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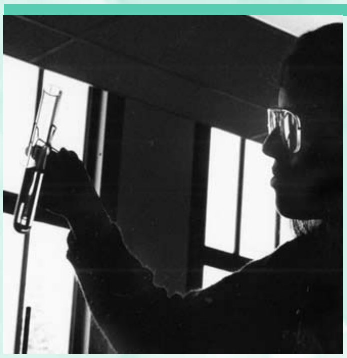


# The Science Content Standards for Grades Nine Through Twelve

# 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 appropriately 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 experi-ments. 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.

# 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 1. 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.

**1. 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 $5.96 \times 10^{12}$ 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.

**1. 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.

**1. 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.

**1. 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.

**1. 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).

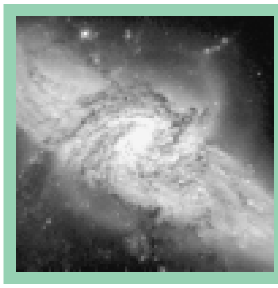
**1. f.** *Students know* the evidence for the dramatic effects that asteroid impacts have had in shaping the surface of planets and their moons and in mass extinctions of life on Earth.

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.

**1. 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.

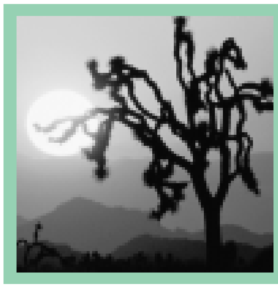
The violence of volcanic eruptions is a function of the viscosity of the lava that erupted. All magmas contain dissolved volatiles (or gases) that expand and rise buoyantly as the magma rises to the surface—much like the bubbles in a bottle of soda. Fluid lavas allow gases to bubble away relatively harmlessly, 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 byproduct 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.

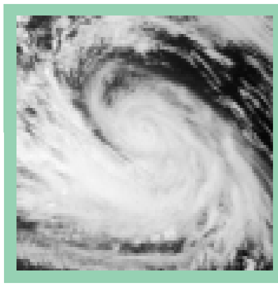
As air is warmed in the tropics, water is evaporated, and the resulting warm, moist air rises and cools. When this moist tropical air cools enough, it becomes saturated and precipitates water as rain. The once warm, moist air is now dryer and cold and heavy. This air is then displaced to the north or 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.

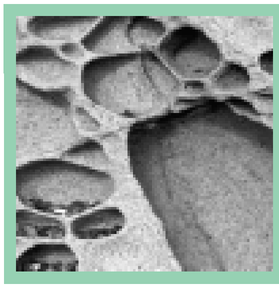
The *troposphere,* the layer in which weather occurs, supports life on Earth. The *stratosphere* is less dense than the troposphere but has a similar composition except that this second layer is nearly devoid of water. The other difference is that solar radiation ionizes atoms in the stratosphere and 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.

**1. 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).