is quite small. Carbon and only five other elements make up most of Earth's biomass. Those six elements, however, can combine in many different ways to make large, organic molecules and compounds. To demonstrate this idea, teachers may burn organic material, such as bone, leaves, wood, or a variety of candles. They may hold a cold glass or plate above the flame to condense droplets of water, one of the combustion products. They may also hold a heat-treated glass in the flames to collect carbon deposits in the form of soot. Students can discuss what elements were in the organic material. Teachers may draw students' attention to the black material that forms when meat is roasted or grilled or when toast is charred.

6. c. *Students know* that living organisms have many different kinds of molecules, including small ones, such as water and salt, and very large ones, such as carbohydrates, fats, proteins, and DNA.

Living organisms require a variety of molecules; some molecules contain carbon and some do not. The molecules that make up organisms and control the biochemical reactions that take place within them are usually large molecules, such as DNA, proteins, carbohydrates, and fats. Organisms also require simple substances, such as water and salt, to support their functioning. Teachers may encourage students to research why plants and animals need simple molecules such as water. Other activities for teachers may include squeezing the water from celery or turnips to demonstrate the presence of water. Or they may ask students how they can demonstrate that water is in fruits and vegetables (e.g., dried fruit). Teachers may also ask students how they know that there is salt in their bodies. Most students know that their perspiration tastes salty.

STANDARD SET 7. Periodic Table

Students will need to know the chemical symbols of the common elements. It will be helpful for them to be familiar with other properties of materials, such as melting temperatures, boiling points, density, hardness, and thermal and electrical conductivity. By the time students begin the study of this standard set, they should be familiar with the periodic table and should know the names and chemical symbols of most of the common elements. In this standard set they must now look in greater detail at and learn the significance of atomic numbers and isotopes and how they relate to the classification of elements. Students need to go more deeply into the elemental properties that serve as the basis for the periodic arrangement. Meeting the standards in this set will serve as a strong foundation for the study of atomic and molecular structures and of the relationship between these structures and the arrangement of elements on the periodic table that will take place in high school chemistry.

A common form of the periodic table has 18 columns (groups of elements) in the main body. This form shows the periodicity, or repeating pattern, of chemical and some physical properties of the elements. What varies most in published periodic tables is the information provided in the box that represents each element. The most useful tables are those that show the physical properties of the most common form of the element in addition to the atomic number and the atomic weight. A table that color-codes metals and nonmetals is also useful.

Elements shown toward the top of the periodic table are lighter, and those toward the bottom are heavier. Elements shown to the left are generally metallic, and those toward the right are nonmetallic. The word *metallic* refers to the collective properties of common metals: luster, malleability, high electrical and thermal (heat) conductivity. Although the majority of elements in the periodic table are metals, a few are classified as semimetals and may be found bordering the transition between the metals and nonmetals. When atoms from the left side of the table combine with atoms from the right side, they tend to form ionic salts, which are brittle crystalline compounds with high melting temperatures.

At the high school level, students will learn that the arrangement of the elements in the columns of the periodic table reflects the electron structure of the atoms of each element. This pattern explains the similarity in the chemical properties of the elements in each column of the periodic table.

Students should be readily able to use the periodic table to find the atomic number of an element and should know that there is a pattern of increasing atomic numbers as the table is read from left to right and down one row at a time. The lanthanides and actinides are placed off the table to save space; however, if they were placed in the table they would still be read in the same manner—from left to right and then down. Students should also know that the atomic number is the number of protons in the nucleus.

7. The organization of the periodic table is based on the properties of the elements and reflects the structure of atoms. As a basis for understanding this concept:

a. *Students know* how to identify regions corresponding to metals, nonmetals, and inert gases.

The periodic table of elements is structured so that metals are shown on the left, with the most reactive metals on the far left. Nonmetals are located on the right, with the most reactive next to the "inert" gases on the far right. Despite the name, inert gases are not truly inert. Although no naturally occurring inert gas compounds are known, some have been synthesized in the laboratory. Therefore most scientists use the term *noble* gas instead of inert gas. Semimetals, found between the metals and nonmetals in the periodic table, are elements, such as silicon, that have some properties of metals but also have properties that are typical of nonmetals. Although only a few elements fit this category, the unique electrical property of semimetal elements is that they are semiconductors, an essential property for computer chips. The rare earth elements can be used to produce very strong magnets.

Students should know that scientists have the right to name their discoveries and that some elements have been named after famous men and women scientists, such as curium, einsteinium, and seaborgium.

7. b. *Students know* each element has a specific number of protons in the nucleus (the atomic number) and each isotope of the element has a different but specific number of neutrons in the nucleus.

A rigorous definition of the term *element* is based on the number of protons in the atom's nucleus (the atomic number). All atoms of a given element have the same number of protons in the nucleus. Atoms with different atomic numbers are atoms of different elements. Although the number of protons is fixed for a particular element, the same is not true for the number of neutrons in the nucleus. An element that has different numbers of neutrons in its atoms is called an *isotope* of the element. For example, all hydrogen atoms have one proton in the nucleus, but there are two additional isotopes of hydrogen with different numbers of neutrons. One is called deuterium (one proton and one neutron), and the other is called tritium (one proton and two neutrons). The common isotope of hydrogen has one proton and no neutrons in its nucleus.

Some isotopes are *radioactive,* meaning that the nucleus is unstable and can spontaneously emit particles or trap an electron to become the nucleus of a different element with a different atomic number. All the isotopes of some elements are radioactive, such as element 43, technetium, or element 86, radon. No stable samples of those elements exist. Element 92, uranium, is another example of an element in which no stable isotopes exist. However, uranium (atomic weight 238) is found in nature because it decays so slowly that it is still present in Earth's crust. The atomic number of each element represents the number of protons in the nucleus. Therefore, as the atomic number increases, the mass of the atoms of succeeding elements generally increases although exceptions exist because of the varying numbers of neutrons in some isotopes. Typically, however, the atoms of the elements in the periodic table increase from left to right, and those elements listed in the lower rows are more massive than those in the upper rows.

7. c. *Students know* substances can be classified by their properties, including their melting temperature, density, hardness, and thermal and electrical conductivity.

The physical properties of substances reflect their chemical composition and atomic structure. The melting temperature or hardness of the common forms of the elements is related to the forces that hold the atoms and molecules together. One can compare the boiling points of carbon and nitrogen. Carbon is solid up to very high temperatures (3,600 degrees Celsius); nitrogen, the element next to it, is a gas until it is cooled to below negative 196 degrees Celsius. This dramatic difference between two adjacent elements on the periodic table shows there must be very different intermolecular forces acting as a result of a slight change in atomic structure.

Density is the mass per unit volume and is a function of both the masses of individual atoms and the closeness with which the atoms are packed.

Electrical conductivity and thermal conductivity are strongly dependent on how tightly electrons are held to individual atoms. Metals and nonmetals may be found in portions of the periodic table. Metal atoms combine in regular patterns in which some electrons are free to move from atom to atom, a condition that accounts for both high electrical and high thermal conductivity.

STANDARD SET 8. Density and Buoyancy

The central goal of this standard set is to be able to answer the simple question, Will an object sink or will it float? Students will learn that density is a physical property of a substance independent of how much of the substance is available, and they will be able to relate the property of density to the phenomenon of buoyancy. Archimedes, a Greek mathematician, is credited with first recognizing that different substances have different densities and that fluids exert a buoyant force on objects submerged in them. He came to this understanding while trying to determine what else was in a supposedly gold crown.

Archimedes came to a simple realization: water does not sink in water. That is, if one focuses on one drop of water in a container of water (and if one could keep the drop intact and distinct), the drop would not fall to the bottom of the container even though it has weight. The surrounding water must exert an upward buoyant force on the drop equal to the weight of the drop. The drop would fall if its weight were greater than the buoyant force supplied by the surrounding water. The drop would rise if it weighed less than the buoyant force. The surrounding water exerts an upward buoyant force on any volume within it equal to the weight of that volume of water. Understanding the nature of floating and sinking led Archimedes to realize that different substances have different densities—the key to determining whether the crown was gold or a fake.

Density is a property characteristic of the material itself and does not change whether the material is subdivided or the amount available is altered. Different substances have different densities, so knowing the density of a sample is useful in determining its composition. For example, the composition of Earth's interior was first inferred to be different from the composition of rocks in the lithosphere because the density of lithospheric rocks is different from the average density of Earth.

The density of solids and liquids, the two condensed states of matter, does not vary much with changes in pressure or temperature. However, small differences in density within a liquid or gas may be caused by local heating and result in convection currents. Because gases are so compressible, their densities may vary over a wide range of values. That is why tables of measured values of density are found only for solids and liquids.

Most fluids (gases and liquids) are very poor conductors of heat. Normally, fluids expand when their temperature increases because of the more rapid motion of the constituent molecules. If a fluid is heated locally, the thermal energy is not conducted rapidly to other parts of the fluid; the region that is hotter expands, becoming less dense than the cooler surrounding fluid. The buoyant force supplied by the cooler surrounding fluid on the hotter expanded region is greater than the weight of the hotter region. This force causes the hotter, less dense region of fluid to be pushed up, a phenomenon known as "Hot air rises."

A thorough understanding of density and buoyancy will be helpful in mastering the earth science standards in high school.

8. All objects experience a buoyant force when immersed in a fluid. As a basis for understanding this concept:

a. *Students know* density is mass per unit volume.

Density is a physical property of a substance independent of the quantity of the substance. That is, a cubic centimeter of a substance has the same density as a cubic kilometer. Density may be expressed in terms of any combination of measurements of mass and volume. The measurement units most commonly used in science are grams per cubic centimeter for solids and grams per milliliter for liquids.

8. b. *Students know* how to calculate the density of substances (regular and irregular solids and liquids) from measurements of mass and volume.

Density is calculated by dividing the mass of some quantity of material by its volume. Mass may be determined by placing the material on a balance or scale and subtracting the mass of its container. The volume of a liquid may be measured easily by using graduated cylinders, and the volume of a regular solid may be measured by using a ruler and the appropriate geometry formula. It is not as simple, however, to measure the volume of an irregular solid. The volume of an irregularly shaped solid object may be determined by water displacement.

8. c. *Students know* the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid the object has displaced.

Whether an object will float depends on the magnitude of the buoyant force of the surrounding fluid (liquid or gas) compared with the weight of the object. The buoyant force is equal to the weight of the volume of fluid displaced by the object. The net force acting on a submerged body is the difference between the upward buoyant force of the surrounding fluid and the downward pull of gravity on the object (its weight). The same relationship applies to two separate fluids of differing densities. Therefore, if the volume of the fluid displaced by a submerged solid object weighs more than the object, the object will rise to the surface and float. If the values are the same, the object is said to be neutrally buoyant and will neither sink nor rise to the surface. If the volume of the surrounding fluid displaced by a solid object weighs less than the object, the object will sink.

The buoyant force can be demonstrated convincingly by placing a water-filled, sealed plastic sandwich bag in a container of water and noting that the sandwich bag filled with water does not sink even though gravity applies a downward force on the water-filled bag (its weight). Therefore, there must be an upward, buoyant force applied by the surrounding water. If the sandwich bag is filled with a liquid that weighs more than an equal volume of water, it will sink. If the liquid in the sandwich bag is less dense than water, it will float. Students can fill another sandwich bag with hot water to demonstrate that it floats in room-temperature water. They can fill a third sandwich bag with water slightly above the freezing point and repeat the experiment to show that cold water will sink in room-temperature water.

To demonstrate buoyant forces dramatically, the teacher may place a heavy object, such as a large rock, in a large container of water and ask students first to lift the object in the container without removing the object from the water. Then the teacher asks students to lift the object completely from the water. Students are usually startled by how much easier it is to lift the object while it is in a container of water than to lift that same object when it is on a dry surface. People can move heavy stones from one place to another when the stones are immersed in rivers and lakes, but they often cannot lift the stone from the water. A small beach ball pushed down into a large container of water produces the same effect in reverse for students who have never experienced the large buoyant force that water can exert on a volume that is mostly air.

8. d. *Students know* how to predict whether an object will float or sink.

The most direct way to predict whether a substance or solid object will sink or float in a fluid is to compare the density of the substance or object with the density of the fluid, either by measurement or by looking up the values on a table of densities. If the object is less dense than the fluid, it will float. Materials with densities greater than that of a liquid can be made to float on the liquid (e.g., steel boats and concrete canoes floating on water) if they can be shaped to displace a volume of the liquid equal to their weight before they submerge completely.

The density of liquids may be determined by using a hydrometer, either one that is commercially available or one that is made from a pencil with a thumbtack in the eraser. The depth to which an object of uniform density will sink in a liquid is a relative measure of the density of the liquid. Simple hydrometers, based on this principle, can be used to compare the densities of a variety of liquids with the density of water. The length of the hydrometer submerged in an unknown liquid *(U)* compared with the length submerged in water *(W)* can be used to determine the density of an unknown liquid *(W/U)* in metric units of grams per cubic centimeter. How far a pencil hydrometer sinks in water may be marked as "1 gram per cubic centimeter." If the pencil sinks twice as far in another liquid, its density is 0.5 gram per cubic centimeter; if it sinks half as far, the density is 2 grams per cubic centimeter; and so on.

Air is also a fluid and exerts a buoyant force on objects submerged in it. Hot-air balloons rise because the upward buoyant force of the cooler surrounding air is greater than the weight of the hot, less dense air inside the balloon and the trappings of the balloon. Helium balloons rise because a volume of helium gas is much lighter than an equal volume of air at the same temperature and pressure.

STANDARD SET 9. Investigation and Experimentation

Experiments can yield consistent, reproducible answers, but the answers may be incorrect or off the mark for many reasons. By the time students complete grade eight, they should have a foundation in experimental design and be able to apply logical thinking processes to evaluate experimental results and conclusions. Mathematical representation of data is the key to making quantitative scientific predictions. Graphs expressing linear relationships utilize proportional reasoning and algebra. Students should be taught to apply their knowledge of proportions and algebra to the reporting and analysis of data from experiments.

9. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

a. Plan and conduct a scientific investigation to test a hypothesis.

b. Evaluate the accuracy and reproducibility of data.

c. Distinguish between variable and controlled parameters in a test.

d. Recognize the slope of the linear graph as the constant in the relationship $y = kx$ and apply this principle in interpreting graphs constructed from data.

e. Construct appropriate graphs from data and develop quantitative statements about the relationships between variables.

f. Apply simple mathematical relationships to determine a missing quantity in a mathematic expression, given the two remaining terms (including speed = distance/time, density = mass/volume, force = pressure × area, volume = area × height).

g. Distinguish between linear and nonlinear relationships on a graph of data.

Notes

1. *Reading/Language Arts Framework for California Public Schools, Kindergarten Through Grade Twelve.* Sacramento: California Department of Education, 1999; *Mathematics Framework for California Public Schools, Kindergarten Through Grade Twelve* (Revised edition). Sacramento: California Department of Education, 2000.
2. *Mathematics Content Standards for California Public Schools, Kindergarten Through Grade Twelve.* Sacramento: California Department of Education, 1999.
3. *Science Safety Handbook for California Public Schools.* Sacramento: California Department of Education, 1999.
4. *Health Framework for California Public Schools, Kindergarten Through Grade Twelve.* Sacramento: California Department of Education, 1994.
5. Charles Darwin, *On the Origin of Species by Means of Natural Selection.* Reprinted from the 6th edition. New York: Macmillan, 1927.
6. Thomas R. Malthus, *An Essay* on *the Principle of Population.* 1798. Reprint. Amherst, N.Y.: Prometheus Books, 1998.
7. Richard P. Feynman, Robert B. Leighton, and Matthew Sands, Vol. 1 of *The Feynman Lectures on Physics.* Reading, Mass.: Addison-Wesley, 1963, pp.1–2.