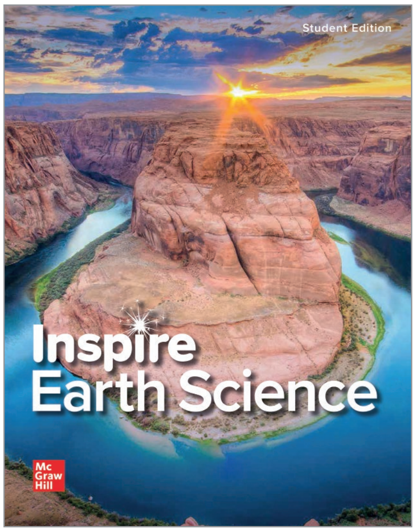
Student Edition

Inspire Earth Science

Mc Graw Hill Education

Inspire
Earth Science

McGraw Hill



Phenomenon: Canyon formation

This spectacular shot is only possible because of a change in Earth's surface leading to a process called rejuvenation.

Fun Fact

To cause rejuvenation, Earth's surface must rise above its base level. The river will then cut through the rock to go back to the original base level.

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STEM

McGraw-Hill is committed to providing instructional materials in Science, Technology, Engineering, and Mathematics (STEM) that give all students a solid foundation, one that prepares them for college and careers in the 21st century.

Welcome to

Inspire Earth Science

Explore Our Phenomenal World

The Inspire High School Series brings phenomena to the forefront of learning to engage and inspire students to investigate key science concepts through their three-dimensional learning experience.

Start exploring now!

Inspire Curiosity • Inspire Investigation • Inspire Innovation

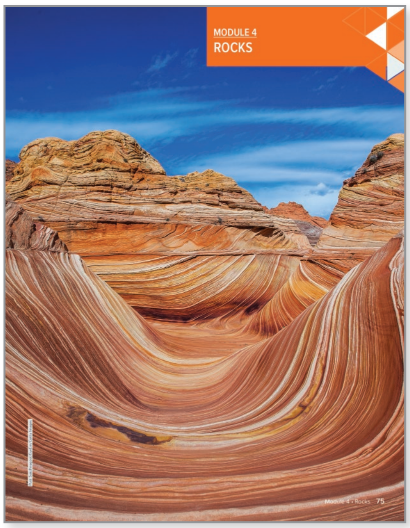
WELCOME TO INSPIRE EARTH SCIENCE

Owning Your Learning

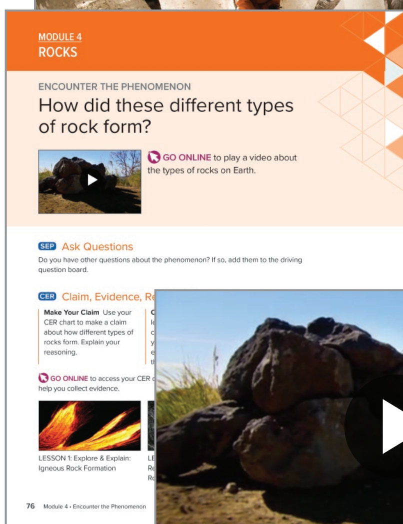
1 Encounter the Phenomenon

Every day, you are surrounded by natural phenomena that makes you wonder.

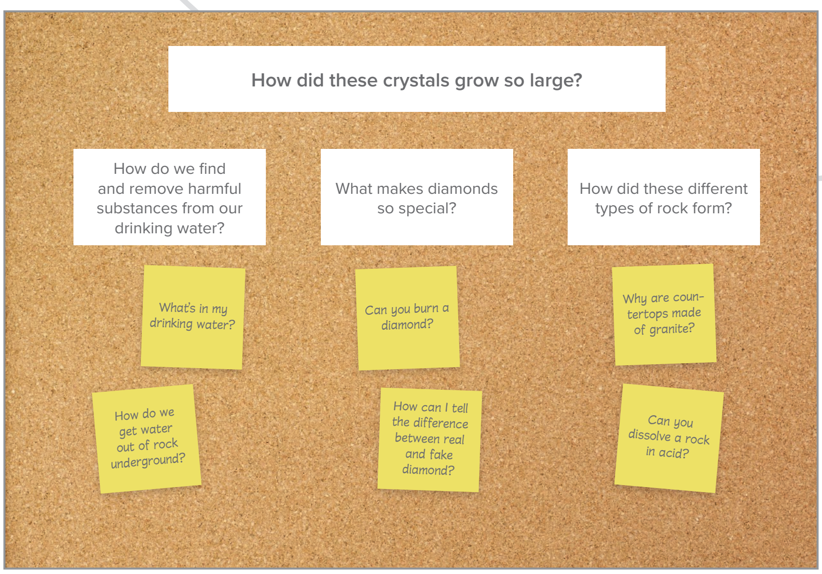
Unit Opener



Module Opener



Phenomenon Video



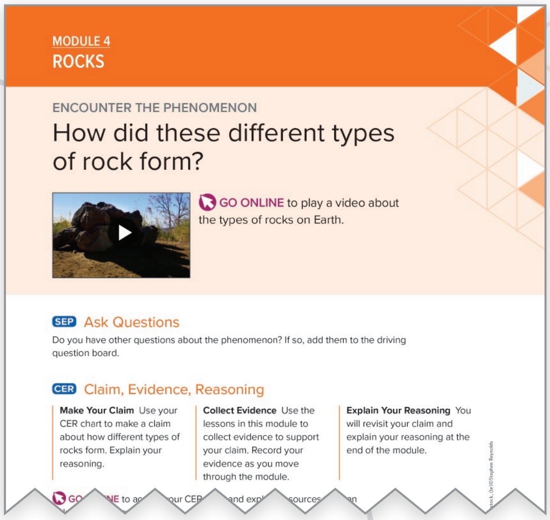
2 Ask Questions

At the beginning of each unit and module, make a list of the questions you have about the phenomenon. Share your questions with your classmates.

(t)Video supplied by BBC Worldwide Learning, (b)moi/amanaimagesRF/Getty Images

3 Claim, Evidence, Reasoning

As you investigate each phenomenon, you will write your claim, gather evidence by performing labs and completing reading assignments and Applying Practices, and explain your reasoning to answer the unit and module phenomena.


MODULE 4
ROCKS

ENCOUNTER THE PHENOMENON

How did these different types of rock form?

GO ONLINE to play a video about the types of rocks on Earth.

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about how different types of rocks form. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

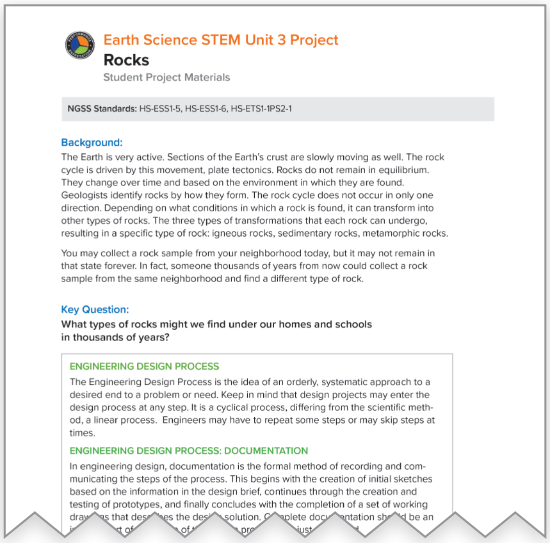
SUMMARY TABLE					
Activity Model	Observation Evidence	Explanation Reasoning	Connection to Phenom	Questions Answered	New Questions
Virtual Investigation: Mineral Properties	Minerals have distinct properties that can be used to identify them.	A mineral's chemical composition and crystal structure give it unique properties, by which it can be identified.	Unit: There is no limit the size a crystal can grow, because the chemical patterns can repeat indefinitely. Module: Diamond is special because of its chemical make-up and crystal structure.	How can I tell the difference between real and fake diamond?	How is diamond made in nature?

4 Summarize Your Work

When you collect evidence, you can record your data in a summary table and use the data to collaborate with others to answer the questions you had.

5 Apply Your Evidence and Reasoning

At the end of the unit, modules, and lessons, you can use all of the data you collected to help complete your STEM Unit Project.


Earth Science STEM Unit 3 Project

Rocks

Student Project Materials

NGSS Standards: HS-ESS1-5, HS-ESS1-6, HS-ETS1-1PS2-1

Background:

The Earth is very active. Sections of the Earth's crust are slowly moving as well. The rock cycle is driven by this movement, plate tectonics. Rocks do not remain in equilibrium. They change over time and based on the environment in which they are found. Geologists identify rocks by how they form. The rock cycle does not occur in only one direction. Depending on what conditions in which a rock is found, it can transform into other types of rocks. The three types of transformations that each rock can undergo, resulting in a specific type of rock: igneous rocks, sedimentary rocks, metamorphic rocks.

You may collect a rock sample from your neighborhood today, but it may not remain in that state forever. In fact, someone thousands of years from now could collect a rock sample from the same neighborhood and find a different type of rock.

Key Question:

What types of rocks might we find under our homes and schools in thousands of years?

ENGINEERING DESIGN PROCESS

The Engineering Design Process is the idea of an orderly, systematic approach to a desired end to a problem or need. Keep in mind that design projects may enter the design process at any step. It is a cyclical process, differing from the scientific method, a linear process. Engineers may have to repeat some steps or may skip steps at times.

ENGINEERING DESIGN PROCESS: DOCUMENTATION

In engineering design, documentation is the formal method of recording and communicating the steps of the process. This begins with the creation of initial sketches based on the information in the design brief, continues through the creation and testing of prototypes, and finally concludes with the completion of a set of working

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The Teacher Advisory Board gave the editorial staff and design team feedback on the content and design of both the Student Edition and Teacher Edition. We thank these teachers for their hard work and creative suggestions.

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Following the mission of its founder James Smithson for “an establishment for the increase and diffusion of knowledge,” the Smithsonian Institution today is the world’s largest museum, education, and research complex. To further their vision of shaping the future, a wealth of Smithsonian online resources are integrated within this program.

SpongeLab Interactives

SpongeLab Interactives is a learning technology company that inspires learning and engagement by creating gamified environments that encourage students to interact with digital learning experiences.

Students participate in inquiry activities and problem-solving to explore a variety of topics using games, interactives, and video while teachers take advantage of formative, summative, or performance-based assessment information that is gathered through the learning management systems.

PhET Interactive Simulations

The PhET Interactive Simulations project at the University of Colorado Boulder provides teacher and students with interactive science and math simulations. Based on extensive education research, PhET sims engage students through an intuitive, game-like environment where students learn through exploration and discovery.

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Carsten Peter/Speleoresearch & Films/National Geographic/Getty Images

UNIT 1

COMPOSITION OF EARTH

ENCOUNTER THE PHENOMENON

How did these crystals grow so large?

INTRODUCTION TO EARTH SCIENCE

This module introduces the what Earth science is and provides tools for the study of Earth science.

MODULE 1: INTRODUCTION TO EARTH SCIENCE

MODULE 2: MATTER AND CHANGE

MODULE 3: MINERALS

MODULE 4: ROCKS

UNIT 2

SURFACE PROCESSES ON EARTH

ENCOUNTER THE PHENOMENON

How did wind, water, and ice shape this landscape?

MODULE 5: WEATHERING, EROSION, AND SOIL

MODULE 6: MASS MOVEMENTS, WIND, AND GLACIERS

MODULE 7: WATER

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UNIT 3

THE ATMOSPHERE AND THE OCEANS

ENCOUNTER THE PHENOMENON

How are animals in the ocean affected by things that happen in the sky?

UNIT 4
THE DYNAMIC EARTH

ENCOUNTER THE PHENOMENON

Why are the rock layers sideways?

MODULE 13: PLATE TECTONICS

MODULE 14: VOLCANISM

MODULE 15: EARTHQUAKES

MODULE 16: MOUNTAIN BUILDING

Ian_Redding/iStock/Getty Images

UNIT 5

GEOLOGIC TIME

ENCOUNTER THE PHENOMENON

What can these fossils tell us about Earth millions of years ago?

MODULE 17: FOSSILS AND THE ROCK RECORD

MODULE 18: GEOLOGIC TIME SCALE

UNIT 6

RESOURCES AND THE ENVIRONMENT

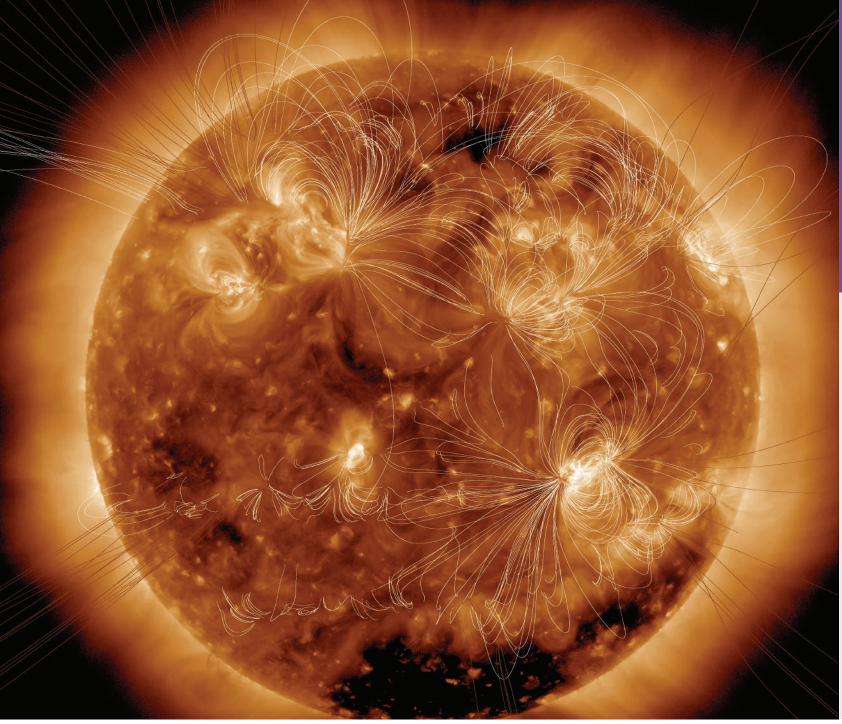
ENCOUNTER THE PHENOMENON

How does coal mining affect both Earth and human communities?

David T. Stephenson/Shutterstock

MODULE 19: EARTH'S RESOURCES

MODULE 20: HUMAN IMPACT ON RESOURCES



UNIT 7
BEYOND EARTH

ENCOUNTER THE PHENOMENON

How is space different from the planet we call home?

Indeed/Getty Images

MODULE 1

INTRODUCTION TO EARTH SCIENCE

ENCOUNTER THE PHENOMENON

What can maps tell us about our world?

GO ONLINE to play a video about the importance of cartography.

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about what maps tell us about our world. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 2: Explore & Explain: Projections

LESSON 3: Explore & Explain: The Geographic Information System

Smithsonian

Additional Resources

Video Supplied by BBC Worldwide Learning

LESSON 1
WHAT IS EARTH SCIENCE?

FOCUS QUESTION

Why is understanding Earth important?

The Scope of Earth Science

From the maps you use when traveling to the weather report you use when deciding whether or not to carry an umbrella, Earth science is a part of your everyday life. The scope of Earth science is vast. It is partly for this reason that the broad field of Earth science is often broken into five major areas of specialization: astronomy, meteorology, geology, oceanography, and environmental science.

Astronomy

The study of objects beyond Earth's atmosphere is called **astronomy.** Prior to the invention of sophisticated instruments, such as the telescope shown in **Figure 1,** many astronomers merely described the locations of objects in space in relation to each other. Today, Earth scientists study the universe and everything in it, including galaxies, stars, planets, moons, and other bodies they have identified. Astronomers focus on the movement, composition, and structure of bodies in space.

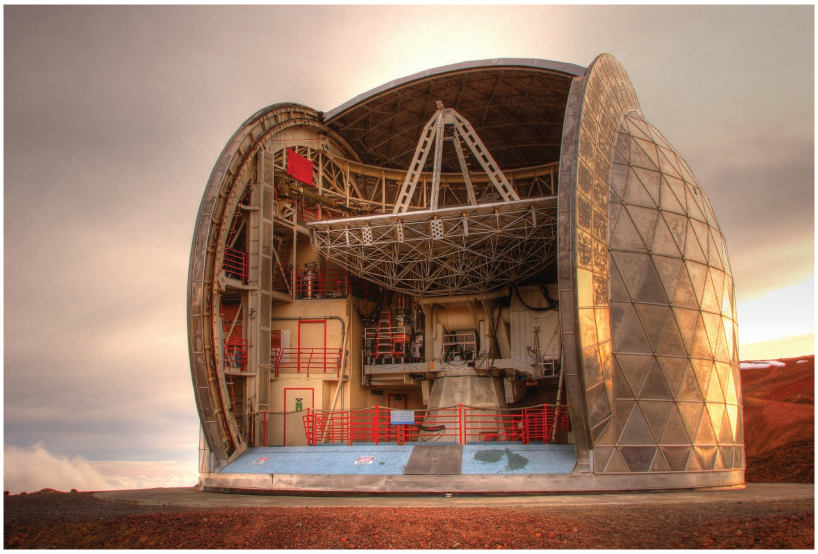


Figure 1 This telescope is one of 13 located on Mauna Kea in Hawaii.

Tomas Banik/Shutterstock

Meteorology

The study of forces and processes that cause the atmosphere to change and produce weather is **meteorology.** Meteorologists also try to forecast the weather and learn how changes in weather over time might affect Earth's climate. They use technology ranging from satellites to thermometers to make forecasts and to analyze trends.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Virtual Investigation: The Nature of Science
Plan and carry out an investigation using a scientific method to optimize a design solution.

Investigation Lab: Observing and Analyzing Stream Flow
Analyze and interpret data to determine the effect water has on earth materials.

Geology

The study of materials that make up Earth, the processes that form and change these materials, and the history of the planet and its life-forms since its origin is the branch of Earth science known as **geology.** Geologists identify rocks and fossils, study glacial movements, interpret clues to Earth's 4.6-billion-year history, and determine how forces change our planet.

Oceanography

The study of Earth's oceans, which cover nearly three-fourths of the planet, is called **oceanography.** Oceanographers study the creatures that inhabit salt water, measure different physical and chemical properties of the oceans, and observe various processes in these bodies of water. When oceanographers are conducting field research, they often have to dive into the ocean to gather data, as shown in **Figure 2.**

Figure 2 Oceanographers study the life and properties of the ocean.

Investigate *What kind of training would this Earth scientist need?*

Environmental science

The study of interactions among organisms and their surroundings is called **environmental science.** Environmental scientists study how organisms impact the environment both positively and negatively. The topics an environmental scientist might study include the use of natural resources, the effects of pollution, alternative energy sources, and the impact of humans on the atmosphere.

Subspecialties

The study of our planet is a broad endeavor, and, as such, each of the five major areas of Earth science consists of a variety of subspecialties. These include climatology, paleontology, and environmental chemistry. The descriptions of several subspecialties of Earth science are listed in **Table 1.**

Table 1 **Subspecialties of Earth Science**

Major Area of Study	Subspecialty	Subjects Studied
Astronomy	astrophysics	physics of the universe, including the physical properties of objects in space
	planetary science	planets of the solar system and the processes that form them
Meteorology	climatology	patterns of weather over a long period of time
	atmospheric chemistry	chemistry of Earth's atmosphere and the atmospheres of other planets
Geology	paleontology	remains of organisms that once lived on Earth; ancient environments
	geochemistry	Earth's composition and the processes that change it
Oceanography	physical oceanography	physical characteristics of oceans, such as salinity, waves, and currents
	marine geology	geologic features of the ocean floor, plate tectonics of the ocean
Environmental science	environmental soil science	interactions between humans and the soil, such as the impact of farming practices; effects of pollution on soil, plants, and groundwater
	environmental chemistry	chemical alterations to the environment through pollution and natural means

Figure 3 These Earth scientists are monitoring water quality to ensure that the water is safe for human consumption.

ESB Professional/Shutterstock

Importance of Earth Science

The study of science, including Earth science, has led to many discoveries that have been applied to address society's needs and problems. The application of scientific discoveries is called technology. Technology is transferable, which means that it can be applied to new situations. Freeze-dried foods, ski goggles, laptops, and the ultralight materials used to make many pieces of sports equipment were created from technologies used in our space program. Smoke detectors were also invented as part of the space program and were adapted for use in everyday life.

Impacts on society

In addition to making life easier, technology can make life safer. For example, Earth scientists monitor and analyze natural disasters ranging from earthquakes to hurricanes. They help predict when these disasters will occur, allowing people to seek shelter or evacuate the area. Earth Scientists also aid in the aftermath of a disaster. Mapping areas affected by natural disasters with satellite and aerial images helps relief workers gain safe access. Relief workers are better able to prepare for the changes in local geography, destruction of buildings, and other physical challenges in the disaster zone.

Earth scientists also work to improve farming methods, helping to produce more food for a growing human population. Precision farming provides farmers with detailed data about soil composition, topography, and pest infestations. The data, gathered by satellites and computer simulations, allow farmers to increase crop yields, reduce waste, and protect natural resources.

In addition to an adequate food supply, people need clean water and clean air. Earth scientists such as those in **Figure 3** monitor water quality and air quality and develop strategies to reduce environmental degradation. Through computer simulations and other studies, important discoveries are being made about how Earth's systems are modified in response to human activities.

Impacts on worldview

Ancient people had a limited view of their surroundings. They were not sure of the shape of Earth or its landmasses. Through exploration and advances in mapping technology, we now have a clear image of Earth and can navigate around the world. **Figure 4** shows some advances in Earth science over time.

Figure 4

Major Events in Earth Science

Many discoveries during the twentieth and early twenty-first centuries revolutionized our understanding of Earth and its systems.

1 **1907** Scientists begin using radioactive decay to determine that Earth is billions of years old. This method will be used to develop the first accurate geological time scale.

2 **1913** French physicists discover the ozone layer in Earth's upper atmosphere and propose that it protects Earth from the Sun's ultraviolet radiation.

3 **1925** Cecilia Payne's analysis of the spectra of stars reveals that hydrogen and helium are the most abundant elements in the universe.

4 **1936** Inge Lehmann proposes that Earth's center consists of a solid inner core and a liquid outer core based on her studies of seismic waves.

5 **1962** Harry Hess's seafloor spreading hypothesis, along with discoveries made about the ocean floor, lays the foundation for plate tectonic theory.

6 **1990** The Hubble Space Telescope goes into orbit, exploring Earth's solar system, measuring the expansion of the universe, and providing evidence of black holes.

7 **2004** A sediment core retrieved from the ocean floor discloses 55-million-year Earth's atmospheric and climatic history. The sample reveals that the North Pole once had a warm climate.

8 **2015** Scientists observe gravitational waves for the first time. The existence of gravitational waves was predicted by Albert Einstein in 1916.

Earth's Systems

Scientists who study Earth have identified four main Earth systems: the geosphere, atmosphere, hydrosphere, and biosphere. Each system is unique, yet each interacts with the others. When investigating Earth's systems, scientists define the boundaries of each system. The inputs and outputs of the systems can be analyzed using models.

Geosphere

The area from the surface of Earth down to its center is called the **geosphere.** The geosphere is divided into three main parts: the crust, mantle, and core. These three parts are illustrated in **Figure 5.**

The rigid outer shell of Earth is called the crust. There are two kinds of crust—continental crust and oceanic crust. Continental crust can be billions of years old. It is generally older than oceanic crust, which is less than 200 million years old. Just below the crust is Earth's mantle. The mantle differs from the crust both in composition and behavior. The mantle ranges in temperature from 100°C to 4000°C—much warmer than the temperatures found in Earth's crust. Below the mantle is Earth's core. Temperatures in the core may be as high as 7000°C.

Atmosphere

The blanket of gases that surrounds our planet is called the **atmosphere.** Earth's atmosphere contains about 78 percent nitrogen and 21 percent oxygen. The remaining 1 percent of gases in the atmosphere include water vapor, argon, carbon dioxide, and other trace gases. Earth's atmosphere provides oxygen for living things, protects Earth's inhabitants from harmful radiation from the Sun, and helps to keep the planet at a temperature suitable for life.

Hydrosphere

All the water on Earth, including the water in the atmosphere, makes up the **hydrosphere.** About 97 percent of Earth's water exists as salt water, while the remaining 3 percent is freshwater contained in lakes and rivers, beneath Earth's surface as groundwater, and in glaciers. The region of permanently frozen water on Earth is called the **cryosphere.** Only a fraction of Earth's total amount of freshwater is in lakes, ponds, streams, and rivers.

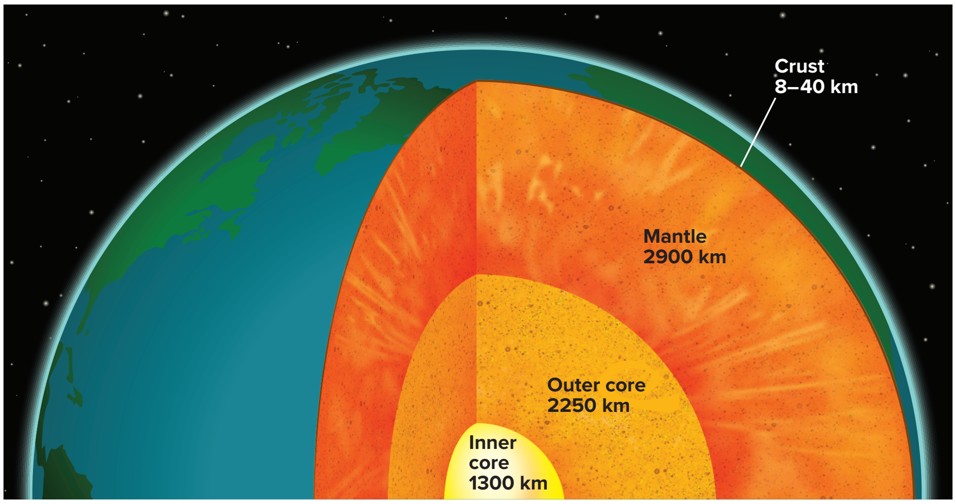


Figure 5 Earth's geosphere is composed of everything from the crust to the center of Earth. Notice how thin the crust is in relation to the rest of the geosphere's components.

CCC CROSSCUTTING CONCEPTS

Systems and Models Make observations of the natural world. Cite evidence of interactions among Earth's systems. Describe how you could model these interactions.

SCIENCE USAGE v. COMMON USAGE

crust

Science usage: the thin, rocky outer layer of Earth

Common usage: the hardened exterior or surface part of bread

Biosphere

The **biosphere** includes all organisms on Earth and the environments in which they live. Most organisms live within a few meters of Earth's surface, but some exist deep within the vast ocean or high atop rugged mountain peaks.

As illustrated in **Figure 6,** Earth's systems are dynamic and interactive. Feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and living things. For example, the atmosphere of early Earth did not contain oxygen. Roughly 2.5 billion years ago, photosynthesizing organisms in Earth's biosphere helped form Earth's present atmosphere by releasing oxygen as a by-product of photosynthesis. The addition of oxygen in the atmosphere greatly influenced the evolution of complex life-forms.

Such interactions among Earth's systems cause feedback effects that can increase or decrease the original changes. For example, when trees in the biosphere are cut down, rates of photosynthesis decrease, and the atmosphere is affected.

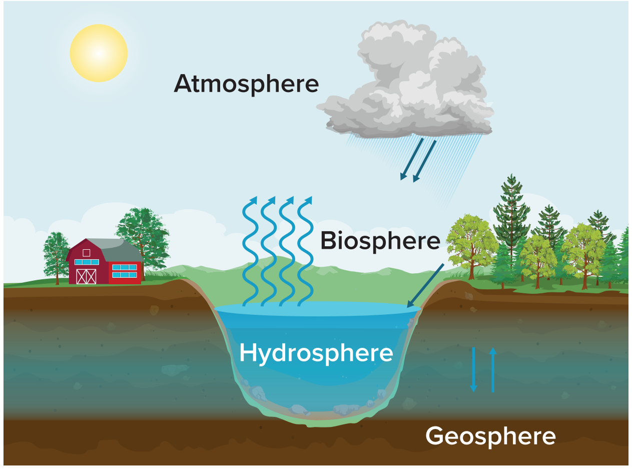


Figure 6 All of Earth's systems are interdependent. Notice how water from the hydrosphere enters the atmosphere, falls on the biosphere, and soaks into the geosphere.

Check Your Progress

Summary

- Earth is divided into four main systems: the geosphere, hydrosphere, atmosphere, and biosphere.
- Earth systems are all dynamic and interactive.
- Identifying the interrelationships among Earth systems leads to specialties and subspecialties of Earth science.
- Earth science has contributed to society and to the development of many items used in everyday life.

Demonstrate Understanding

1. **Explain** why it is helpful to identify specialties and subspecialties of Earth science.
2. **Apply** What are three items you use on a daily basis that have come from research in Earth science?
3. **Hypothesize** how organisms in the biosphere, including humans, can cause the co-evolution of one other Earth system.
4. **Compare and contrast** geology and the geosphere.
5. **Differentiate** between the hydrosphere and the biosphere.

Explain Your Thinking

6. **Predict** what would happen if the composition of the atmosphere changed. How might this affect the biosphere?
7. **WRITING Connection** Research an interaction among Earth's systems. Make a flowchart that shows how the interaction causes feedback effects that can increase or decrease the original changes.

LEARNSMART® Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

LESSON 2
UNDERSTANDING MAPS

FOCUS QUESTION

How do we use maps to describe Earth?

Latitude

Maps are flat models of three-dimensional objects. For thousands of years, people have used maps to define borders and to find places. The science of mapmaking is called **cartography.**

Cartographers use an imaginary grid of parallel lines to locate exact points on Earth. In this grid, the **equator** horizontally circles Earth halfway between the North and South Poles. The equator separates Earth into two equal halves called the northern hemisphere and the southern hemisphere.

Lines on a map running parallel to the equator are called lines of **latitude.** Latitude is the distance in degrees north or south of the equator, as shown in **Figure 7.** The equator, which serves as the reference point for latitude, is numbered 0° latitude. The poles are each numbered 90° latitude. Latitude is thus measured from 0° at the equator to 90° at the poles.

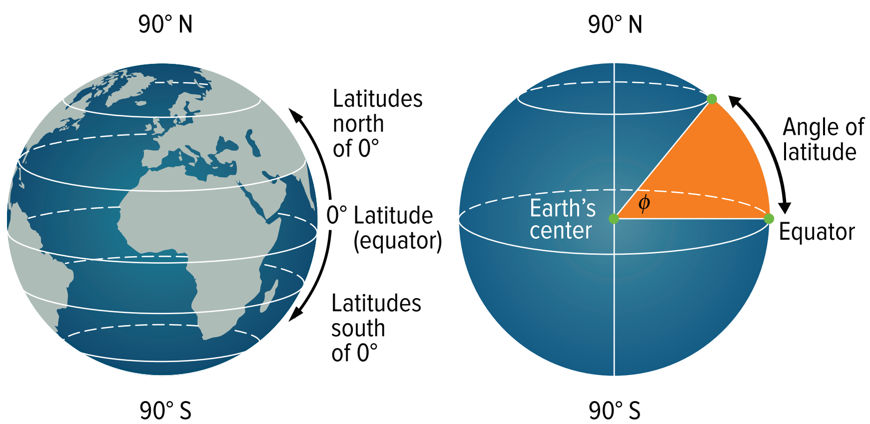


Figure 7 Lines of latitude are parallel to the equator. The value in degrees of each line of latitude is determined by measuring the imaginary angle created between the equator, the center of Earth, and the line of latitude, as seen in the globe on the right.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

GeoLAB: Use a Topographic Map

Use a model to visualize the surface structure of Earth.

Investigation Lab: Interpreting Political and Landform Maps

Develop and use models at different scales to optimize the design of a map.

Locations north of the equator are referred to by degrees north latitude (N). Locations south of the equator are referred to by degrees south latitude (S). For example, Syracuse, New York, is located at 43°N, and Christchurch, New Zealand, is located at 43°S.

Degrees of latitude

Each degree of latitude is equivalent to about 111 km on Earth's surface. How did cartographers determine this distance? Earth is a sphere and can be divided into 360°. The circumference of Earth is about 40,000 km. To find the distance of each degree of latitude, cartographers divided 40,000 km by 360°.

To locate positions on Earth more precisely, cartographers break down degrees of latitude into 60 smaller units, called minutes. The symbol for a minute is '. The actual distance on Earth's surface of each minute of latitude is 1.85 km, which is obtained by dividing 111 km by 60'.

A minute of latitude can be further divided into seconds, which are represented by the symbol ". Longitude is also divided into degrees, minutes, and seconds.

Longitude

To locate positions in east and west directions, cartographers use lines of longitude, also known as meridians. As shown in **Figure 8,** **longitude** is the distance in degrees east or west of the prime meridian, which is the reference point for longitude.

The **prime meridian** represents 0° longitude. In 1884, astronomers decided that the prime meridian should go through Greenwich, England, home of the Royal Naval Observatory. Points west of the prime meridian are numbered from 0° to 180° west longitude (W); points east of the prime meridian are numbered from 0° to 180° east longitude (E).

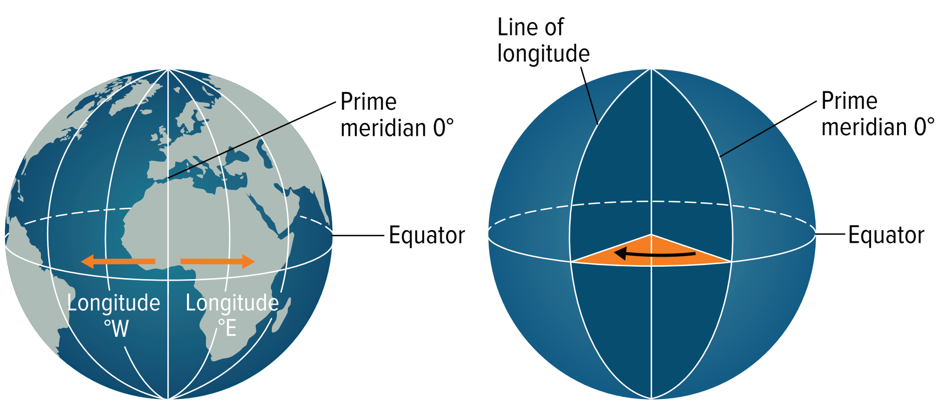


Figure 8 The reference line for longitude is the prime meridian. The degree value of each line of longitude is determined by measuring the imaginary angle created between the prime meridian, the center of Earth, and the line of longitude, as seen on the globe on the right.

SCIENCE USAGE v. COMMON USAGE

minute

Science usage: a unit used to indicate a portion of a degree of latitude

Common usage: a unit of time comprised of 60 seconds

Semicircles

Unlike lines of latitude, lines of longitude are not parallel. Instead, they are large semicircles that extend vertically from pole to pole. For instance, the prime meridian runs from the North Pole, through Greenwich, England, to the South Pole.

The line of longitude on the opposite side of Earth from the prime meridian is the 180° meridian. There, east lines of longitude meet west lines of longitude. This meridian, also known as the International Date Line, will be discussed later in this lesson.

Degrees of longitude

Degrees of latitude cover relatively consistent distances. So, the distance between any two latitude lines is approximately the same everywhere on Earth. The distances covered by degrees of longitude, however, vary with location. Lines of longitude converge at the poles into a point. Thus, one degree of longitude varies from about 111 km at the equator to 0 km at the poles.

Get It?

Compare degrees of latitude and degrees of longitude.

Using coordinates

Both latitude and longitude are needed to locate positions on Earth precisely. For example, it is not sufficient to say that Charlotte, North Carolina, is located at 35°14'N because that measurement includes any place on Earth located along the 35°14' line of north latitude.

The same is true of the longitude of Charlotte; 80°50'W could be any point along that longitude from pole to pole. To locate Charlotte, you must use its complete coordinates—latitude and longitude—as shown in **Figure 9.**

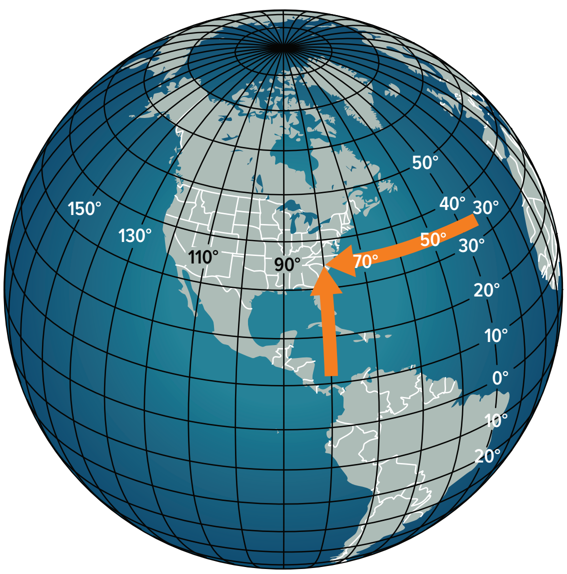


Figure 9 The precise location of Charlotte, North Carolina, is 35°14'N, 80°50'W. Note that latitude comes first in reference to the coordinates of a particular location.

Time zones

Earth is divided into 24 time zones. Why 24? Earth takes about 24 hours to rotate once (360°) on its axis. Therefore, there are 24 times zones, each representing a different hour. Every hour Earth spins approximately 15°, so each time zone is 15° wide, corresponding roughly to lines of longitude. To avoid confusion, however, time zone boundaries have been adjusted in local areas so that cities and towns are not split into different time zones.

For example, all of Morton County, North Dakota, operates within the central time zone, even though the western part of the county is within the mountain-time-zone boundary. As shown in **Figure 10,** there are six time zones in the United States. The majority of states within these time zones recognize Daylight Saving Time (DST), wherein clocks are set forward one hour in the spring and back one hour in the fall. This system was put in place to extend daylight hours during warmer months, and so save energy.

International Date Line Each time you travel through a time zone, you gain or lose time until, at some point, you gain or lose an entire day. The **International Date Line,** which is the 180° meridian, serves as the transition line for calendar days. This imaginary line runs through the Pacific Ocean, as shown in **Figure 10.** If you were traveling west across the International Date Line, you would advance your calendar one day. If you were traveling east, you would move your calendar back one day. Note that the International Date Line runs in a general north-south direction, but it tends to follow political boundaries so that countries are not split into different calendar days.

Get It?

Estimate the time difference between your home and places that are 60° east and west longitude of your home.

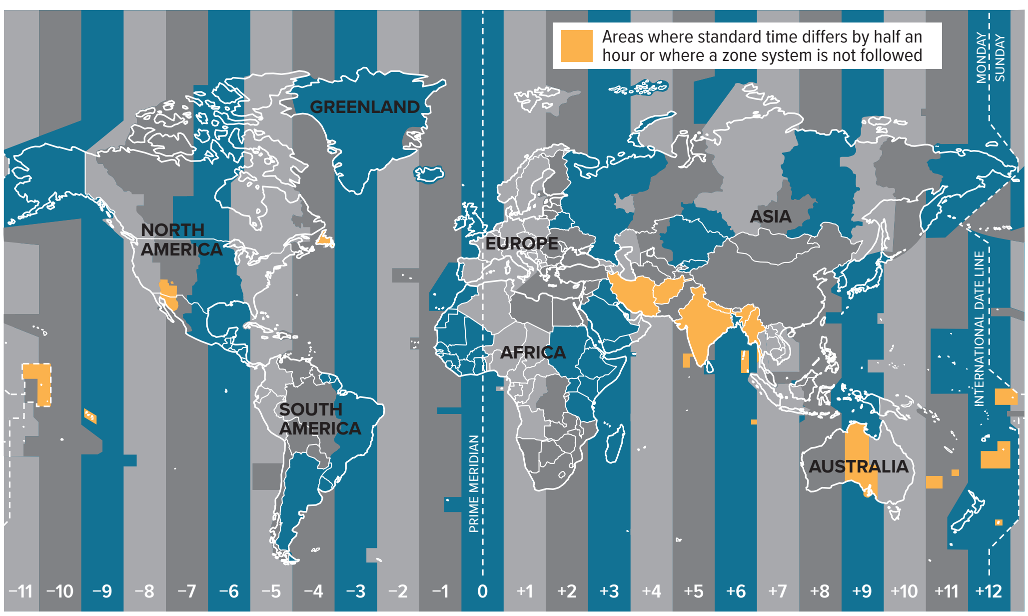


Figure 10 In most cases, each time zone represents a different hour. However, there are some exceptions. **Identify** *two areas where the time zone is not standard.*

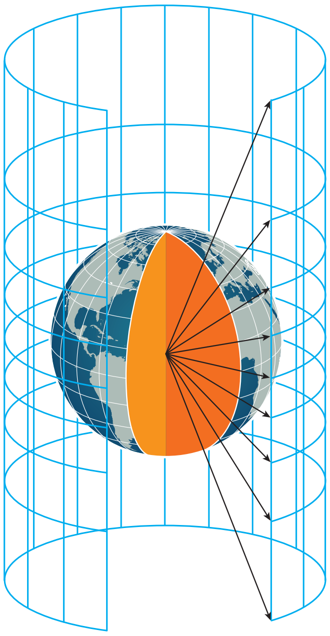


Figure 11 In a Mercator projection, points and lines on a globe are transferred onto cylinder-shaped paper. Mercator projections show true direction but distort the size of the regions near the poles.

Projections

Because Earth is spherical, it is difficult to represent on a piece of paper. For this reason, all flat maps distort to some degree either the shapes or the areas of landmasses. Cartographers use projections to make maps. A map projection is made by transferring points and lines on a globe's surface onto a sheet of paper.

Mercator projections

A **Mercator projection** is a map that has parallel lines of latitude and longitude. Recall that lines of longitude meet at the poles. When lines of longitude are projected as being parallel on a map, landmasses near the poles are exaggerated. So, in a Mercator projection, the shapes of the landmasses are correct, but their areas are distorted.

Figure 11 shows a Mercator projection. As you can see, Greenland appears much larger than Australia. In reality, Greenland is much smaller than Australia. Because Mercator projections show the correct shapes of landmasses and also clearly indicate direction in straight lines, they are most commonly used for navigating ships.

Get It?

Determine On a Mercator projection, where does most of the distortion occur? Why?

STEM CAREER Connection

GIS Technician

Would you like to create a map that shows how much wood is in the world's forests? Then you may want to explore a career as a Geographic Information System (GIS) technician. GIS technicians have backgrounds in cartography and computer science. They analyze data and create detailed, layered maps that can show data about Earth from the top of its atmosphere to deep underground.

Conic projections

A **conic projection** is made by projecting points and lines from a globe onto a paper cone, as shown in **Figure 12.** The cone touches the globe at a particular line of latitude. There is little distortion in the areas or shapes of landmasses that fall along this line of latitude. Distortion is evident, however, near the top and bottom of the projection. In **Figure 12,** the landmass at the top of the map is distorted.

Because conic projections have a high degree of accuracy for limited areas, they are excellent for mapping small regions. Hence, they are used to make road maps and weather maps.

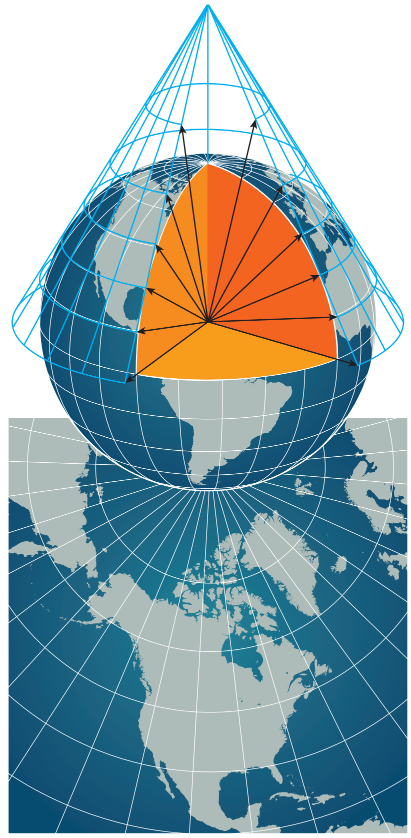


Figure 12 In a conic projection, points and lines on a globe are projected onto cone-shaped paper. There is little distortion along the line of latitude touched by the paper.

Gnomonic projections

A **gnomonic (noh MAHN ihk) projection** is made by projecting points and lines from a globe onto a piece of paper that touches the globe at a single point. At the single point where the map is projected, there is no distortion. But outside of this single point, great amounts of distortion are visible both in direction and landmass, as shown in **Figure 13.**

Because Earth is a sphere, it is difficult to plan long travel routes on a flat projection with great distortion, such as a conic projection. To plan such a trip, a gnomonic projection is often used. Although the direction and landmasses on the projection are distorted, it is useful for navigation. A straight line on a gnomonic projection is the straightest route from one point to another when traveled on Earth. This straight line is called a "great circle route" because it represents a segment of the largest circle that can be drawn on a globe.

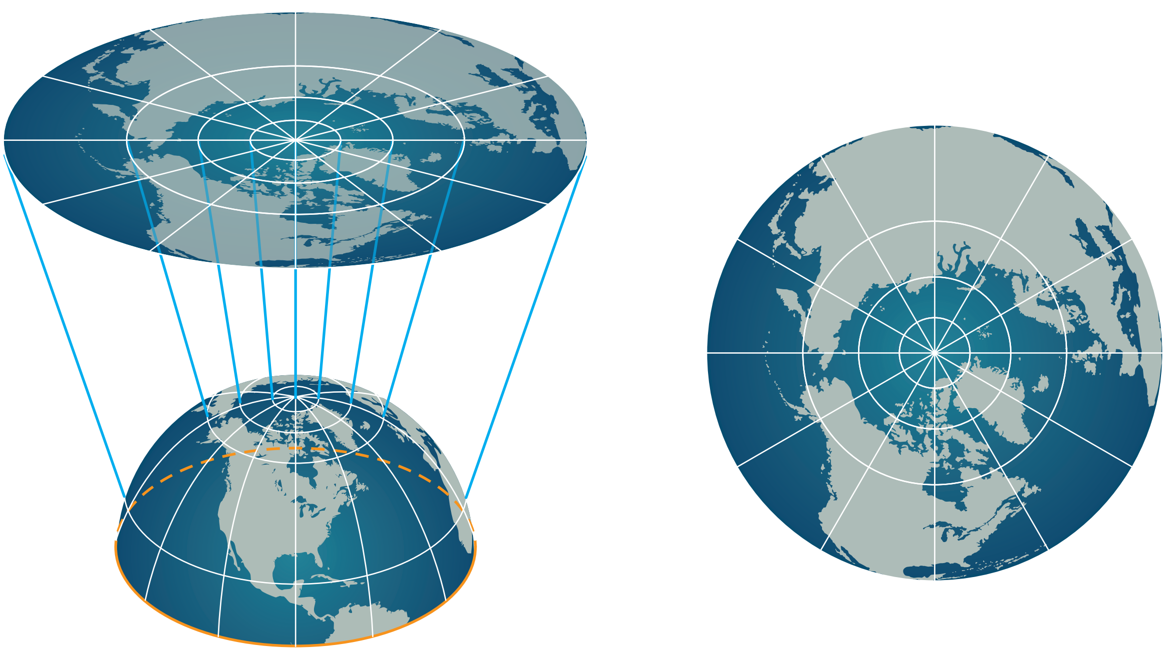


Figure 13 In a gnomonic projection, points and lines from a globe are projected onto paper that touches the globe at a single point.

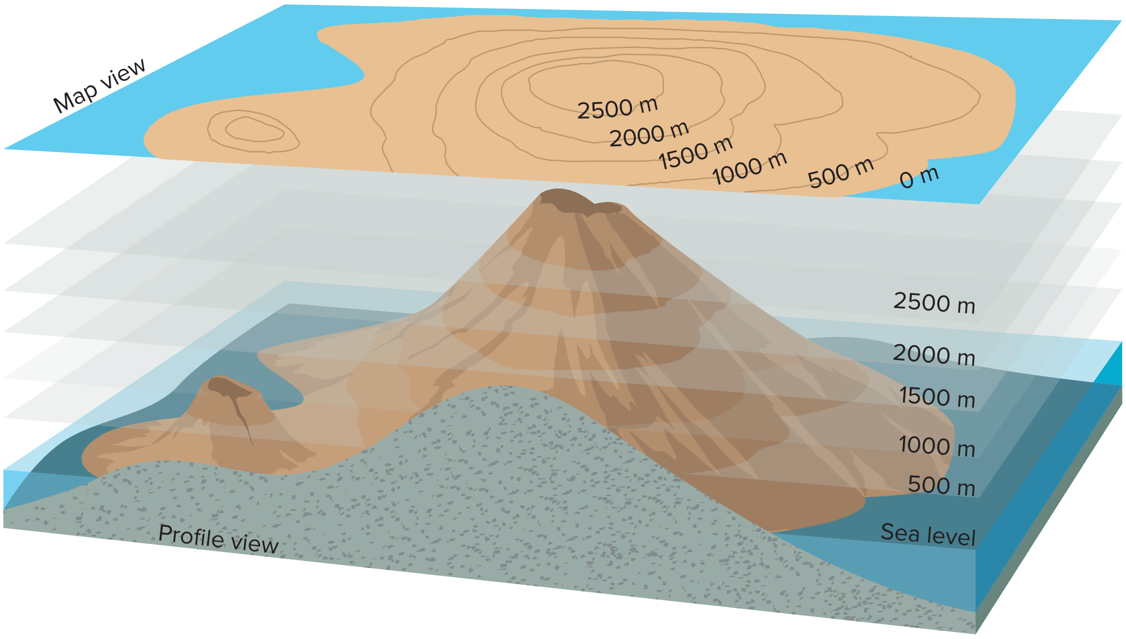


Figure 14 Points of elevation on Earth's surface are projected onto paper to make a topographic map.
Interpret *How many meters high is the highest point on the map?*

Topographic Maps

Detailed maps showing the hills and valleys of an area are called topographic maps. **Topographic maps** show changes in elevation of Earth's surface, as shown in **Figure 14.** They also show mountains, rivers, forests, and bridges, among other features. Topographic maps use lines, symbols, and colors to represent changes in elevation and features on Earth's surface. These types of maps are used for a wide variety of purposes, from hiking to surveying. Because topographic maps include symbols for roads, buildings, and other structures, they are useful for city and county planning.

Contour lines

Elevation on a topographic map is represented by a contour line. Elevation refers to a location's distance above or below sea level. A **contour line** connects points of equal elevation. Because contour lines connect points of equal elevation, they never cross. If they did, it would mean that the point where they crossed had two different elevations, which is impossible.

Contour intervals As **Figure 14** shows, topographic maps use contour lines to show changes in elevation. The difference in elevation between two side-by-side contour lines is called the **contour interval.** The contour interval is dependent on the terrain.

For mountains, the contour lines might be very close together, and the contour interval might be as great as 100 m. This would indicate that the land is steep because there is a large change in elevation between lines. For flat areas, such as plains, the contour lines would be far apart, and the contour interval would be small because there is not much change in elevation over a large area.

Get It?
Describe how you could use a contour map to determine the best route to take when hiking up a mountain.

Index contours To aid in the interpretation of topographic maps, some contour lines are marked by numbers representing their elevations. These contour lines are called index contours, and they are used hand-in-hand with contour intervals to help determine elevation.

If you look at a map with a contour interval of 5 m, you can determine the elevations represented by other lines around the index contour by adding or subtracting 5 m from the elevation indicated on the index contour.

Get It?

Analyze If you were looking at a topographic map with a contour interval of 50 m and the contour lines were far apart, would this indicate a rapid increase or slow increase in elevation? Explain your answer.

Depression contour lines The elevations of some features, such as volcanic craters and mines, are lower than that of the surrounding landscape. Depression contour lines are used to represent such features.

On a map, depression contour lines look like regular contour lines, but they have hachures—short lines at right angles to the contour line—to indicate depressions. As shown in **Figure 15,** the hachures point toward lower elevations. Any point inside a depression contour line is at a lower elevation than the contour line. Any point outside a depression contour line is at a higher elevation than the contour line. This is the opposite of regular contour lines, where points inside a regular contour line are at higher elevations than the contour line, and points outside a regular contour line are at lower elevations than the contour line.

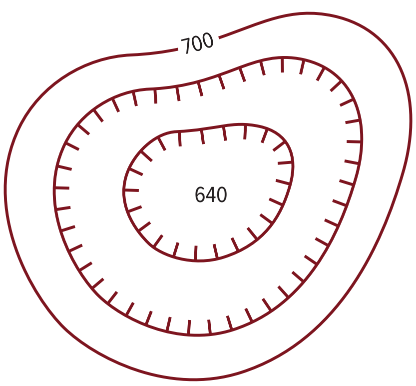


Figure 15 The depression contour lines shown here indicate that the center of the area has a lower elevation than the outer portion of the area. The short lines pointing inward are called hachures and indicate the direction of the elevation change.

Geologic Maps

A useful tool for a geologist is a geologic map. A **geologic map** is used to show the distribution, arrangement, and type of rocks located below the soil. A geologic map can also show features such as fault lines, bedrock, and geologic formations.

Using the information contained on a geologic map, combined with data from visible rock formations, geologists can infer how rocks might look below Earth's surface. They can also gather information about geologic trends, based on the type and distribution of rock shown on the map.

Geologic maps are most often superimposed over topographic maps and color coded by the type of rock formation, as shown in the map of the Grand Canyon in **Figure 16.** Each color corresponds to the type of rock present in a given area. Symbols are used to represent mineral deposits and other structural features. The key under the map shows what the colors and symbols represent.

Study the map shown in **Figure 16** closely. Notice the abundance of Older Precambrian rock formations in the Grand Canyon. These rock formations formed relatively early in Earth's geologic past. Extensive uplift and erosion by water and wind have resulted in the exposure of these ancient rocks.

Three-dimensional maps

Topographic and geologic maps are two-dimensional models of Earth’s surface. They are flat, so symbols, numbers, and lines must be used to interpret Earth’s features. Sometimes, scientists need to visualize Earth three-dimensionally. For example, they may want to study the path of a river down a mountain. To do this, scientists often rely on computers to digitize features such as rivers, mountains, valleys, and hills, creating three-dimensional maps. Refer to **Table 2** on the following page to compare three-dimensional maps to the other maps you have learned about in this module.

Geologic Map of Grand Canyon

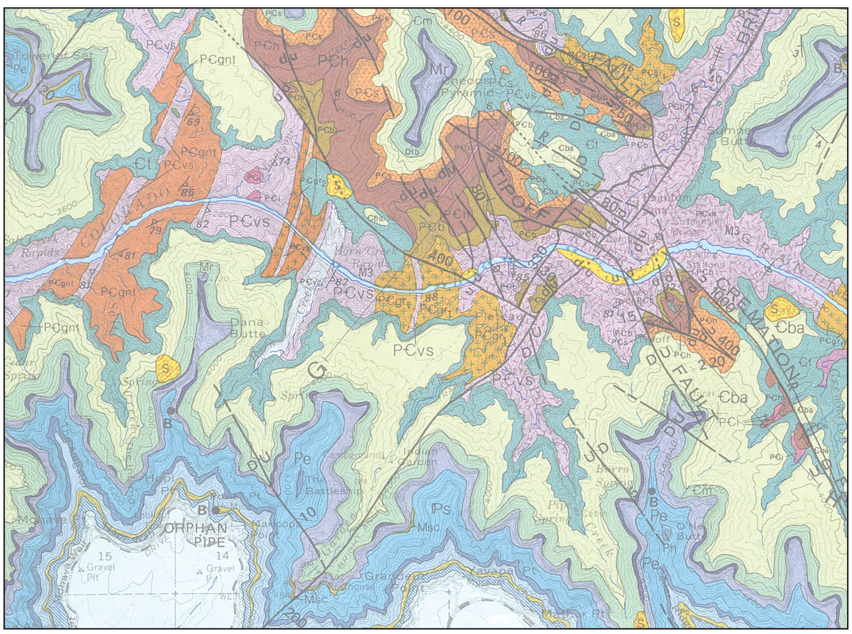


Figure 16 Geologic maps show the distribution of surface geologic features. This map of the Grand Canyon uses colors and symbols to distinguish different types of rock.

QUATERNARY
- S — Landslides and rockfalls
- r — River sediment

PERMIAN
- Pk — Kaibab Limestone
- Pt — Toroweap Formation
- Pc — Coconino Sandstone
- Ph — Hermit Shale
- Pe — Esplanade Sandstone

PENNSYLVANIAN
- Ps — Supai Formation

MISSISSIPPIAN
- Mr — Redwall Limestone

DEVONIAN
- Dtb — Temple Butte Limestone

CAMBRIAN
- Ꞓm — Muav Limestone
- Ꞓba — Bright Angel Shale
- Ꞓt — Tapeats Sandstone

YOUNGER PRECAMBRIAN
- PꞒi — Diabase sills and dikes
- PꞒs — Shinumo Quartzite
- PꞒh — Hakatai Shale
- PꞒb — Bass Formation

OLDER PRECAMBRIAN
- PꞒgr — Zoroaster Granite
- PꞒgnt — Trinity Gneiss
- PꞒvs — Vishnu Schist

Table 2 **Types of Maps and Projections**

Map or Projection	Common Uses	Distortions
Mercator projection	ship navigation	The land near the poles is distorted.
Conic projection	road and weather maps	The areas at the top and the bottom of the map are distorted.
Gnomonic projection	great circle routes	The direction and distance between land-masses are distorted.
Topographic map	show elevation changes on a flat projection	It depends on the type of projection used.
Geologic map	show the types of rocks present in a given area	It depends on the type of projection used.
Three-dimensional map	aid in conceptualizing geologic structures and processes	It depends on the type of projection used.

Map Legends

Most maps include both human-made and natural features located on Earth's surface. These features are represented by symbols, such as black dotted lines for trails, solid red lines for highways, and small black squares and rectangles for buildings. A **map legend,** such as the one shown in **Figure 17,** explains what the symbols represent.

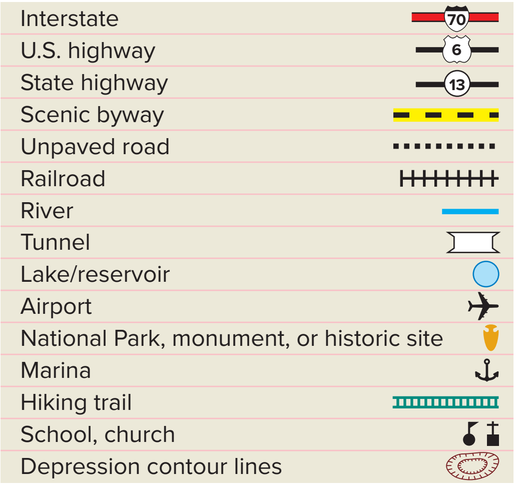


Figure 17 Map legends explain what the symbols on maps represent.

Get It?

Identify You see a blue line on a map. Which feature on Earth's surface does this represent?

Map Scales

When using a map, you need to know how to measure distances. This is accomplished by using a map scale. A **map scale** is the ratio between distances on a map and actual distances on the surface of Earth. Normally, map scales are measured in SI units, such as kilometers and centimeters, but sometimes they are measured in different units, such as miles and inches. There are three types of map scales: verbal scales, graphic scales, and fractional scales.

Verbal scales

To express distance as a statement, such as "one centimeter is equal to one kilometer," Earth scientists use verbal scales. The verbal scale, in this example, means that one centimeter on the map represents one kilometer on Earth's surface.

Graphic scales

Instead of stating the map scale in words, graphic scales consist of a line that represents a certain distance, such as 5 km or 5 miles. The line is labeled and divided into sections with hash marks, with each section representing a distance on Earth's surface. For instance, a graphic scale of 5 km might be divided into five sections, with each section representing 1 km. Graphic scales are the most common type of map scale.

Get It?

Infer why an Earth scientist might use different types of scales on different types of maps.

Fractional scales

Fractional scales express distance as a ratio, such as 1:63,500. This means that one unit of distance on the map represents 63,500 units of distance on Earth's surface. One centimeter on a map, for instance, would be equivalent to 63,500 centimeters on Earth's surface. Any unit of distance can be used in fractional scales, but the units on each side of the ratio must always be the same.

A large ratio indicates that the map represents a large area, while a small ratio indicates that the map represents a small area. Therefore, a map with a large fractional scale, such as 1:100,000 km, would show less detail than a map with a small fractional scale, such as 1:1000 km.

Check Your Progress

Summary

- Latitude lines run parallel to the equator. Longitude lines run vertically, wrapping around Earth and meeting at the North and South Poles.
- Both latitude and longitude lines are necessary to locate exact places on Earth.
- Earth is divided into 24 time zones, each 15° wide.
- Different types of map projections are used for different purposes.
- Geologic maps help Earth scientists study large-scale patterns in geologic formations.
- Maps often include a map legend for interpreting map symbols and a map scale for determining distances.

Demonstrate Understanding

1. **Explain** why it is important to include both latitude and longitude when giving coordinates.
2. **Describe** how the distance of a degree of longitude varies from the equator to the poles.
3. **Compare and contrast** Mercator and gnomonic projections. What are these projections commonly used for?
4. **Describe** what it would be like to fly from where you live to Paris, France. How many time zones would you cross? What would it be like to adjust to the time difference?

Explain Your Thinking

5. **Evaluate** If you were flying directly south from the North Pole and reached 70°N, how many degrees of latitude would be between you and the South Pole?
6. **Model** how a conic projection is made. Why is this type of projection best suited for small areas?
7. **WRITING Connection** Suppose you are a city planner. Explain how a geologic map could help you decide where to build a city park.

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LESSON 3
REMOTE SENSING

FOCUS QUESTION

What tools do we use to map Earth?

Landsat Satellite

Advanced technology has changed the way maps are made. The process of gathering data about Earth using instruments mounted on satellites, airplanes, or ships is called **remote sensing.**

One form of remote sensing uses satellites. Features on Earth's surface, such as rivers and forests, radiate warmth at slightly different frequencies. **Landsat satellites** record reflected wavelengths of energy from Earth's surface. To obtain images such as the one in **Figure 18,** each Landsat satellite is equipped with a moving mirror that scans Earth's surface. This mirror has rows of detectors that measure the intensity of energy received from Earth. Computers then convert this information into digital images that show landforms in great detail.

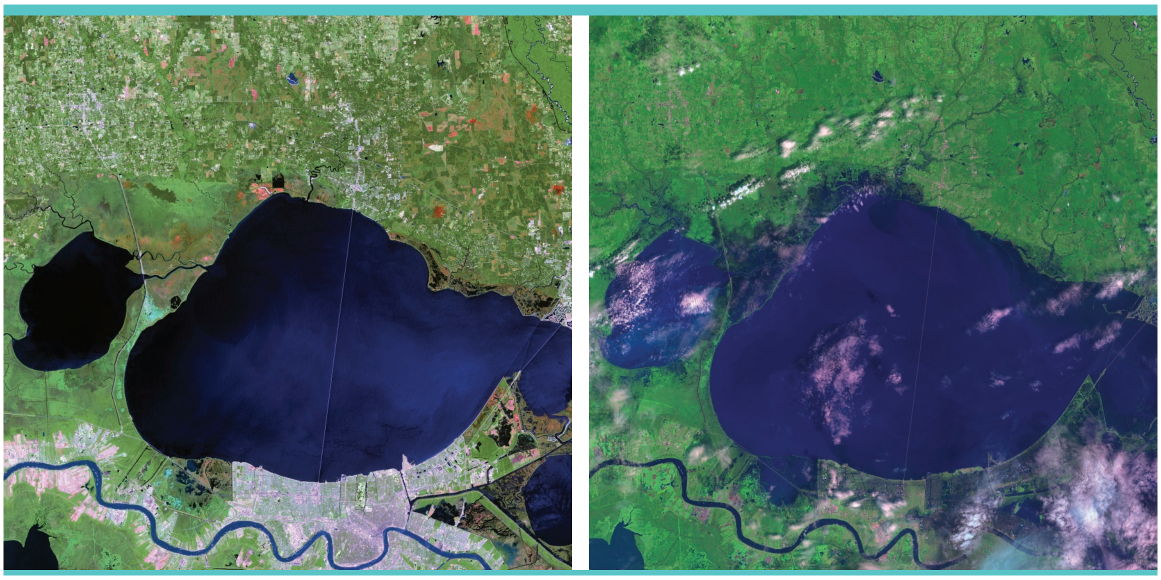


Figure 18 Landsat satellites are used to study pollution, the movements of Earth's plates, and the melting of glaciers and ice caps. They are also used to aid in natural disaster relief planning. Notice the differences between the two Landsat photos of New Orleans.

Interpret *Which image was taken after Hurricane Katrina in 2005? Explain.*

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Review the News

Obtain information from a current news story about current remote sensing research. Evaluate your source and communicate your findings to your class.

Revisit the Encounter the Phenomenon Question

What information from this lesson can help you answer the Unit and Module questions?

OSTM/Jason Satellites

One satellite that uses radar to measure and map sea surface height is the *OSTM/Jason-3* satellite. **OSTM** stands for **O**cean **S**urface **T**opography **M**ission and is a follow-on to the *TOPEX/Poseidon, Jason-1,* and *Jason-2* satellites. Radar uses high-frequency signals that are transmitted from the satellite to the surface of the ocean. A receiving device then picks up the returning echo as it is reflected off the water.

The distance to the water's surface is calculated using the known speed of light and the time it takes for the signal to be reflected. These data are used to make images, such as the one in **Figure 19,** that are important for measuring variations in sea level and monitoring changes in global ocean currents and heat transfer. A rise in regional or global sea level is often caused by the melting of ice sheets and glaciers, which is associated with climate change. A rise in ocean surface temperatures is also indicative of climate change.

Using *OSTM/Jason* satellite data, scientists are able to accurately estimate global sea level to within a few millimeters. Scientists can use these data combined with other existing data to create maps of ocean-floor features. For instance, ocean water bulges over sea-floor mountains and forms depressions over seafloor valleys.

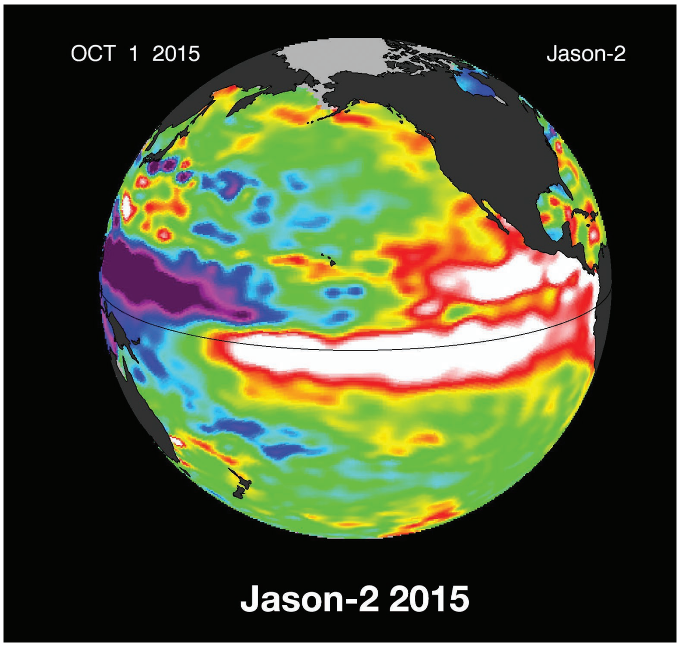


Figure 19 This image, which focuses on the Pacific Ocean, was created with data from *OSTM/Jason-2*. The red color along the equator shows the rise in ocean depth and temperature (relative to normal) during an El Niño event.

SeaBeam

SeaBeam technology is also used to map the ocean. **Figure 20** shows an example of a map created with information gathered with SeaBeam technology. To map ocean-floor features, SeaBeam relies on **sonar,** which is the use of sound waves to detect and measure objects underwater.

First, to gather the information needed to map the seafloor, a sound wave is sent from a ship toward the ocean floor. A receiving device then picks up the returning echo when it bounces off the seafloor.

Computers on the ship calculate the distance from the ship to the ocean floor using the speed of sound in water and the time it takes for the sound to be reflected. SeaBeam technology is used by fishing fleets; deep-sea drilling operations; and scientists such as oceanographers, volcanologists, and archaeologists. See **Figure 21** for a history of mapping technology.

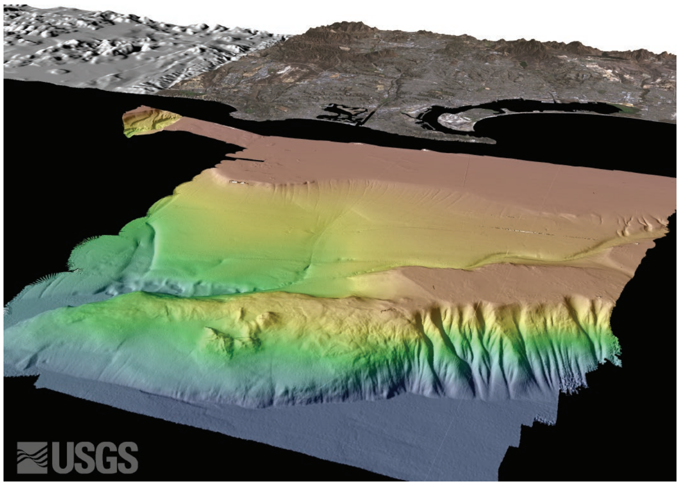


Figure 20 This offshore image of an area near San Diego, CA, was created with data from SeaBeam. The change in color indicates a change in elevation. The red-orange colors are the highest elevations, and the blue colors are the lowest.

Figure 21

Mapping Technology

Advances in mapping have relied on technological developments.

1 **1300 B.C.** An ancient Egyptian scribe draws the oldest surviving topographical map.

2 **150 B.C.** The ancient Greek scientist Ptolemy creates the first map using a coordinate grid. It depicts Earth as a sphere and includes Africa, Asia, and Europe.

3 **A.D. 1154** Arab scholar Al-Idrisi creates a world map used by European explorers for several centuries. Earlier medieval maps showed Jerusalem as the center of a flat world.

4 **1569** Flemish geographer Gerhardus Mercator devises a way to project the globe onto a flat map using lines of longitude and latitude.

5 **1752** A French cartographer first uses contour lines to represent elevation and marine depth for sailors exploring the New World.

6 **1875** American governess Ellen Eliza Fitz invents a method to mount a globe that shows the position of the Sun and the length of nights and days.

7 **1966** Harvard University researchers develop the first computerized grid-based mapping system, the forerunner of GIS.

8 **2000** Space shuttle *Endeavour* collects the most complete topographical data of Earth, mapping almost 80 percent of Earth's land surface.

9 **2016** *OSTM/Jason-3* launches. The satellite measures the height of the ocean's surface to help scientists study climate change.

1 2 3 4 5 6 7 8 9

The Global Positioning System

The **Global Positioning System (GPS)** is a satellite navigation system that allows users to locate their approximate position on Earth. There are at least 24 satellites orbiting Earth for use with GPS units. The satellites are positioned around Earth and are constantly orbiting so that signals from at least three or four satellites can be picked up at any given moment by a GPS receiver.

You need a GPS receiver to find your location on Earth. The receiver calculates your approximate latitude and longitude—usually within 10 m—by processing the signals emitted by the satellites. If enough information is present, these satellites can also relay information about elevation, direction of movement, and speed. With signals from three satellites, a GPS receiver can calculate locations on Earth without elevation, while four satellite signals will allow a GPS receiver to also calculate elevation. For more information on how the satellites are used to determine location, see **Figure 22** on the next page.

Uses for GPS technology GPS technology is used extensively for navigation by airplanes and ships. However, it is also used to help detect earthquakes, create maps, and track wildlife.

GPS technology also has many applications for everyday life. GPS receivers are often placed in cars to help navigate to preprogrammed destinations such as restaurants, hotels, and homes. Portable, handheld GPS systems are also used in hiking, biking, and other travels. They allow for finding destinations more quickly and can help in determining specific locations on a map. Cell phones may also contain GPS systems that aid in finding locations.

The Geographic Information System

The **Geographic Information System (GIS)** combines many of the traditional types and styles of mapping described in this module. GIS mapping uses a database of information gathered by scientists, professionals, and students like you from around the world to create layers, or "themes," of information that can be placed one on top of the other to create a comprehensive map. These "themes" are often maps that were created with information gathered by remote sensing.

Scientists from many disciplines use GIS technologies. A geologist might use GIS mapping when studying a volcano to help track historical eruptions. An ecologist might use GIS mapping to track pollution or to follow animal or plant population trends of a given area.

Get It?

Compare applications for GPS and GIS technology. Give an example of how you would use each type of technology in a scientific investigation.

ACADEMIC VOCABULARY

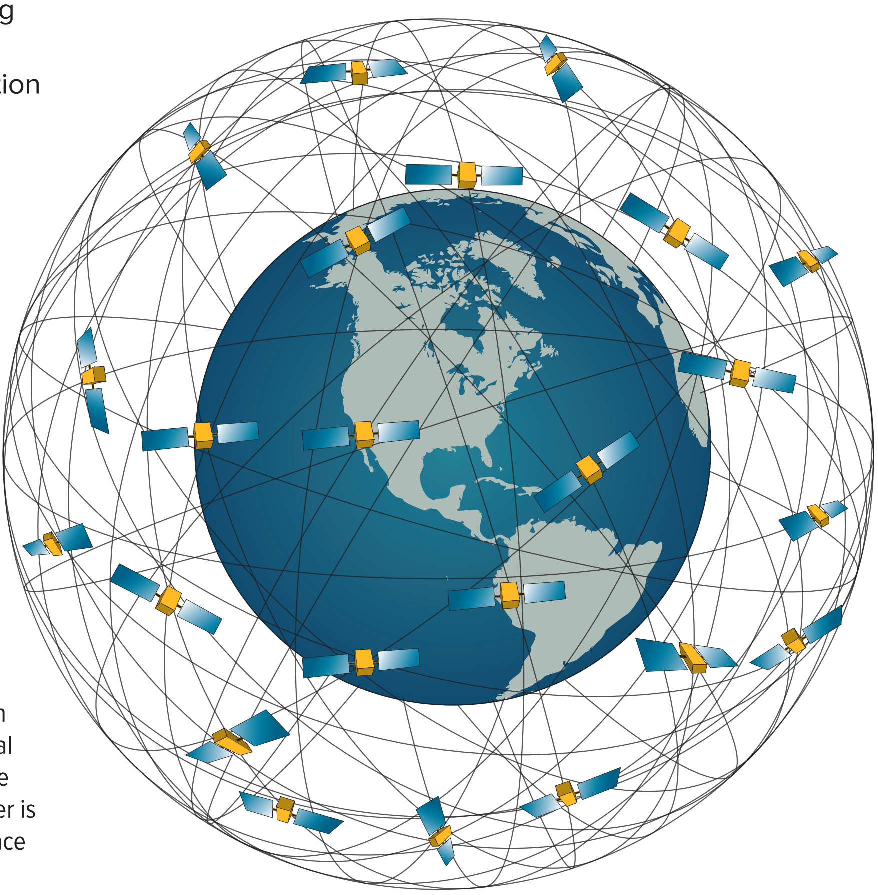
comprehensive

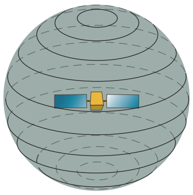
covering completely or broadly

The teacher gave the students a comprehensive study guide for the final exam.

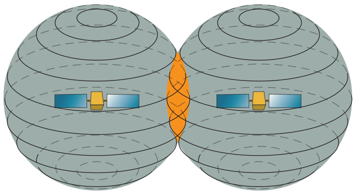
Figure 22 Visualizing GPS Satellites

GPS receivers detect signals from a core group of at least 24 GPS satellites orbiting Earth. Using signals from at least three satellites, the receiver can calculate location to within 10 m.

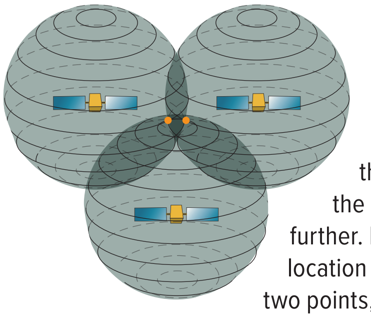




First, a GPS receiver, located in New York City, receives a signal from one satellite. The distance from the satellite to the receiver is calculated. Suppose the distance is 20,000 km. This limits the possible location of the receiver to anywhere on a sphere 20,000 km from the satellite.



Next, the receiver measures the distance to a second satellite. Suppose this distance is calculated to be 21,000 km away. The location of the receiver has to be somewhere within the area where the two spheres intersect, shown here in orange.



Finally, the distance to a third satellite is calculated. Using this information, the location of the receiver can be narrowed even further. By adding a third sphere, the location can be calculated to be one of two points, as shown. Often one of these points can be rejected as an improbable or impossible location.

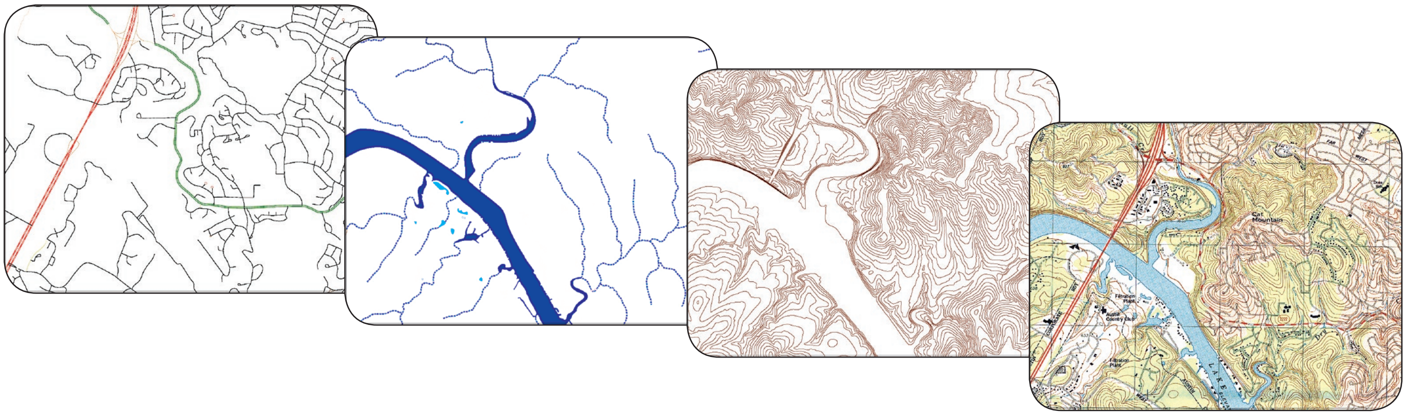


Figure 23 GIS mapping involves layering one map on top of another. In this image, you can see how one layer builds on the next.

GIS maps might contain many layers of information compiled from different types of maps, such as a geologic map and a topographic map. As shown in **Figure 23,** maps of rivers, topography, roads, cities, and other notable landforms from the same geographic area can be layered on top of each other to create one comprehensive map.

In addition, GIS can interpret aerial photographs and data from spreadsheets, such as population trends. Digital images from satellites can also be incorporated into the system to produce a comprehensive map. GIS and other technologies increase the ability of scientists to model, predict, and manage current and future impacts of human activities.

Check Your Progress

Summary

- Remote sensing is an important part of modern cartography.
- Satellites are used to gather data about features on Earth's surface.
- Sonar is also used to gather data about features on Earth's surface.
- GPS is a navigational tool that is now used for many everyday applications.
- GIS mapping uses different databases to create comprehensive maps.

Demonstrate Understanding

1. **Describe** how remote sensing works and why it is important to cartography.
2. **Apply** Why is GPS navigation important to Earth scientists?
3. **Compare and contrast** SeaBeam images with *OSTM/Jason-2* images and how each might be used.
4. **Predict** why it might be important to be able to add and subtract map layers, as with GIS mapping.

Explain Your Thinking

5. **Infer** How could GIS mapping be helpful in determining where to build a housing development?
6. **Explain** why it is important to have maps of the ocean floor, such as those gathered with SeaBeam technology.
7. **WRITING Connection** The impact of human activities on Earth's systems is greater than ever. Explain how remote sensing can help scientists reduce the impact of human activities.

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U.S. Geological Survey

A Bird's-Eye View of Disasters

Uncrewed aerial vehicles (UAVs), more commonly known as drones, are changing how governments respond to disasters such as hurricanes and earthquakes. Drones can be deployed quickly, can fly into places that are not safe or accessible to humans, and are less expensive than traditional aircraft. The data that drones gather are used to coordinate disaster relief and plan rebuilding.

After Hurricane Maria hit Puerto Rico in 2017, a drone captured this image of a destroyed road.

Assistance from Above

One might wonder how such small aircraft can make a difference in a large-scale disaster. The key is their versatility and flexibility. Drones do not need an airstrip to take off. They can be in the air almost immediately after a disaster, and they can fly long distances on battery power. Drones are equipped with cameras that first responders use to locate obstacles—such as crumpled roads and bridges—that could impede them as they move into areas to help survivors.

Some drones are operated by pilots on the ground, while others use autonomous flight and coordination capability. Drones can gather information with neural network image recognition. To identify damage, they compare pre-disaster images of the affected area to what they are "seeing" now. Imaging drones can be deployed in a grid pattern so that no part of an area is missed. In addition, drones can concentrate on important sites, such as bridges, railways, and hospitals.

Drones Around the World

China uses drones to help first responders find survivors in collapsed buildings after earthquakes. In Africa, Malawi is testing the use of drones to deliver medical supplies to remote areas, and Rwanda transports blood supplies to hospitals via a drone network.

The United States used drones to survey damage in Texas, Florida, and Puerto Rico during the intense hurricane season of 2017. In that same year, Mexico used drones to assist its recovery from a 7.1-magnitude earthquake.

In the future, areas that experience frequent disasters could have sets of drones with secure power sources ready to use. After a disaster, these drones could be employed to survey the damage and to locate survivors.

ASK QUESTIONS TO CLARIFY

Brainstorm and write two questions you have about how drones can aid first responders in disaster areas. Use print or online sources to find answers. Present your research to your class.

MODULE 1

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 WHAT IS EARTH SCIENCE?

- Earth is divided into four main systems: the geosphere, hydrosphere, atmosphere, and biosphere.
- Earth systems are all dynamic and interactive.
- Identifying the interrelationships among Earth systems leads to specialties and subspecialties.
- Earth science has contributed to society and to the development of many items used in everyday life.

- astronomy
- meteorology
- geology
- oceanography
- environmental science
- geosphere
- atmosphere
- hydrosphere
- cryosphere
- biosphere

Lesson 2 UNDERSTANDING MAPS

- Latitude lines run parallel to the equator. Longitude lines run east and west of the prime meridian.
- Both latitude and longitude lines are necessary to locate exact places on Earth.
- Earth is divided into 24 time zones, each 15° wide.
- Different types of map projections are used for different purposes.
- Geologic maps help Earth scientists study large-scale patterns in geologic formations.
- Maps often include a map legend for interpreting map symbols and a map scale for determining distances.

- cartography
- equator
- latitude
- longitude
- prime meridian
- International Date Line
- Mercator projection
- conic projection
- gnomonic projection
- topographic map
- contour line
- contour interval
- geologic map
- map legend
- map scale

Lesson 3 REMOTE SENSING

- Remote sensing is an important part of modern cartography.
- Satellites and sonar are used to gather data about features on Earth's surface.
- GPS is a navigational tool that is now used for many everyday applications.
- GIS mapping uses different databases to create comprehensive maps.

- remote sensing
- Landsat satellite
- sonar
- Global Positioning System (GPS)
- Geographic Information System (GIS)

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

What can maps tell us about our world?

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

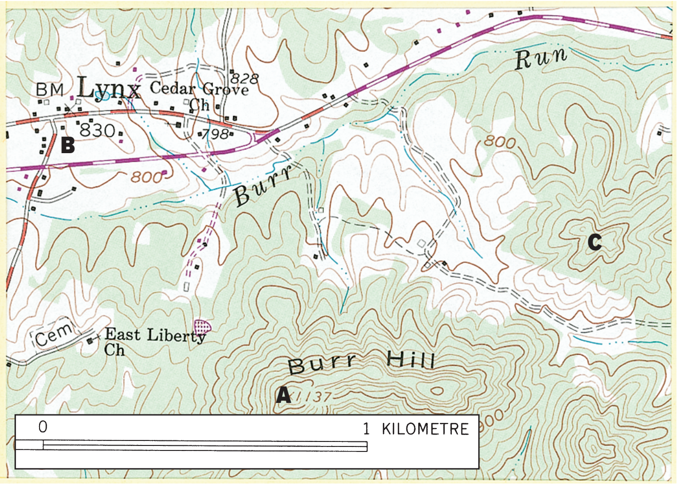
GO FURTHER

SEP Data Analysis Lab

How can you analyze changes in elevation?

Gradient refers to the steepness of a slope. To measure gradient, divide the change in elevation between two points on a map by the distance between the two points.

Data and Observations Use the map scale to determine the distance from Point A to Point B on the map. Convert your answers to SI units. Record the change in elevation.



CER Analyze and Interpret Data

1. **Claim** If you were to hike the distance from Point A to Point B, what would be the gradient of your climb?
2. **Reasoning** Would it be more difficult to hike from Point A to Point B or from Point B to Point C? Explain.
3. **Claim, Evidence** Between Point A and Point C, where is the steepest part of the hike? How do you know?

Carsten Peter/Speleoresearch & Films/National Geographic/Getty Images

UNIT 1

COMPOSITION OF EARTH

ENCOUNTER THE PHENOMENON

How did these crystals grow so large?

SEP Ask Questions

What questions do you have about the phenomenon? Write your questions on sticky notes and add them to the driving question board for this unit.

What are rocks and minerals made of?

Look for Evidence

As you go through this unit, use the information and your experiences to help you answer the phenomenon question as well as your own questions. For each activity, record your observations in a Summary Table, add an explanation, and identify how it connects to the unit and module phenomenon questions.

Solve a Problem

STEM UNIT PROJECT

Composition of Earth Investigate and research more about Earth's composition. Use the results of these investigations and the evidence you collected during the unit to complete your unit project.

GO ONLINE In addition to reading the information in your Student Edition, you can find the STEM Unit Project and other useful resources online.

tdub303/E+/Getty Images

MODULE 2

MATTER AND CHANGE

ENCOUNTER THE PHENOMENON

How do we find and remove harmful substances from our drinking water?

GO ONLINE to play a video about changing the pH of mine water.

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about how we find and remove harmful substances from our drinking water. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 2: Explore & Explain: Chemical Reactions

LESSON 2: Explore & Explain: Mixtures and Solutions

Smithsonian

Additional Resources

LESSON 1
MATTER

FOCUS QUESTION
What is water made of?

Atoms

Matter is anything that has volume and mass. Everything in the physical world that surrounds you is composed of matter. On Earth, matter usually occurs as a solid, a liquid, or a gas. All matter is made of substances called elements. An **element** is a substance that cannot be broken down into simpler substances by physical or chemical means. For example, gold, which is often used in jewelry, is so soft that it can be molded, hammered, sculpted, or drawn into wire. Whatever its size or shape, the gold is still gold. Gold is a type of element.

Each element has unique physical and chemical properties. Although aluminum has different properties from gold, both aluminum and gold are elements that are made up of atoms. All atoms consist of even smaller particles—protons, neutrons, and electrons. **Figure 1** shows one method of representing an atom. The center of an atom is called the nucleus (NEW klee us) (plural, *nuclei*). The **nucleus** of an atom is made up of protons and neutrons. A **proton** (p) is a tiny particle that has mass and a positive electric charge. A **neutron** (n) is a particle with approximately the same mass as a proton, but it is electrically neutral; that is, it has no electric charge. All atomic nuclei have positive charges because they are composed of protons with positive electric charges and neutrons with no electric charge.

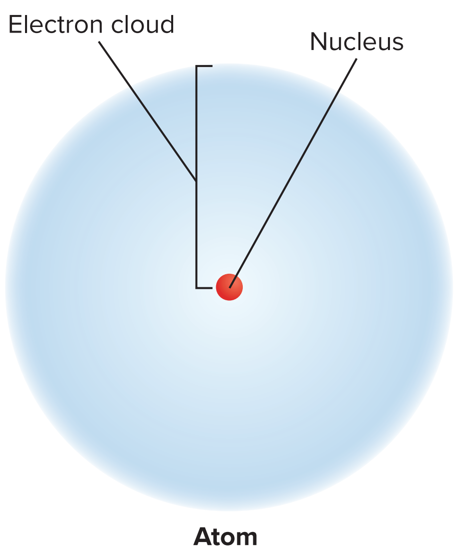


Figure 1 In this representation of an atom, the fuzzy area surrounding the nucleus is referred to as an electron cloud.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE
Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE
GO ONLINE to find these activities and more resources.

Quick Investigation: Identify Elements
Obtain and communicate information about the function and use of natural resources in your environment.

Virtual Investigation: Properties of Elements
Analyze and interpret data to identify elements by their properties.

PERIODIC TABLE OF THE ELEMENTS

Key: Atomic number: 1 · Symbol: H · Element: Hydrogen · Atomic mass: 1.008

Metal · Metalloid · Nonmetal · Synthetic

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.008																	2 He Helium 4.003
2	3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
3	11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.847	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.80
5	37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.82	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.60	53 I Iodine 126.904	54 Xe Xenon 131.290
6	55 Cs Cesium 132.905	56 Ba Barium 137.327	57 La Lanthanum 138.905	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium 208.982	85 At Astatine 209.987	86 Rn Radon 222.018
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium * (267)	105 Db Dubnium * (270)	106 Sg Seaborgium * (269)	107 Bh Bohrium * (270)	108 Hs Hassium * (277)	109 Mt Meitnerium * (278)	110 Ds Darmstadtium * (281)	111 Rg Roentgenium * (281)	112 Cn Copernicium * (285)	113 Nh Nihonium * (286)	114 Fl Flerovium * (289)	115 Mc Moscovium * (289)	116 Lv Livermorium * (293)	117 Ts Tennessine * (294)	118 Og Oganesson * (294)

The number in parentheses is the mass number of the longest-lived isotope for that element.

* Properties are largely predicted.

Lanthanide series	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.965	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinide series	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium * (252)	100 Fm Fermium * (257)	101 Md Mendelevium * (258)	102 No Nobelium * (259)	103 Lr Lawrencium * (262)

Figure 2 The periodic table of the elements is arranged so that a great deal of information about all of the known elements is provided in a small space.

Surrounding the nucleus of an atom are smaller particles called electrons. An **electron** (e^-) has little mass, but it has a negative electric charge that is exactly the same magnitude as the positive charge of a proton. When an atom has an equal number of protons and electrons, the electric charge of an electron cancels the positive charge of a proton, resulting in an atom that has no overall charge. Notice that the electrons in **Figure 1** are shown as a cloudlike region surrounding the nucleus. This is because electrons are in constant motion around an atom's nucleus, and their exact positions at any given moment cannot be determined.

Get It?

Describe the charges of the three atomic particles in a neutral atom.

Symbols for elements

There are 92 elements that occur naturally on Earth and in the stars. Other elements have been produced in laboratory experiments. Generally, each element is identified by a one-, two-, or three-letter abbreviation known as a chemical symbol. For example, the symbol H represents the element hydrogen, C represents carbon, and O represents oxygen. Elements identified in ancient times, such as gold and mercury, have symbols of Latin origin. For example, gold is identified by the symbol Au for its Latin name, *aurum,* and mercury is identified by the symbol Hg for its Latin name, *hydrargyrum.* All elements are classified and arranged according to their chemical properties in the periodic table of the elements, shown in **Figure 2.**

Mass number

The number of protons and neutrons in atoms of different elements varies widely. The lightest of all atoms is hydrogen, which has only one proton in its nucleus. The heaviest naturally occurring atom is uranium. Uranium-238 has 92 protons and 146 neutrons in its nucleus. The number of protons in an atom's nucleus is its **atomic number.** The sum of the protons and neutrons is its **mass number.** Because electrons have little mass, they are not included in determining mass number. For example, the atomic number of uranium is 92, and its mass number is 238 (92 protons + 146 neutrons). **Figure 3** illustrates how atomic numbers and mass numbers are listed in the periodic table of the elements.

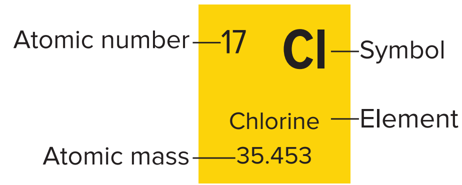


Figure 3 The element chlorine is atomic number 17.

Isotopes

Recall that all atoms of an element have the same number of protons. However, the number of neutrons of an element's atoms can vary. For example, all chlorine atoms have 17 protons in their nuclei, but they can have either 18 or 20 neutrons. This means that a chlorine atom could have a mass number of 35 (17 protons + 18 neutrons) or 37 (17 protons + 20 neutrons). Atoms of the same element that have the same number of protons but a different number of neutrons, and thus different mass numbers, are called **isotopes.** The element chlorine has two isotopes: Cl-35 and Cl-37. Because the number of electrons in a neutral atom equals the number of protons, isotopes of an element have the same chemical properties.

Look again at the periodic table in **Figure 2.** Scientists have measured the mass of atoms of elements. The atomic mass of an element is the average of the mass numbers of the isotopes of an element. Most elements are mixtures of isotopes. For example, notice in **Figure 2** that the atomic mass of chlorine is 35.453. This number is the average of the mass numbers of the naturally occurring isotopes of chlorine-35 and chlorine-37.

Radioactive isotopes

The nuclei of some isotopes are unstable and tend to break down. When this happens, the isotope also emits energy in the form of radiation. Radioactive decay is the spontaneous process through which unstable nuclei emit radiation. In the process of radioactive decay, a nucleus will either lose protons and neutrons, change a proton to a neutron, or change a neutron to a proton. Because the number of protons in a nucleus identifies an element, decay also changes the identity of an element. For example, the isotope polonium-218 decays at a steady rate over time into bismuth-214. The polonium originally present in a rock is gradually replaced by bismuth. The process of radioactive decay is often used to calculate the ages of rocks.

HISTORY Connection Some isotopes have played an important role in deciphering the history of ancient people. For example, carbon-14 (C-14), an isotope of carbon, can be used to date organic remains up to 60,000 years old. Testing of clothing, dried food, and even mummies have provided date ranges for the lifetimes of ancient people, plants, and animals. Carbon-14 is used for remains that are much more recent as well. In recent years, carbon-14 has been used to solve modern missing persons cases by dating found remains and comparing the ages to missing persons cases in the area. The technique is becoming so refined that some researchers claim that date of death and even year of birth, can be determined using carbon-14.

Electrons in Energy Levels

Although the exact position of an electron cannot be determined, scientists have discovered that electrons occupy areas called energy levels. Look again at **Figure 1** and the relative size of the nucleus compared to the electron cloud. The volume of an atom is mostly empty space. However, the size of an atom depends on the number and arrangement of its electrons.

Filling energy levels

Figure 4 presents a model to help you visualize atomic particles. Note that electrons are distributed over one or more energy levels in a predictable pattern. Keep in mind that the electrons are not sitting still in one place. Each energy level can hold only a limited number of electrons. For example, the smallest, innermost energy level can hold only two electrons, as illustrated by the oxygen atom in **Figure 4.** The second energy level is larger, and it can hold up to eight electrons. The third energy level can hold up to 18 electrons, and the fourth energy level can hold up to 32 electrons. Depending on the element, an atom might have electrons in as many as seven energy levels surrounding its nucleus.

Get It?

Analyze Look at **Figure 4.** How can you use the number of electrons in an aluminum atom to determine how many protons and neutrons are in its nucleus?

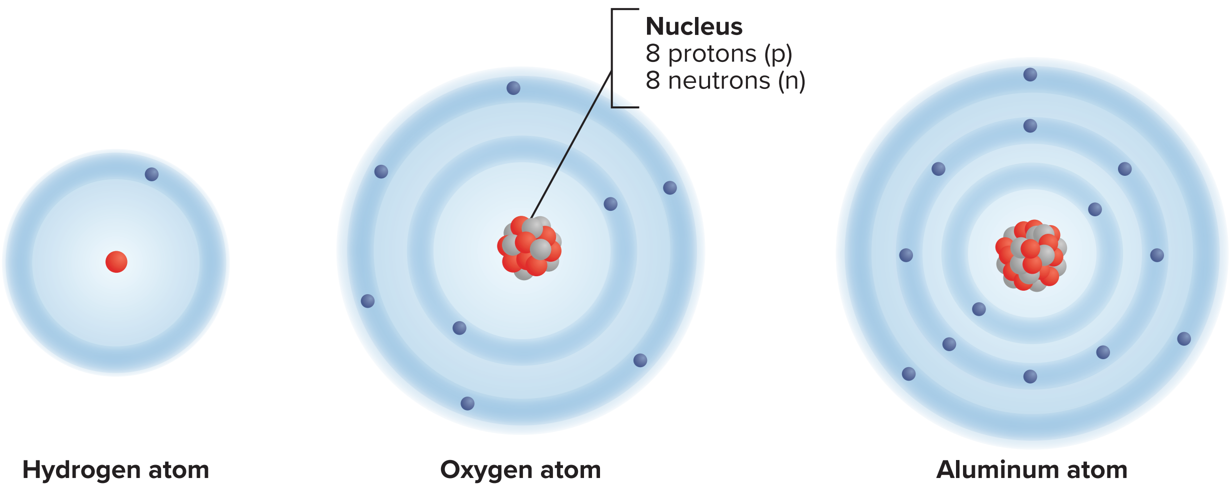
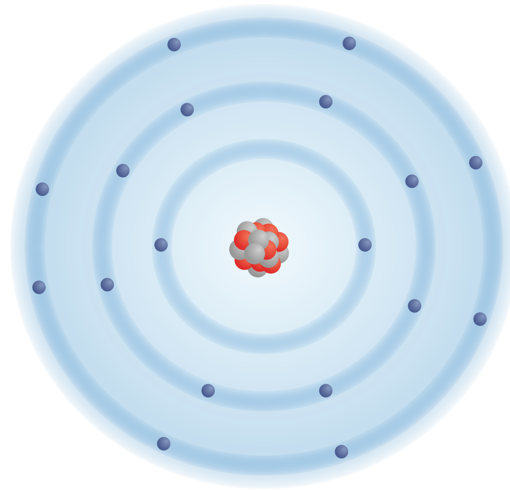


Figure 4 Electrons occupy one energy level in hydrogen, two energy levels in oxygen, and three energy levels in aluminum.

Valence electrons

The electrons in the outermost energy level determine the chemical behavior of an element. These outermost electrons are called valence electrons. Elements with the same number of valence electrons have similar chemical properties. For example, on the left side of the periodic table are sodium and potassium; they have different atomic numbers, but each has one valence electron. Thus, sodium and potassium exhibit similar chemical behavior. These elements are highly reactive metals, which means that they combine easily with many other elements. For example, sodium and potassium both combine easily with chlorine, making sodium chloride (NaCl), also known as table salt, and potassium chloride (KCl), a salt sometimes used to treat low levels of potassium in the blood.

On the right side of the periodic table are the noble gases. These elements, including helium and argon, have full outermost energy levels. For example, an argon atom, shown in **Figure 5,** has 18 electrons, with two electrons in the first energy level and eight electrons in the second and third (outermost) energy levels. Elements that have full outermost energy levels are highly unreactive. Compare this to the elements oxygen and hydrogen. These are also gases at room temperature, but they are highly flammable. Their outermost electron shells are not full so they readily react with other elements.



Argon atom

Figure 5 The inert nature of argon makes it an ideal gas to use inside an incandescent lightbulb because it does not react with the extremely hot filament.

Ions

Sometimes atoms gain or lose electrons from their outermost energy levels. Recall that atoms are electrically neutral when the number of electrons, which have negative charges, balances the number of protons, which have positive charges. An atom that gains or loses an electron has a net electric charge and is called an **ion.** In general, an atom in which the outermost energy level is less than half-full—that is, it has fewer than four valence electrons—tends to lose its valence electrons. When an atom loses valence electrons, it becomes positively charged. In chemistry, a positive ion is indicated by a superscript plus sign. For example, a sodium ion is represented by Na^+. If more than one electron is lost, that number is placed before the plus sign. For example, a magnesium ion, which forms when a magnesium atom has lost two electrons, is represented by Mg^{2+}.

Get It?

Explain what makes an ion positive.

An atom in which the outermost energy level is more than half-full—that is, it has more than four valence electrons—tends to fill its outermost energy level. Such an atom forms a negatively charged ion. Negative ions are indicated by a superscript minus sign. For example, a nitrogen atom that has gained three electrons is represented by N^{3-}. Some substances contain ions that are made up of groups of atoms—for example, silicate ions $(SiO_4)^{4-}$. These complex ions are important constituents of most rocks and minerals.

CCC CROSSCUTTING CONCEPTS

Patterns The periodic table of the elements is based on the very orderly nature of atoms and the particles that form them. Patterns can be observed across all of the periodic table. Using **Figure 5** as your guide, predict what the next atom will be if one more electron energy level is filled. How many protons, neutrons, and electrons will there be?

ACADEMIC VOCABULARY

exhibit

to show or display outwardly

The dog exhibited aggression by baring its teeth and growling.

Abundance of Elements

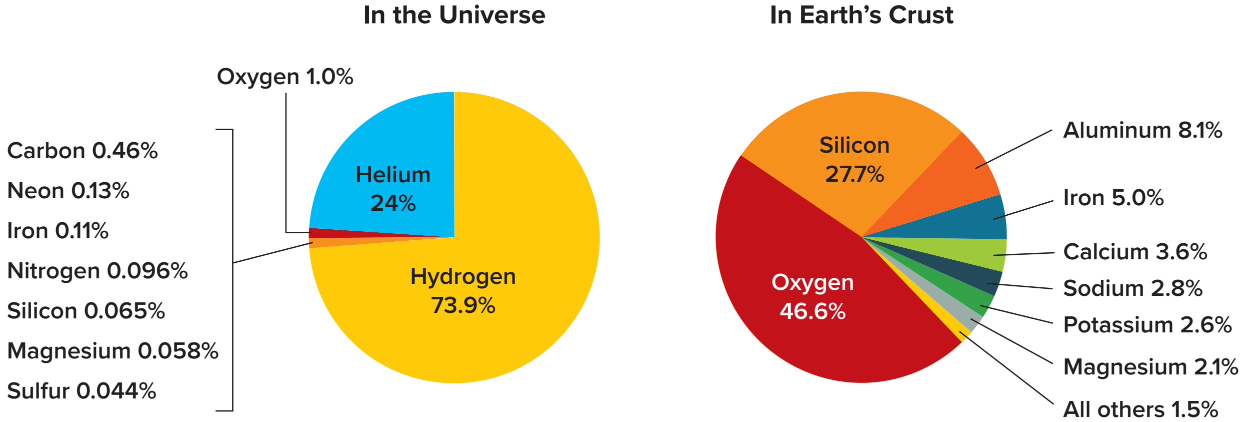


Figure 6 The most abundant elements in the universe are greatly different from the most abundant elements on Earth.

What elements are most abundant?

Astronomers have identified the two most abundant elements in the universe as hydrogen and helium. All other elements account for less than 1 percent of all atoms in the universe, as shown in **Figure 6.** Analyses of the composition of rocks and minerals on Earth indicate that the percentages of elements in Earth's crust differ from the percentages in the universe. As shown in **Figure 6,** 98.5 percent of Earth's crust is made up of only eight elements. Two of these elements, oxygen and silicon, account for almost 75 percent of the crust's composition. This means that most of the rocks and minerals on Earth's crust contain oxygen and silicon. Minerals that contain oxygen and silicon are called silicates. The next two most abundant elements in Earth's crust are aluminum and iron.

Check Your Progress

Summary

- Atoms consist of protons, neutrons, and electrons.
- An element consists of atoms that have a specific number of protons in their nuclei.
- Isotopes of an element differ by the number of neutrons in their nuclei.
- Elements with full outermost energy levels are highly unreactive.
- Ions are electrically charged atoms or groups of atoms.

Demonstrate Understanding

1. **Differentiate** among the three particles of an atom in terms of their location, charge, and mass.
2. **Infer** why the elements magnesium and calcium have similar properties.
3. **Illustrate** how a neutral atom becomes an ion.
4. **Compare and contrast** these isotopes: uranium-239, uranium-238, and uranium-235.

Explain Your Thinking

5. **Illustrate** a model of a calcium atom, including the number and position of protons, neutrons, and electrons in the atom.
6. **Interpret** the representation of magnesium in the periodic table. Explain why the atomic mass of magnesium is not a whole number.
7. **MATH Connection** As the radioactive isotope radium-226 decays, it emits two protons and two neutrons. How many protons and neutrons are now left in the nucleus? What is the atom's new atomic number? What is the name of this element?

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LESSON 2
COMBINING MATTER

FOCUS QUESTION

Why does water readily mix with other chemicals?

Compounds

Look at **Figure 7.** How can two dangerous elements combine to form a material that you sprinkle on your popcorn? Table salt is a compound, not an element. A **compound** is a substance that is composed of atoms of two or more different elements that are chemically combined. Water is another example of a compound because it is composed of two elements—hydrogen and oxygen. Most compounds have different properties from the elements of which they are composed. For example, both oxygen and hydrogen are highly flammable gases at room temperature, but in combination they form water—a liquid.

Chemical formulas

Compounds are represented by chemical formulas. These formulas include the symbol for each element followed by a subscript number that stands for the number of atoms of that element in the compound. If there is only one atom of an element, no subscript number follows the symbol. Thus, the chemical formula for table salt is NaCl. The chemical formula for water is H_2O.

Figure 7 Chlorine is a green, poisonous gas. Sodium is a silvery metal that is soft enough to cut with a knife. When they react, they produce sodium chloride, a white solid.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

GeoLAB: Precipitate Salt
Carry out an investigation to determine which factors affect salt solubility and precipitation.

Design Your Own: Rates of Chemical Reactions
Carry out an investigation to determine which factors affect a chemical reaction.

Covalent Bonds

Recall that an atom is chemically stable when its outermost energy level is full. A state of stability is achieved by some elements by forming chemical bonds. A **chemical bond** is the force that holds together the elements in a compound. One way in which atoms fill their outermost energy levels is by sharing electrons. For example, individual atoms of hydrogen each have just one electron. Each atom becomes more stable when it shares its electron with another hydrogen atom so that each atom has two electrons in its outermost energy level. **Figure 8** shows an example of this bond. How do these two atoms stay together? The nucleus of each atom has one proton with a positive charge, and the two positively charged protons attract the two negatively charged electrons. This attraction of two atoms for a shared pair of electrons that holds the atoms together is called a **covalent bond.**

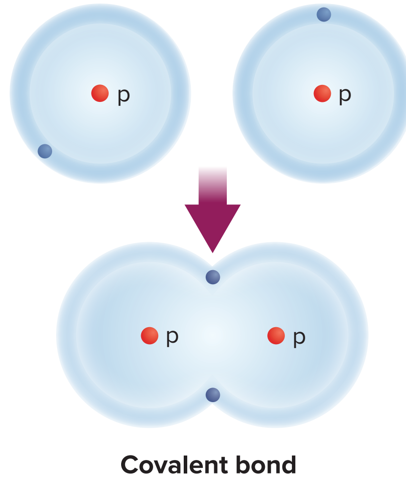


Figure 8 In this covalent bond example, notice the positions of the electrons in the outermost energy levels. They can now be considered as part of each atom.

Molecules

A **molecule** is composed of two or more atoms held together by covalent bonds. Molecules have no overall electric charge because the total number of electrons equals the total number of protons. Water is an example of a compound whose atoms are held together by covalent bonds, as illustrated in **Figure 9.** The chemical formula for a water molecule is H_2O because, in this molecule, two atoms of hydrogen, each of which need to gain an electron to become stable, are combined with one atom of oxygen, which needs to gain two electrons to become stable. A compound comprised of molecules is called a molecular compound.

Polar molecules

Although water molecules are held together by covalent bonds, the atoms do not share the electrons equally. As shown in **Figure 9,** the shared electrons in a water molecule are attracted more strongly by the oxygen atom than by the hydrogen atoms. As a result, the electrons spend more time near the oxygen atom than they do near the hydrogen atoms. This unequal sharing of electrons results in polar molecules. A polar molecule has a slightly positive end and a slightly negative end.

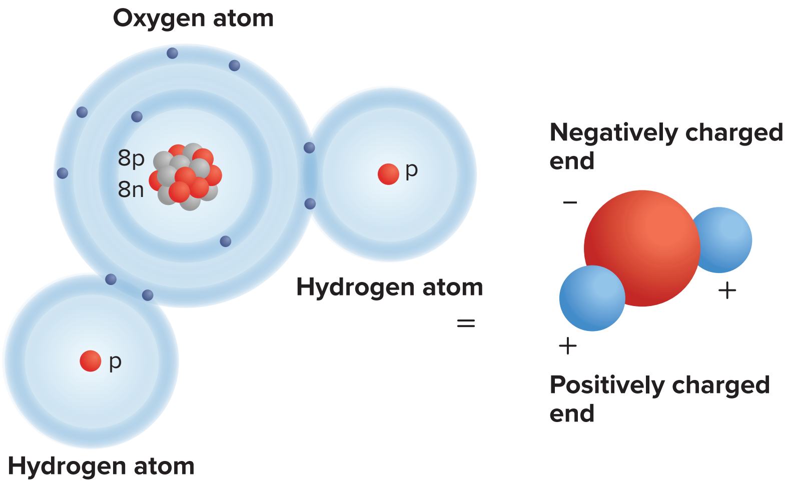


Figure 9 Polar molecules are similar to bar magnets. At one end of a water molecule, the hydrogen atoms have a positive charge, while at the opposite end, the oxygen atom has a negative charge.

Ionic Bonds

As you might expect, positive and negative ions attract each other. An **ionic bond** is the attractive force between two ions of opposite charge. **Figure 10** illustrates an ionic bond between a positive ion of sodium and a negative ion of chlorine, called chloride. The chemical formula for common table salt is NaCl, which consists of equal numbers of sodium ions (Na^+) and chloride ions (Cl^-). Note that positive ions are always written first in chemical formulas.

Within the compound NaCl, there are as many positive ions as negative ions; therefore, the positive charge on the sodium ion equals the negative charge on the chloride ion, and the net electric charge of the compound NaCl is zero. Magnesium and oxygen ions combine in a similar manner to form the compound magnesium oxide (MgO)—one of the most common compounds on Earth. Compounds formed by ionic bonding are called ionic compounds. Other ionic compounds have different proportions of ions. For example, oxygen and sodium ions combine in the ratio shown by the chemical formula for sodium oxide (Na_2O), in which there are two sodium ions to each oxygen ion.

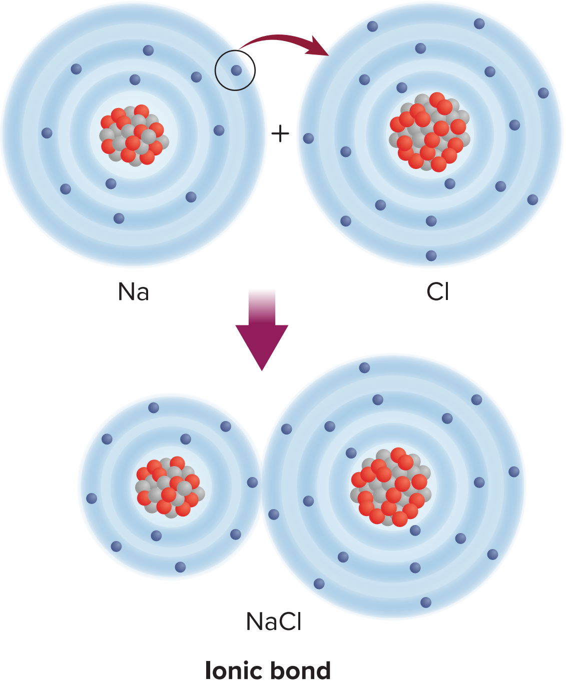


Figure 10 The single valence electron in a sodium atom is used to form an ionic bond with a chlorine atom. Once an ionic bond is formed, the negatively charged ion is slightly larger than the positively charged ion.

Metallic Bonding

Most compounds on Earth are held together by ionic or covalent bonds, or by a combination of these bonds. Another type of bond is shown in **Figure 11.** In metals, the valence electrons are shared by all the atoms, not just by adjacent atoms, as they are in covalent compounds. You could think of a metal as a group of positive ions surrounded by a sea of freely moving negative electrons. The positive ions of the metal are held together by the attraction to the negative electrons between them. This type of bond, known as a **metallic bond,** allows metals to conduct electricity because the electrons can move freely throughout the entire solid metal.

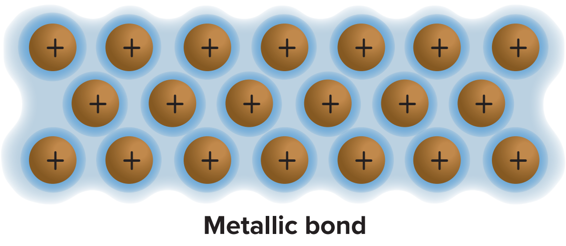


Figure 11 Metallic bonds are formed when valence electrons are shared equally among all the positively charged atoms. Because the electrons flow freely among the positively charged ions, you can visualize electricity flowing through electrical wires.

Get It?
Explain the difference between covalent, ionic, and metallic bonds.

SCIENCE USAGE v. COMMON USAGE

polar

Science usage: the unequal sharing of electrons

Common usage: locations of or near the North or South Pole, or the ends of a magnet

Metallic bonding also explains why metals are so easily deformed. When a force, such as the blow of a hammer, is applied to a metal the electrons are pushed aside. This allows the metal ions to move past each other, thus deforming or changing the shape of the metal. **Figure 13** summarizes how valence electrons are used to form the three different types of bonds.

Figure 12 When a copper wire is placed in a solution of silver nitrate in the beaker, a chemical reaction occurs in which silver replaces copper in the wire, and an aqua-colored copper nitrate solution forms.

Chemical Reactions

You have learned that atoms gain, lose, or share electrons to become more stable and that these atoms form compounds. Sometimes, compounds break down into simpler substances. The change of one or more substances into other substances, such as those in **Figure 12,** is called a **chemical reaction.** Chemical reactions are described by chemical equations. For example, water (H_2O) is formed by the chemical reaction between hydrogen gas (H_2) and oxygen gas (O_2). The formation of water can be described by the following chemical equation.

$$2H_2 + O_2 \rightarrow 2H_2O$$

You can read this chemical equation as "two molecules of hydrogen and one molecule of oxygen react to yield two molecules of water." In this reaction, hydrogen and oxygen are the reactants, and water is the product. When you write a chemical equation, you must balance the equation by showing an equal number of atoms for each element on each side of the equation. Therefore, the same amount of matter is present both before and after the reaction. Note that there are four hydrogen atoms on each side of the above equation ($2 \times 2 = 4$). There are also two oxygen atoms on each side of the equation.

Another example of a chemical reaction, one that takes place between iron (Fe) and oxygen (O), is represented by the following chemical equation.

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

Chemical reactions also occur when materials dissolve. Water is often called the universal solvent because so many of Earth's materials dissolve readily in it. For example, NaCl is a common mineral in Earth's crust. It dissolves quickly in water, which often leads to changes in the rock and mineral composition at Earth's surface.

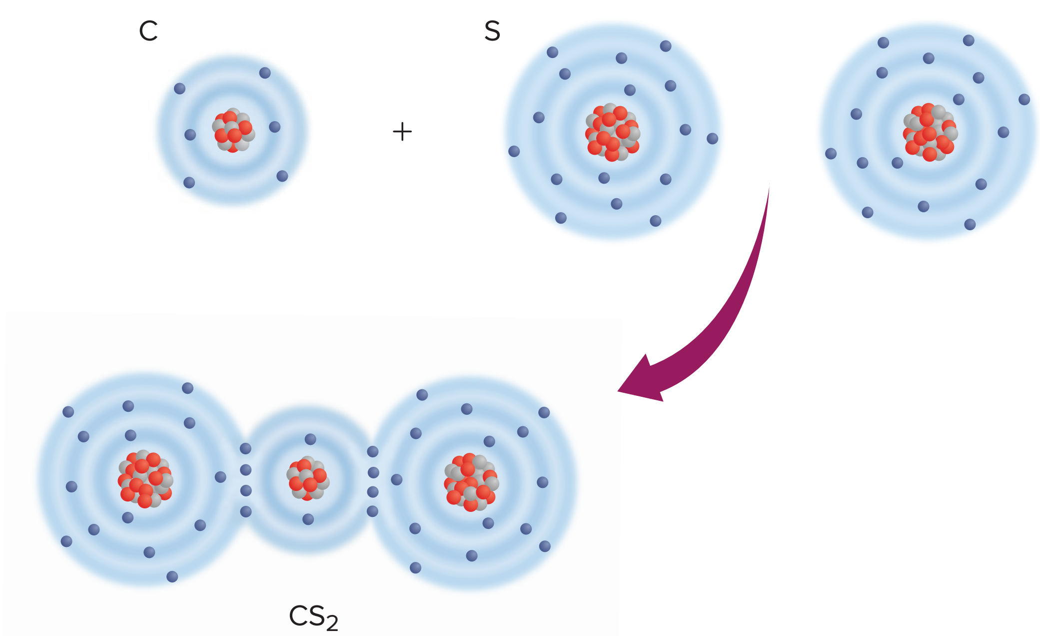
STEM CAREER Connection

Electroplate Technician

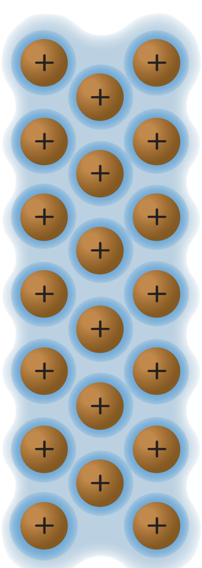
No one can turn straw into gold. But electroplate technicians can make substances look like gold. When an electrical current is passed through a solution of carefully chosen chemicals, a chemical reaction occurs, and a thin metal layer is attached to the surface of the object being coated. In the case of jewelry, the piece could appear to be made out of gold or silver. Electroplating is also used to protect metals from corrosion, to prevent rust from forming, and, in the case of space suit helmets, to protect astronauts' eyes from solar radiation.

Figure 13 Visualizing Bonds

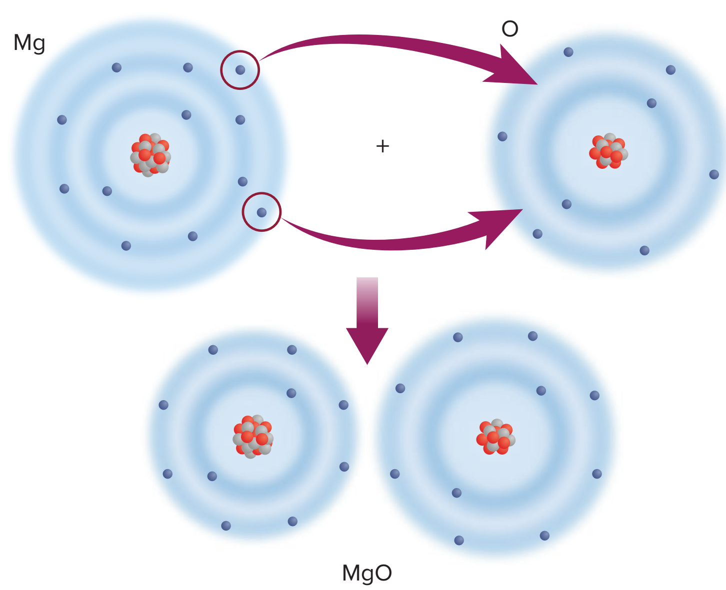
Atoms gain stability by sharing, gaining, or losing electrons to form ions and molecules. The properties of metals can be explained by metallic bonds.



Covalent bond Shared electrons fill outermost energy levels and make stable molecular compounds.



Metallic bond Within metals, valence electrons move freely around positively charged ions.



Ionic bond Once valence electrons are gained or lost to fill outermost energy levels and form stable ions, the oppositely charged ions are attracted to each other.

Mixtures and Solutions

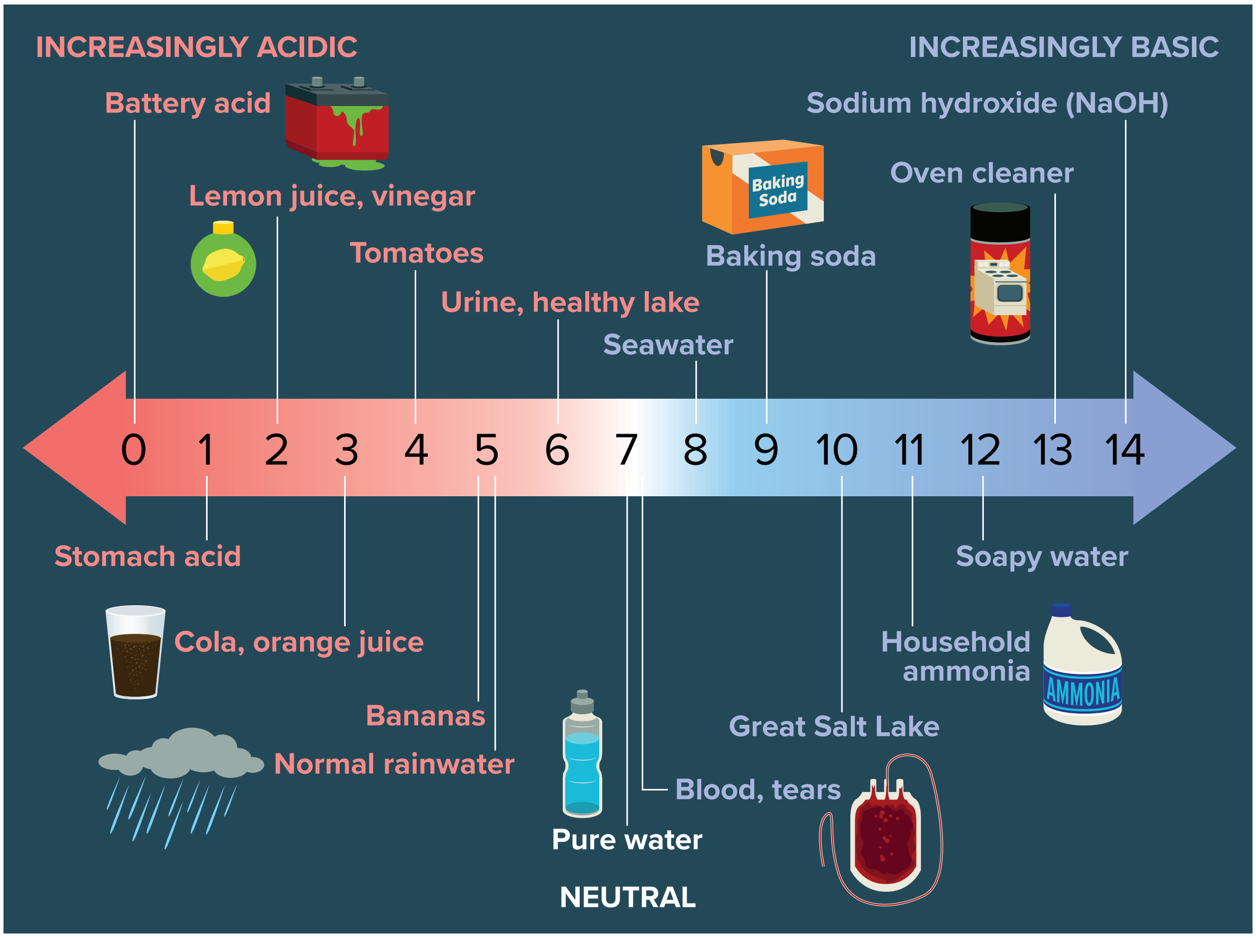
Unlike a compound, in which the atoms combine and lose their identities, a mixture is a combination of two or more components that retain their identities. When a mixture's components are easily recognizable, it is called a heterogeneous mixture. For example, beach sand, shown in **Figure 14,** is a heterogeneous mixture because its components—shells, small pieces of broken shells, grains of minerals, and so on—are still recognizable. In a homogeneous mixture, which is also called a **solution,** the component particles cannot be distinguished from each other, even though they still retain their original properties.

Figure 14 Not all mixtures of beach sand and shells are alike. Mixtures from the Atlantic Ocean contain components that are different from mixtures that form in the Pacific Ocean.

A solution can be liquid, gaseous, or solid. Seawater is a solution consisting of water molecules and ions of many elements that exist on Earth. Molten rock is also a liquid solution; it is composed of ions representing all atoms that were present in the solid rock before it melted. Air is a solution of gases, mostly nitrogen and oxygen molecules mixed with other atoms and molecules. Metal alloys, such as bronze and brass, are also solutions. Bronze is a homogeneous mixture of copper and tin atoms; brass is a similar mixture of copper and zinc atoms. Such solid homogeneous mixtures are called solid solutions.

Get It?

Describe three examples of solutions.



kosmos111/iStock/Getty Images

Figure 15 The pH scale is not only relevant to science class. All substances have a pH value, as you can see by the common household substances shown here.

Acids

Many chemical reactions on Earth involve acids and bases. An **acid** is a solution containing a substance that produces hydrogen ions (H^+) in water. A hydrogen atom has one proton and one electron. When a hydrogen atom loses its electron, it becomes a hydrogen ion (H^+). The pH scale, shown in **Figure 15,** is based on the amount of hydrogen ions in a solution, referred to as the concentration. A value of 7 is considered neutral; distilled water usually has a pH of 7. A solution with a pH value below 7 is considered to be acidic. The lower the number, the more acidic the solution.

The most common acid on Earth is carbonic acid (H_2CO_3). It is produced when carbon dioxide (CO_2) is dissolved in water (H_2O) by the following reaction.

$$H_2O + CO_2 \rightarrow H_2CO_3$$

Some of the carbonic acid (H_2CO_3) in the water ionizes, or breaks apart, into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-), as shown by the equation

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

These two equations play a major role in the dissolution of limestone and the formation of caves. In addition, rainwater is slightly acidic, with a pH of 5.0 to 5.6. Because many of the reaction rates involved in geological processes are very slow, it takes thousands of years for enough carbonic acid mixed with groundwater to dissolve limestone and form a cave.

Bases

A **base** is a substance that produces hydroxide ions (OH^-) in water. A base can neutralize an acid because hydrogen ions (H^+) from the acid react with the hydroxide ions (OH^-) from the base to form water through the following reaction.

$$H^+ + OH^- \rightarrow H_2O$$

Figure 15 shows the pH values of some basic substances. A solution with a reading above 7 is considered to be basic. The higher the number, the more basic the solution. Many household cleaning products are basic, with pH values from 11 to 13.

Check Your Progress

Summary

- Atoms of different elements combine to form compounds.
- Covalent bonds form from shared electrons between atoms.
- Ionic compounds form from the attraction of positive and negative ions.
- There are two types of mixtures—heterogeneous and homogeneous.
- Acids are solutions containing hydrogen ions. Bases are solutions containing hydroxide ions.

Demonstrate Understanding

1. **Explain** why molecules do not have electric charges.
2. **Differentiate** between molecules and compounds.
3. **Calculate** the number of atoms needed to balance the following equation: $CaCO_3 + HCl \rightarrow CO_2 + H_2O + CaCl$
4. **Diagram** how an acid can be neutralized.
5. **Compare and contrast** mixtures and solutions by using specific examples of each.

Explain Your Thinking

6. **Design** a procedure to demonstrate whether whole milk, which consists of microscopic fat globules suspended in a solution of nutrients, is a homogeneous or heterogeneous mixture.
7. **Predict** what kind of chemical bond forms between nitrogen and hydrogen atoms in ammonia (NH_3). Sketch this molecule.
8. **WRITING Connection** Antacids are used to relieve indigestion and upset stomachs. Write an advertisement for a new antacid product. Explain how the product works in terms that people who are not taking a science class will understand.

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LESSON 3
STATES OF MATTER

FOCUS QUESTION

What forms does water take?

Solids

Solids are substances with densely packed particles, which can be ions, atoms, or molecules. Most solids are **crystalline structures,** with particles arranged in regular geometric patterns. Examples of crystals are shown in **Figure 16.** Because of their crystalline structures, solids have both a definite shape and volume.

Perfectly formed crystals are rare. When many crystals form in the same space at the same time, crowding prevents the formation of smooth, well-defined crystal faces. The result is a mass of intergrown, randomly arranged crystals. **Figure 16** shows the crystalline nature of the rock granite.

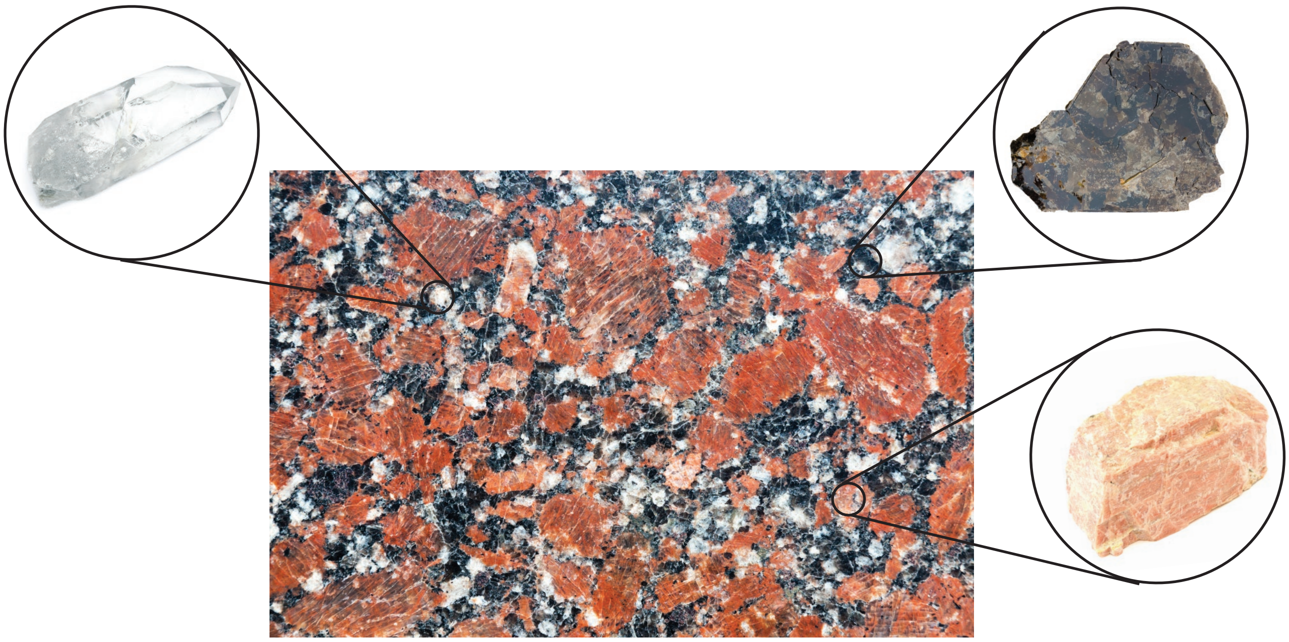

Figure 16 This granite is composed of mineral crystals that fit together like interlocking puzzle pieces. The minerals that make up the rock are composed of individual atoms and molecules that are aligned in a repeating pattern.

3D THINKING | DCI Disciplinary Core Ideas | CCC Crosscutting Concepts | SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Design Your Own: Changes in State

Plan and carry out an investigation to demonstrate and compare the properties of matter.

Revisit the Encounter the Phenomenon Question

What information from this lesson can help you answer the Unit and Module questions?

Some solid materials have no regular internal patterns. **Glass** is a solid that consists of densely packed atoms arranged randomly. Glasses form when molten material is chilled so rapidly that atoms do not have enough time to arrange themselves in a regular pattern. These solids do not form crystals. Window glass consists mostly of disordered silicon and oxygen (SiO_2).

Figure 17 Each of these containers has the same volume of liquid in it.

Liquids

At any temperature above absolute zero (−273°C), the atoms in a solid vibrate. Because these vibrations increase with increasing temperature, they are called thermal vibrations. At the melting point of the material, these vibrations become vigorous enough to break the forces holding the solid together. The particles can then slide past each other, and the substance becomes liquid. Liquids take the shape of the container they are placed in, as you can see in **Figure 17.** However, liquids do have definite volume.

Gases

The particles in liquids vibrate vigorously. As a result, some particles can gain sufficient energy to escape the liquid. This process of change from a liquid to a gas at temperatures below the boiling point is called **evaporation.** When any liquid reaches its boiling point, it vaporizes quickly as a gas. In gases, the particles are separated by relatively large distances, and they travel at high speeds in one direction until they bump into another gas particle or the walls of a container. Gases, like liquids, have no definite shape. Gases also have no definite volume unless they are restrained by a container or a force such as gravity. For example, Earth's gravity keeps gases in the atmosphere from escaping into space.

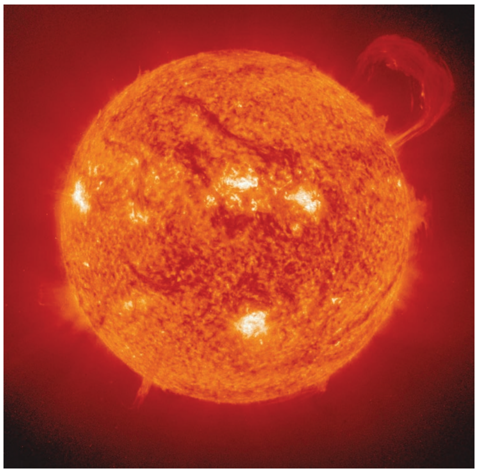

Figure 18 The Sun's temperature is often expressed in kelvins; 273 K is equal to 0°C. The Sun's corona, which is a plasma, has a temperature of about 15,000,000 K.

Plasma

When matter is heated to a temperature greater than 5000°C, the collisions between particles are so violent that electrons are knocked away from atoms. Such extremely high temperatures exist in stars and, as a result, the gases of stars consist entirely of positive ions and free electrons. These hot, highly ionized, electrically conducting gases are called **plasmas. Figure 18** shows the plasma that forms the Sun's corona. You have seen matter in the plasma state if you have ever seen lightning or a neon sign.

STEM CAREER Connection

Cosmetic Chemist

Are you intrigued by different lotions, shampoos, and sunscreens? Do you wonder how they are made? Formulators of these types of products know a lot about chemistry and the chemical makeup of the products. All of these items you see on store shelves started out on the lab table of a cosmetic chemist.

CCC CROSSCUTTING CONCEPTS

Energy and Matter Scientists have determined that during any chemical reaction, no energy or matter is created or destroyed. Lighting a candle and letting it burn involves chemical reactions. Describe the chemical reactions you observe. What energy changes do you notice? Where do the candle wax and the candle wick go during burning? Share your observations with your class.

Changes of State

Solids melt when they absorb enough thermal energy to cause their orderly internal crystalline structure to break down. This happens at the melting point. When liquids are cooled, they solidify at that same temperature and release thermal energy. This temperature is called the freezing point. Freezing is the reverse of melting. When a liquid is heated to the boiling point and absorbs enough thermal energy, vaporization occurs, and the liquid becomes a gas. When a gas is cooled to the boiling point, it becomes a liquid in a process called **condensation,** shown in **Figure 19.** Condensation is the reverse of vaporization. Energy that was absorbed during vaporization is released upon condensation. A special type of vaporization, called sublimation, can occur below the boiling point. You might have noticed that even on winter days with temperatures below freezing, snow gradually disappears. This slow change of state from a solid (ice crystals) to a gas (water vapor) without an intermediate liquid state is called **sublimation.**

Figure 19 As hot, moist air from the shower encounters the cool glass of the mirror, water vapor in the air condenses on the glass.

Conservation of Energy

Matter can be changed through chemical reactions and nuclear processes, and its state can be changed under different thermal conditions. A chemical equation must be balanced because matter cannot be created or destroyed. This fundamental fact is the law of conservation of matter. Like matter, energy cannot be created or destroyed, but it can be changed from one form to another. For example, electric energy can be converted into light energy. This law, called the conservation of energy, is also known as the first law of thermodynamics.

Check Your Progress

Summary

- Changes of state involve thermal energy.
- The law of conservation of matter states that matter cannot be created or destroyed.
- The law of conservation of energy states that energy is neither created nor destroyed.

Demonstrate Understanding

1. **Explain** how thermal energy is involved in changes of state.
2. **Evaluate** the nature of the thermal vibrations in each of the four states of matter.
3. **Apply** what you know about thermal energy to compare evaporation and condensation.

Explain Your Thinking

4. **Infer** how the boiling point of water (100°C) would change if water molecules were not polar molecules.
5. **Consider** glass and diamond—two clear, colorless solids. Why does glass shatter more easily than diamond?
6. **MATH Connection** Refer to **Figure 18.** Calculate the corona's temperature in degrees Celsius. Remember that 273 K is equal to 0°C.

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Seeing the Light

Device screens have come a long way since the days of cathode-ray tube (CRT) displays, used in twentieth-century televisions, and early liquid crystal display (LCD) technology, used in computer screens of the 1980s. Today's LCD screens offer picture quality that was unimaginable in the earliest days of consumer technology.

The picture quality of IPS LCD screens is favorably compared with the picture quality of any other type of screens.

How LCD Technology Works

LCD technology is made using two sheets of glass, with a row of light-emitting diode (LED) lights, called backlights, behind the bottom piece of glass. Layers of materials distribute this light equally over all parts of the glass. Each sheet of glass is lined with polarizing film. Sandwiched between the layers are a type of liquid crystal called twisted nematics (TN). Liquid crystals are a state of matter that have properties of both a liquid and a solid. They have some of the order of a solid and also some of the fluidity of a liquid. Their molecules can move around.

The amount and arrangement of light we see depends on the liquid crystals' orientation. Applying electric current causes the crystals to untwist, which controls the passage of light. The light that passes through the crystals looks white when the crystals are in their twisted state. But when electric current is applied, the crystals untwist and line up in such a way that light cannot pass through them.

Over the front sheet of glass, there are millions of tiny, colored blocks called pixels. Each pixel is controlled by a thin-film transistor (TFT) on the back sheet of glass. The pixels are switched on and off by the TFTs regulating the electricity flowing through the liquid crystals. This updates the screen from top to bottom at a speed so rapid that people cannot see the change happening.

LCD versus IPS LCD

In-plane switching (IPS) LCD improves on older LCD technology by adding a stronger backlight and by controlling each pixel with two TFTs instead of just one.

IPS LCD screens use more power than older LCD screens, but they also have better color, can be viewed from a wider angle, and are useful in touch-screen technology because they do not show when a screen has been touched. IPS LCD screens are found in a range of smartphones, televisions, and tablets.

USE A MODEL TO ILLUSTRATE

Use print or online sources to find diagrams and more information about how these technologies work. Then work with a partner to create a model of an LCD or IPS LCD screen. Label the parts of your model.

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 MATTER

- Atoms consist of protons, neutrons, and electrons.
- An element consists of atoms that have a specific number of protons in their nuclei.
- Isotopes of an element differ by the number of neutrons in their nuclei.
- Elements with full outermost energy levels are highly unreactive.
- Ions are electrically charged atoms or groups of atoms.

- matter
- element
- nucleus
- proton
- neutron
- electron
- atomic number
- mass number
- isotope
- ion

Lesson 2 COMBINING MATTER

- Atoms of different elements combine to form compounds.
- Covalent bonds form from shared electrons between atoms.
- Ionic compounds form from the attraction of positive and negative ions.
- There are two types of mixtures—heterogeneous and homogeneous.
- Acids are solutions containing hydrogen ions. Bases are solutions containing hydroxide ions.

- compound
- chemical bond
- covalent bond
- molecule
- ionic bond
- metallic bond
- chemical reaction
- solution
- acid
- base

Lesson 3 STATES OF MATTER

- Changes of state involve thermal energy.
- The law of conservation of matter states that matter cannot be created or destroyed.
- The law of conservation of energy states that energy is neither created nor destroyed.

- crystalline structure
- glass
- evaporation
- plasma
- condensation
- sublimation

THREE-DIMENSIONAL THINKING
Module Wrap-Up

REVISIT THE PHENOMENON

How do we find and remove harmful substances from our drinking water?

CER Claim, Evidence, Reasoning

Explain your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

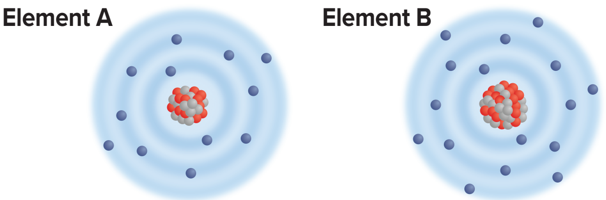
STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will summarize your evidence and apply it to the project.

GO FURTHER

SEP Data Analysis Lab

How do compounds form?



Data and Observations Many atoms gain or lose electrons in order to have eight electrons in the outermost energy level. In the diagram, energy levels are indicated by the circles around the nucleus of each element. The colored spheres in the energy levels represent electrons, and the spheres in the nucleus represent protons and neutrons.

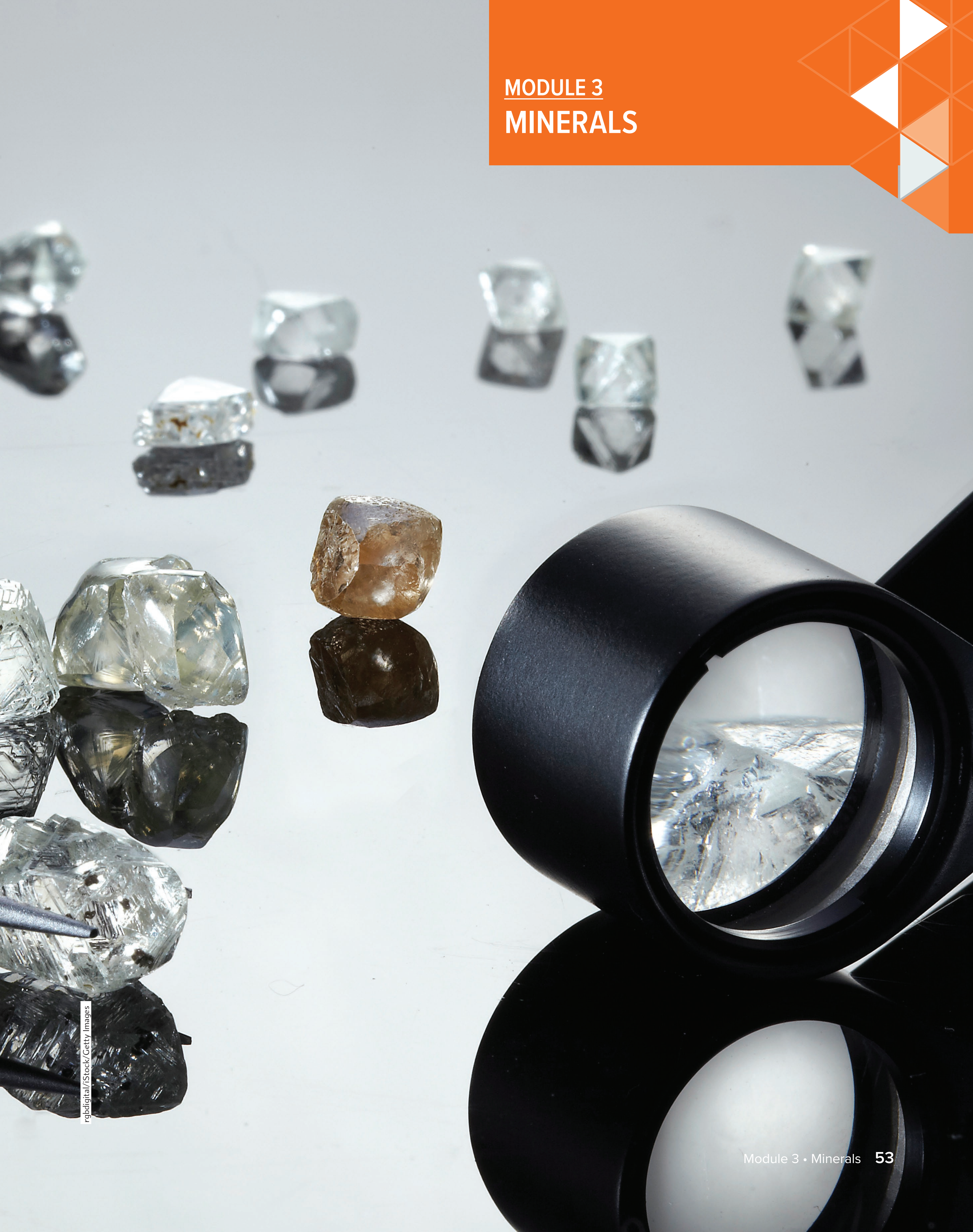
CER Analyze and Interpret Data

1. **Claim** Different atoms have different numbers of electrons. How many electrons are present in atoms of Element A? Element B?
2. **Claim** How many protons are present in the nuclei of these atoms?
3. **Evidence, Reasoning** Use a periodic table to determine the name of and symbol for Element A and Element B.
4. **Reasoning** Decide if these elements can form ions. If so, what would be the electric charges (magnitude and sign) of and chemical symbols for these ions?
5. **Reasoning** Formulate a compound from these two elements. What is the chemical formula for the compound?

tdub303/E+/Getty Images

MODULE 3

MINERALS



rgbdigital/iStock/Getty Images

MINERALS

ENCOUNTER THE PHENOMENON

What makes diamonds so special?

GO ONLINE to play a video to learn more about diamonds.

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about what makes diamonds so special. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 1: Explore & Explain: Mineral Characteristics

LESSON 2: Explore & Explain: Mineral Groups

Smithsonian

Additional Resources

(t)Video Supplied by BBC Worldwide Learning, (bl)(c)Doug Sherman/Geofile, (br)photographieundmehr/123RF

LESSON 1
WHAT IS A MINERAL?

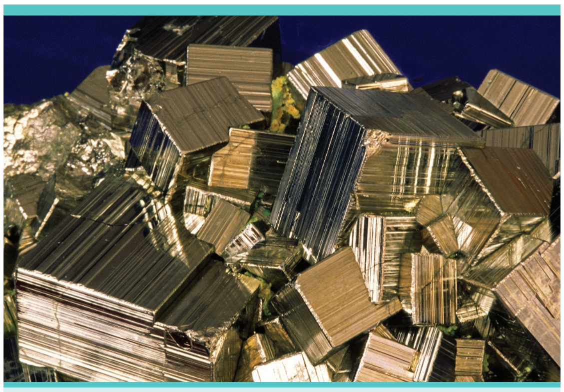
FOCUS QUESTION

What properties does diamond have?

Mineral Characteristics

Earth's crust is composed of about 3000 types of minerals. Minerals play important roles in forming rocks and in shaping Earth's surface. A select few have helped shape civilization. For example, great progress in prehistory was made when early humans began making tools from iron.

A **mineral** is a naturally occurring, inorganic solid with a specific chemical composition and a definite crystalline structure. This crystalline structure is often exhibited by the crystal shape itself. Examples of two mineral crystal shapes, pyrite and calcite, are shown in **Figure 1.**



Pyrite

Calcite

Figure 1 The shapes of these mineral crystals reflect the internal arrangements of their atoms.

Get It?

Identify the requirements a substance must meet in order to be classified as a mineral.

Naturally occurring and inorganic

Minerals are naturally occurring, meaning that they are formed by natural processes. Thus, synthetic diamonds and other substances developed in labs are not minerals. All minerals are inorganic. They are not alive and never were alive. Based on these criteria, salt is a mineral, but sugar, which is harvested from plants, is not. What about coal? According to the scientific definition of minerals, coal is not a mineral because millions of years ago, it formed from organic materials.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Recognize Cleavage and Fracture

Carry out an investigation to visualize the structure found in mineral crystal shapes.

GeoLAB: Make a Field Guide for Minerals

Obtain, evaluate, and communicate information about how to identify minerals by their properties.

Definite crystalline structure

The atoms in minerals are arranged in regular geometric patterns that are repeated. This regular pattern results in the formation of a crystal. A **crystal** is a solid in which the atoms are arranged in repeating patterns. Sometimes, a mineral will form in an open space and grow into one large crystal. The well-defined crystal shapes shown in **Figure 1** are rare. More commonly, the internal atomic arrangement of a mineral is not apparent because the mineral formed in a restricted space. **Figure 2** shows a sample of quartz that formed in a restricted space.

Figure 2 This piece of quartz most likely formed in a restricted space, such as within a crack in a rock.

Get It?

Describe the atomic arrangement of a crystal.

Solids with specific compositions

The fourth characteristic of minerals is that they are solids, like the quartz and aquamarine in **Figure 3.** Recall that solids have definite shapes and volumes, while liquids and gases do not. Because of this, no gas or liquid can be considered a mineral.

Each type of mineral has a chemical composition unique to that mineral. This composition might be specific, or it might vary within a set range of compositions. A few minerals, such as copper, silver, and sulfur, are composed of single elements. The vast majority, however, are made from compounds. The mineral quartz (SiO_2), for example, is a combination of two atoms of oxygen and one atom of silicon. Although other minerals might contain silicon and oxygen, the arrangement and proportion of these elements in quartz are unique to quartz.

Quartz — Aquamarine

Figure 3 Minerals must be solids, each with its own unique chemical composition.

ACADEMIC VOCABULARY

restricted

small space; to have limits

The room was so small that it felt very restricted.

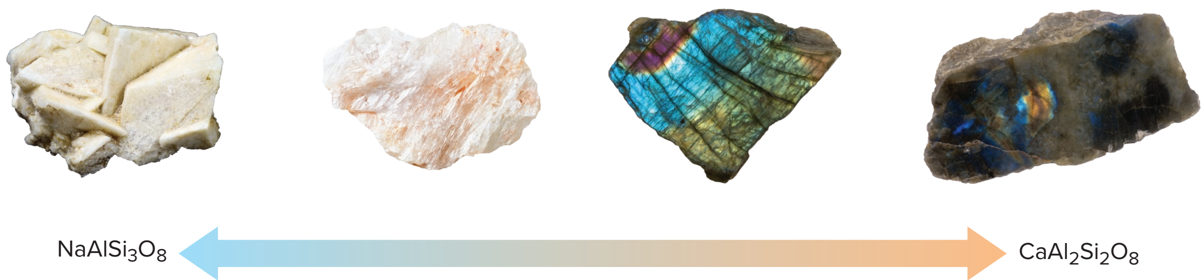


Figure 4 The mineral albite is a sodium-rich feldspar, while anorthite is calcium-rich. Oligoclase and labradorite contain both sodium and calcium in varying compositions.

Variations in composition

In some minerals, chemical composition can vary slightly depending on the temperature at which the mineral crystallizes. The plagioclase feldspar, shown in **Figure 4,** ranges from sodium-rich albite (AHL bite) at low temperatures to calcium-rich anorthite (uh NOR thite) at high temperatures. The difference in the minerals' appearance is due to a slight change in chemical composition and a difference in growth pattern as the temperature changes. At intermediate temperatures, both calcium and sodium are incorporated into the crystal structure. This builds up alternating layers that allow light to interfere with itself, producing a range of colors, as shown in the labradorite in **Figure 4.**

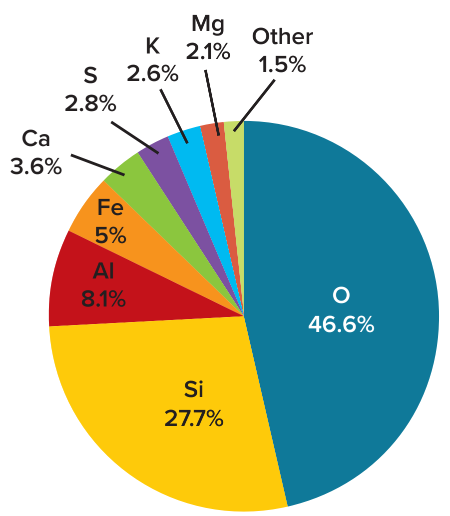
Rock-Forming Minerals

Although about 3000 minerals occur in Earth's crust, only about 30 of these are common. Eight to ten of these minerals are referred to as rock-forming minerals because they make up most of the rocks in Earth's crust. They are primarily composed of the eight most common elements in Earth's crust, which are listed in **Table 1.**

Table 1 **Most Common Rock-Forming Minerals**

Quartz	Feldspar	Mica*	Pyroxene*
SiO_2	$NaAlSi_3O_8$ – $CaAl_2Si_2O_8$ $KAlSi_3O_8$	$K(Mg,Fe)_3(AlSi_3O_{10})$ $(OH)_2$ $KAl_2(AlSi_3O_{10})(OH)_2$	$MgSiO_3$ $Ca(Mg,Fe)Si_2O_6$ $NaAlSi_2O_6$
Amphibole*	**Olivine**	**Garnet***	**Calcite**
$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$ $Fe_7Si_8O_{22}(OH)_2$	$(Mg,Fe)_2SiO_4$	$Mg_3Al_2Si_3O_{12}$ $Fe_3Al_2Si_3O_{12}$ $Ca_3Al_2Si_3O_{12}$	$CaCO_3$

*representative mineral compositions



Minerals from magma

Molten material that forms and accumulates below Earth's surface is called **magma.** Magma is less dense than the surrounding solid rock, so it can rise upward into cooler layers of Earth's interior. Here, the magma cools and crystallizes. The type and number of elements present in the magma determine which minerals will form. The rate at which the magma cools determines the size of the mineral crystals. If the magma cools slowly within Earth's heated interior, the atoms have time to arrange themselves into large crystals. If the magma reaches Earth's surface, comes in contact with air or water, and cools quickly, the atoms do not have time to arrange themselves into large crystals. Thus, small crystals form from rapidly cooling magma, and large crystals form from slowly cooling magma. The mineral crystals in the granite shown in **Figure 5** are the result of slowly cooling magma.

Get It?

Explain how the rate of cooling of magma affects the size of the crystals that form.

Minerals from solutions

Minerals are often dissolved in water. For example, the salts that are dissolved in ocean water make it salty. When a liquid becomes full of a dissolved substance and it can dissolve no more of that substance, the liquid is saturated. If more solute is added, the solution is called supersaturated, and conditions are right for minerals to form. At this point, individual atoms bond together and mineral crystals precipitate, which means that they form into solids from the solution.

Minerals also crystallize when the solution in which they are dissolved evaporates. You might have experienced this if you have ever gone swimming in the ocean. As the water evaporated off your skin, the salts were left behind as mineral crystals. Minerals that form from the evaporation of liquid are called evaporites. The rock salt in **Figure 5** was formed from evaporation. **Figure 6** shows Mammoth Hot Springs, a large evaporite complex in Yellowstone National Park.

Get It?

Identify two ways minerals can form from solutions.

Figure 5 The crystals in these two samples formed in different ways.

Describe *the differences you see in these rock samples.*

Figure 6 This large complex of evaporite minerals is in Yellowstone National Park. The variation in color is a result of the variety of elements that are dissolved in the water.

Identifying Minerals

Geologists rely on several simple tests to identify minerals. These tests are based on a mineral's physical and chemical properties: crystal form, luster, hardness, cleavage, fracture, streak, color, texture, density, specific gravity, and special properties. Scientists usually use a combination of tests instead of just one to identify minerals.

Crystal form

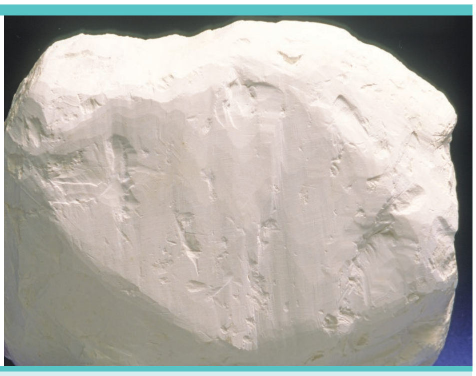
Some minerals form such distinct crystal shapes that they are immediately recognizable. Halite always forms perfect cubes. Quartz crystals, with their double-pointed ends and six-sided structure, are also readily recognized. However, as you learned earlier in this lesson, perfect crystals are not always formed, so identification based only on crystal form is rare.

Luster

The way that a mineral reflects light from its surface is called **luster.** There are two types of luster—metallic luster and nonmetallic luster. Silver, gold, copper, and galena have shiny surfaces that reflect light, like the chrome trim on cars. Thus, they are said to have a metallic luster. Not all metallic minerals are metals. If their surfaces have shiny appearances like metals, they are considered to have a metallic luster. Pyrite, for example, is a mineral with a metallic luster, but it is not a metal.

Minerals with nonmetallic lusters, such as calcite, gypsum, sulfur, and quartz, do not shine like metals. Nonmetallic lusters might be described as dull, pearly, waxy, silky, or earthy. Differences in luster, shown in **Figure 7,** are caused by differences in the chemical compositions of minerals. Describing the luster of nonmetallic minerals is a subjective process. A mineral that appears waxy to one person might not appear waxy to another. When identifying a mineral, luster should be used in combination with other physical characteristics.

Talc



Kaolinite

Figure 7 The flaky and shiny nature of talc gives it a pearly luster. Another white mineral, kaolinite, contrasts sharply with its dull, earthy luster.

STEM CAREER Connection

Mineralogist

A mineralogist studies minerals. Some mineralogists work for mining companies, analyzing economically important minerals and the best way to extract them. Others teach at universities, work in laboratories, or conduct surveys in the field.

Hardness

One of the most useful and reliable tests for identifying minerals is hardness. **Hardness** is a measure of how easily a mineral can be scratched. German geologist Friedrich Mohs developed a scale by which an unknown mineral's hardness can be compared to the known hardness of ten minerals. The minerals in the Mohs scale of hardness were selected because they are easily recognized and, with the exception of diamond, readily found in nature.

Talc is one of the softest minerals and can be scratched by a fingernail; therefore, talc represents 1 on the Mohs scale of hardness. In contrast, diamond is so hard that it can be used as a sharpener and cutting tool, so diamond represents 10 on the Mohs scale of hardness. The scale, shown in **Table 2,** is used in the following way: a mineral that can be scratched by your fingernail has a hardness less than 2.5. A mineral that cannot be scratched by your fingernail and cannot scratch glass has a hardness value between 5.5 and 2.5. Finally, a mineral that scratches glass has a hardness greater than 5.5.

Table 2 Mohs Scale of Hardness

Mineral	Hardness	Hardness of Common Objects
Diamond	10	
Corundum	9	
Topaz	8	
Quartz	7	streak plate = 7
Feldspar	6	steel file = 6.5
Apatite	5	glass = 5.5
Fluorite	4	iron nail = 4.5
Calcite	3	piece of copper = 3.5
Gypsum	2	fingernail = 2.5
Talc	1	

Get It?

Explain what *hardness* means.

Using other common objects, such as those listed in the table, can help you determine a more precise hardness and provide you with more information with which to identify an unknown mineral. Sometimes more than one mineral is present in a sample. If this is the case, it is a good idea to test more than one area of the sample. This way, you can be sure that you are testing the hardness of the mineral you are studying. **Figure 8,** on the next page, shows two minerals that have different hardness values.

Get It?

Analyze What is the hardness of a mineral that can be scratched by a streak plate but not by glass?

Figure 8 The mineral on the left can be scratched with a fingernail. The mineral on the right easily scratches glass.

Determine *Which mineral has greater hardness?*

Cleavage and fracture

Atomic arrangement also determines how a mineral will break. Minerals break along planes where atomic bonding is weak. A mineral that splits relatively easily and evenly along one or more flat planes is said to have **cleavage.** To identify a mineral according to its cleavage, geologists count the number of cleaved planes and study the angle or angles between them. For example, mica has perfect cleavage in one direction. It breaks in sheets because of weak atomic bonds. Halite, shown in **Figure 9,** has cubic cleavage, which means that it breaks in three directions along planes of weak atomic attraction. Quartz and flint do not have natural planes of separation. They fracture instead of cleave.

Halite | Quartz | Flint

Figure 9 Halite, common table salt, breaks apart into pieces that have 90° angles. The strong bonds in quartz prevent cleavage from forming. Conchoidal fractures are characteristic of certain minerals that do not cleave, such as the microcrystalline mineral flint.

Quartz, shown in **Figure 9,** breaks unevenly along jagged edges because of its tightly bonded atoms. Minerals that break with rough or jagged edges are said to have **fracture.** Flint, jasper, and chalcedony (kal SEH duh nee) (microcrystalline forms of quartz) exhibit a unique fracture with arclike patterns resembling clamshells, also shown in **Figure 9.** This fracture is called conchoidal (kahn KOY duhl) fracture and is diagnostic in identifying the rocks and minerals that exhibit it.

Get It?

Differentiate between cleavage and fracture.

Streak

Figure 10 Despite the fact that these pieces of hematite appear remarkably different, their chemical compositions are the same. Thus, the streak that each makes is the same color.

A mineral rubbed across an unglazed porcelain plate will sometimes leave a colored powdered streak on the surface of the plate. **Streak** is the color of a mineral when it is broken up and powdered. The streak of a nonmetallic mineral is usually white. Streak is most useful in identifying metallic minerals.

Sometimes, a metallic mineral's streak does not match its external color, as shown in **Figure 10.** The mineral hematite occurs in two different forms, resulting in two distinctly different appearances. Hematite that forms from weathering and exposure to air and water is a rusty red color and has an earthy luster.

Hematite that forms from crystallization of magma can be silver and metallic in appearance. However, both forms make a reddish-brown streak when tested. The streak test can be used only on minerals that are softer than a porcelain plate. This is another reason why streak cannot be used to identify all minerals.

Get It?

Explain which type of mineral can be identified using streak.

Color

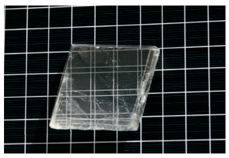
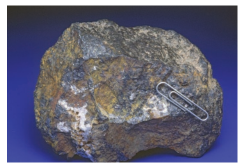
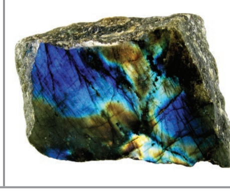
One of the most noticeable characteristics of a mineral is its color. Color is sometimes caused by the presence of trace elements or compounds within a mineral. For example, quartz occurs in a variety of colors, as shown in **Figure 11.** These different colors are the result of different trace elements in the quartz samples. Red jasper, purple amethyst, and orange citrine contain different amounts and forms of iron. Rose quartz contains manganese or titanium. However, the appearance of milky quartz is caused by the numerous bubbles of gas and liquid trapped within the crystal. In general, color is one of the least reliable clues of a mineral's identity.

Red Jasper | Amethyst | Citrine | Rose Quartz

Figure 11 These varieties of quartz all contain silicon and oxygen. Trace elements determine their colors.

(t)Matt Meadows/Photolibrary/Getty Images, (bl)Nikreates/Alamy Stock Photo, (bcl)RF Company/Alamy Stock Photo, (bcr)Nastya22/Shutterstock, (br)Nancy Bauer/Shutterstock

Table 3 **Special Properties of Minerals**

Property	**Double refraction** occurs when a ray of light passes through the mineral and is split into two rays.	**Effervescence** occurs when a reaction with hydrochloric acid causes the mineral calcite in limestone to fizz.	**Magnetism** occurs between minerals that contain iron; only magnetite and pyrrhotite are strongly magnetic.	**Iridescence** is a play of colors, caused by light rays interfering with each other.	**Fluorescence** occurs when some minerals are exposed to ultraviolet light, which causes them to glow in the dark.
Mineral	Calcite—Variety Iceland Spar	Calcite	Magnetite Pyrrhotite	Labradorite	Calcite
Example					

Special properties

Several special properties of minerals can also be used for identification purposes. Some of these properties, shown in **Table 3,** are double refraction, effervescence with hydrochloric acid, magnetism, iridescence, and fluorescence. For example, Iceland spar is a form of calcite that exhibits double refraction. The arrangement of atoms in this type of calcite causes light to be bent in two directions when it passes through the mineral. The refraction of the single ray of light into two rays creates the appearance of two images.

Texture

Texture describes how a mineral feels to the touch. This property, like luster, is subjective. Therefore, texture is often used in combination with other tests to identify a mineral. The texture of a mineral might be described as smooth, rough, ragged, greasy, or soapy. For example, fluorite, shown in **Figure 12,** has a smooth texture, while the texture of talc, shown in **Figure 7,** is greasy.

Figure 12 Textures are interpreted differently by different people. The texture of this fluorite is usually described as smooth.

Density and specific gravity

Sometimes, two minerals of the same size have different weights. Differences in weight are the result of differences in density, which is defined as mass per unit of volume. Density is expressed as follows.

$$D = \frac{M}{V}$$

In this equation, D = density, M = mass, and V = volume. For example, pyrite has a density of 5.2 g/cm^3, and gold has a density of 19.3 g/cm^3. If you had a sample of gold and a sample of pyrite of the same size, the gold would have greater weight because it is denser.

Density reflects the atomic mass and structure of a mineral. Because density is not dependent on the size or shape of a mineral, it is a useful identification tool. Often, however, differences in density are too small to be distinguished by lifting different minerals. Thus, for accurate mineral identification, density must be measured. The most common measure of density used by geologists is **specific gravity,** which is the ratio of the mass of a substance to the mass of an equal volume of water at 4°C. For example, the specific gravity of pyrite is 5.2. The specific gravity of pure gold is 19.3.

Get It?
Explain the relationship among density, mass, and volume.

Check Your Progress

Summary

- A mineral is a naturally occurring, inorganic solid with a specific chemical composition and a definite crystalline structure.
- A crystal is a solid in which the atoms are arranged in repeating patterns.
- Minerals form from magma, supersaturated solutions, or evaporation of solutions in which they are dissolved.
- Minerals can be identified based on physical and chemical properties.
- The most reliable way to identify a mineral is by using a combination of several tests.

Demonstrate Understanding

1. **List** two reasons why petroleum is not a mineral.
2. **Define** *naturally occurring* in terms of mineral formation.
3. **Contrast** the formation of minerals from magma and their formation from solution.
4. **Differentiate** between subjective and objective mineral properties.

Explain Your Thinking

5. **Develop** a plan to test the hardness of a sample of feldspar using the following items: glass plate, copper penny, and streak plate.
6. **Predict** the success of a lab test in which students plan to compare the streak colors of fluorite, quartz, and feldspar.
7. **MATH Connection** Calculate the volume of a 5-g sample of pure gold.

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LESSON 2
TYPES OF MINERALS

FOCUS QUESTION

Why are diamond and graphite so different when they are made of the same element?

Mineral Groups

You have learned that elements combine in many different ways and proportions. One result is the thousands of different minerals present on Earth. In order to study these minerals and understand their properties, geologists have classified them into groups. Each group has a distinct chemical nature and specific characteristics.

Silicates

Oxygen is the most abundant element in Earth's crust, followed by silicon. Minerals that contain silicon and oxygen, and usually one or more additional elements, are known as **silicates.** Silicates make up approximately 96 percent of the minerals present in Earth's crust. The two most common minerals, feldspar and quartz, are silicates. The basic building block of the silicates is the silicon-oxygen tetrahedron, shown in **Figure 13.** A **tetrahedron** (plural, *tetrahedra*) is a geometric solid having four sides that are equilateral triangles, resembling a pyramid. Recall that the electrons in the outermost energy level of an atom are called valence electrons. The number of valence electrons determines the type and number of chemical bonds an atom will form. Because silicon atoms have four valence electrons, silicon has the ability to bond with four oxygen atoms. As shown in **Figure 14,** silicon-oxygen tetrahedra can share oxygen atoms. This structure allows tetrahedra to combine in a number of ways, which accounts for the large diversity of structures and properties of silicate minerals.

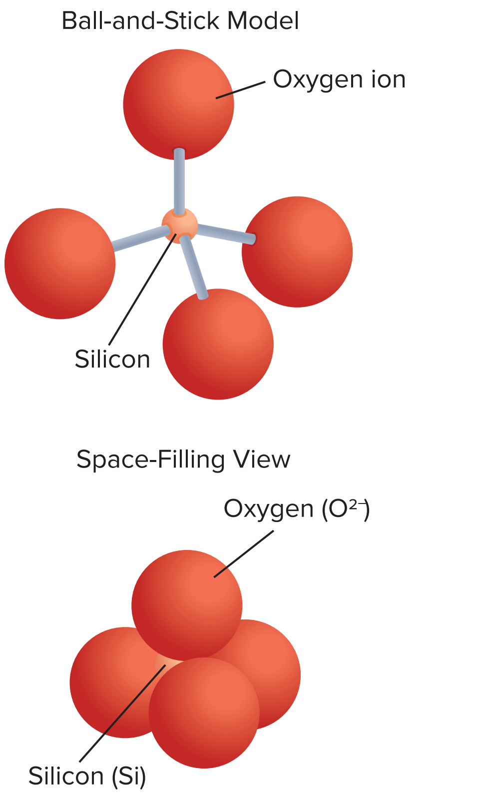


Figure 13 The silicate polyatomic ion SiO_4^{4-} forms a tetrahedron in which a central silicon atom is covalently bonded to oxygen atoms.

Specify *How many atoms are in one tetrahedron?*

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Investigation Lab: Growing Crystals

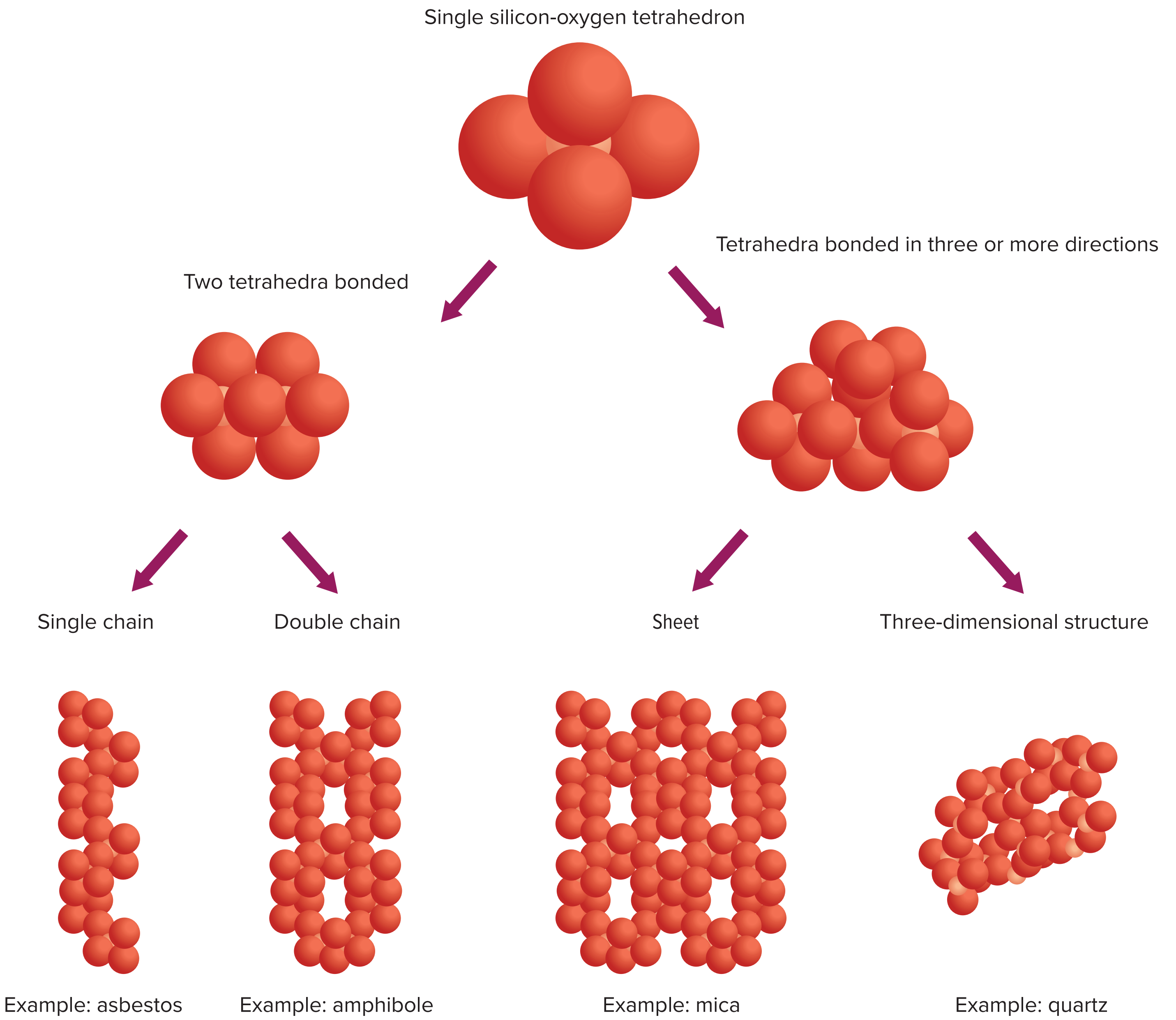
Carry out an investigation to classify the results of evaporating solutions.

Review the News

Obtain information from a current news story about current use of crystals in technology. Evaluate your source and communicate your findings to your class.

Figure 14 Visualizing the Silicon-Oxygen Tetrahedron

A silicon-oxygen tetrahedron contains four oxygen atoms bonded to a central silicon atom. Chains, sheets, and complex structures form when tetrahedra share oxygen atoms. These structures and the types of metal ions bonded to them determine the numerous silicate minerals that are present on Earth.



Asbestos Mica

Figure 15 The differences in silicate minerals are due to differences in the arrangement of their silicon-oxygen tetrahedra. Certain types of asbestos consist of weakly bonded double chains of tetrahedra, while mica consists of weakly bonded sheets of tetrahedra.

Individual tetrahedron ions are strongly bonded. They can bond together to form sheets, chains, and complex three-dimensional structures. The bonds between the atoms help determine several mineral properties, including a mineral's cleavage or fracture. Mica, shown in **Figure 15,** is a sheet silicate, also called a phyllosilicate, in which positive potassium or aluminum ions bond the negatively charged sheets of tetrahedra together. Mica separates easily into sheets because the attraction between the tetrahedra and the aluminum or potassium ions is weak. Asbestos, also shown in **Figure 15,** consists of double chains of tetrahedra that are weakly bonded together. This results in a fibrous nature.

Carbonates

Oxygen combines easily with many elements and forms other mineral groups, such as carbonates. Carbonates are minerals composed of one or more metallic elements and the carbonate ion CO_3^{2-}. Examples of carbonates are calcite, dolomite, and rhodochrosite. Carbonates are the primary minerals found in rocks such as limestone and marble. Some carbonates have distinctive colorations, as exhibited by the calcite and rhodochrosite shown in **Figure 16.**

Calcite Rhodochrosite

Figure 16 Carbonates such as calcite and rhodochrosite occur in distinct colors due to trace elements found in them.

SCIENCE USAGE v. COMMON USAGE

phyllo

Science usage: sheets of silica tetrahedra

Common usage: sheets of dough used to make pastries and pies

Oxides

Oxides are compounds of oxygen and a metal. Hematite (Fe_2O_3) and magnetite (Fe_3O_4) are common iron oxides and good sources of iron. The mineral uraninite (UO_2) is valuable because it is the major source of uranium, which is used to generate nuclear power.

Other Groups

Other major mineral groups are sulfides, sulfates, halides, and native elements. Sulfides, such as pyrite (FeS_2), are compounds of sulfur and one or more elements. Sulfates, such as anhydrite ($CaSO_4$), are composed of elements and the sulfate ion SO_4^{2-}. Halides, such as halite (NaCl), are made up of chloride or fluoride along with calcium, sodium, or potassium. A native element such as silver (Ag) or copper (Cu), is made up of one element only.

Get It?

Compare carbonates and oxides.

Economic Minerals

Minerals are important to society. They are used to make computers, cars, televisions, desks, roads, buildings, jewelry, beds, paints, sports equipment, and medicines, in addition to many other things. You can learn about how the availability and use of minerals has guided the development of human society by examining **Figure 17,** on the next page.

Ores

Many of the items just mentioned are made from ores. A mineral is an **ore** if it contains a valuable substance that can be mined at a profit. Hematite, for instance, is an ore that contains the element iron. Consider your classroom. If any items are made of iron, their original source might have been the mineral hematite. If there are items in the room made of aluminum, their original source was the ore bauxite. A common use of the metal titanium, obtained from the mineral ilmenite, is shown in **Figure 18.**

Figure 18 Parts of this athlete's wheelchair are made of titanium. Its light weight and extreme strength make it an ideal metal for this purpose.

Mines Ores that are located deep within Earth's crust are removed by underground mining. Ores that are near Earth's surface are obtained from large, open-pit mines. When a mine is excavated, unwanted rock and minerals, known as gangue, are dug up along with the valuable ore. The overburden must also be removed before the ore can be used. Removing the overburden can be expensive and, in some cases, harmful to the environment. If the cost of removing the overburden or separating the gangue becomes higher than the value of the ore itself, the mineral will no longer be classified as an ore. It would no longer be economical to mine.

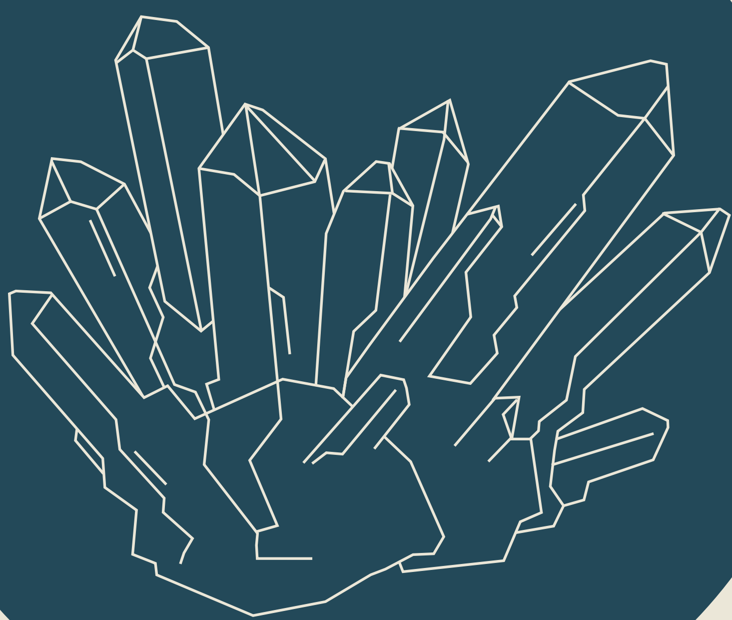


Figure 17

Mineral Use Through Time

While the values and uses of minerals have changed over time, some are consistently important. For example, quartz has always been important—from the first trade routes for flint over 10,000 years ago to the labs that turn quartz into computer chips today.

1 **3300–3000 B.C.** Bronze weapons and tools become common in the Near East as large cities and powerful empires arise.

2 **1200–1000 B.C.** In the Near East, bronze becomes scarce and is replaced by iron in tools and weapons.

3 **800 B.C.** Diamonds spread from India to other parts of the world to be used for cutting, for engraving, and in ceremonies.

4 **506 B.C.** Rome takes over the salt industry at Ostia. The word *salary* comes from *salarium argentums*, the salt rations paid to Roman soldiers.

5 **A.D. 200–400** Iron farming tools and weapons allow people to migrate across Africa, clearing and cultivating land for agricultural settlement and driving out hunter-gatherer societies.

6 **800–900** Chinese alchemists combine saltpeter with sulfur and carbon to make gunpowder, which is first used for fireworks and later used for weapons.

7 **1546** South American silver mines help establish Spain as a global trading power, supplying silver needed for coinage.

8 **2010** Over 60 individual minerals, including quartz, bauxite, and halite, contribute to the modern computer.

Classification of Minerals The classification of a mineral as an ore can also change if the supply of or demand for that mineral changes. Consider a mineral that is used to make computers. Engineers might develop a more efficient design or decide to use a less costly alternative material. In either of these cases, the mineral would no longer be used in computers. Demand for the mineral would drop, so it would not be profitable to mine. Therefore, the mineral would no longer be considered an ore. **Table 4** summarizes the mineral groups and their major uses.

Table 4 Major Mineral Groups

Group	Examples	Economic Use
Silicates	mica (biotite) olivine (Mg_2SiO_4) quartz (SiO_2) vermiculite	furnace windows gem (as peridot) timepieces potting soil additive (swells when wet)
Sulfides	pyrite (FeS_2) marcasite (FeS_2) galena (PbS) sphalerite (ZnS)	used to make sulfuric acid; often mistaken for gold (fool's gold) jewelry lead ore zinc ore
Oxides	hematite (Fe_2O_3) corundum (Al_2O_3) uraninite (UO_2) ilmenite ($FeTiO_3$) chromite ($FeCr_2O_4$)	iron ore; red pigment abrasive, gem (as in ruby or sapphire) uranium source titanium source; pigment (replaced lead in paint) chromium source, plumbing fixtures, auto accessories
Sulfates	gypsum ($CaSO_4{\bullet}_2H_2O$) anhydrite ($CaSO_4$)	plaster, drywall (slows drying in cement) plaster (name indicates absence of water)
Halides	halite (NaCl) fluorite (CaF_2) sylvite (KCl)	table salt, stock feed, weed killer, food preparation and preservative steel manufacturing, enameling cookware fertilizer
Carbonates	calcite ($CaCO_3$) dolomite ($CaMg(CO_3)_2$)	Portland cement, lime, chalk Portland cement, lime; source of calcium and magnesium in vitamin supplements
Native elements	gold (Au) copper (Cu) silver (Ag) sulfur (S) graphite (C)	monetary standard, jewelry coinage, electrical wiring, jewelry coinage, jewelry, photography sulfa drugs and chemicals; match heads; fireworks pencil lead, dry lubricant

Gems

What makes a ruby more valuable than mica? Rubies are rarer and more visually pleasing than mica. Rubies are thus considered gems. **Gems** are valuable minerals that are prized for their rarity and beauty. They are very hard and scratch resistant. Gems such as rubies, emeralds, and diamonds are cut, polished, and used for jewelry. Because of their rareness, rubies and emeralds are more valuable than diamonds. **Figure 19,** on the next page, shows a rough diamond (on the left) and a polished diamond (on the right).

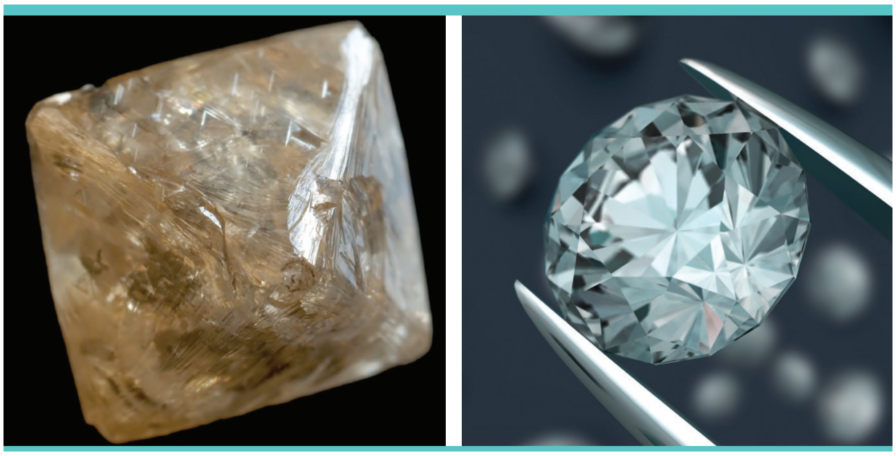


Figure 19 The real beauty of gemstones is revealed once they are cut and polished.

In some cases, the presence of trace elements can make one variety of a mineral more colorful and more prized than other varieties of the same mineral. Amethyst, for instance, is the gem form of quartz. Amethyst contains traces of iron, which gives the gem a purple color. The mineral corundum, which is often used as an abrasive, also occurs as rubies and sapphires. Red rubies contain trace amounts of chromium, while blue sapphires contain trace amounts of cobalt or titanium. Green emeralds are a variety of the mineral beryl and are colored by trace amounts of chromium or vanadium.

Check Your Progress

Summary

- In silicates, one silicon atom bonds with four oxygen atoms to form a tetrahedron.
- Major mineral groups include silicates, carbonates, oxides, sulfides, sulfates, halides, and native elements.
- An ore contains a valuable substance that can be mined at a profit.
- Gems are valuable minerals that are prized for their rarity and beauty.

Demonstrate Understanding

1. **Formulate** a statement that explains the relationship between chemical elements and mineral properties.
2. **List** the two most abundant elements in Earth's crust. What mineral group do these elements form?
3. **Hypothesize** some environmental consequences of mining ores.

Explain Your Thinking

4. **Hypothesize** why the mineral opal is often referred to as a mineraloid.
5. **Evaluate** which metal is better to use in sporting equipment and medical implants: titanium—specific gravity = 4.5, contains only Ti; or steel—specific gravity = 7.7, contains Fe, O, Cr.
6. **WRITING Connection** Design an advertisement for a mineral of your choice. You might choose a gem or industrially important mineral. Include any information that you think will help your mineral sell.

LEARNSMART® Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

Better Than the “Real” Thing?

Synthetic and natural diamonds come in many different shapes, sizes, and colors. They are used in everything from jewelry to industrial drills.

Can you tell which diamonds are synthetic? Synthetic diamonds are visually and chemically identical to natural diamonds.

Victor R. Boswell Jr./National Geographic/Getty Images

Diamonds

When you think about diamonds, expensive jewelry and unethical mining practices might come to mind. But the uses of diamonds extend far beyond fashion, such as drill bits and optics for lasers. With growing accessibility and customization options for synthetic diamonds, materials scientists are exploring new uses for them.

Synthetic diamonds are made in a lab instead of being mined from a chunk of billion-year-old magma. They have the same characteristics as natural diamonds, and usually cost much less.

While scientists have been making diamonds in labs since 1954, modern influences—including a bigger market for sustainable, conflict-free diamonds—have helped to grow the synthetic diamond industry.

How to Make a Diamond

Scientists use two processes to make diamonds in the lab: chemical vapor deposition (CVD) and high pressure, high temperature (HPHT).

For wearable, jewelry-grade gems, CVD is the preferred process. In this process, a chemical vapor, or plasma, of carbon and hydrogen atoms are created by superheating methane and hydrogen in a closed chamber. Diamond seeds, each made of a repeating lattice of carbon atoms, are placed on a disk and added to the chamber.

The temperature is adjusted depending on the qualities the scientists want in that batch of diamonds. Over the course of a few weeks, the diamond seed grows, atom by atom, until the process is complete. The diamonds are then cut and polished, just as a natural diamond would be.

The HPHT process is a little closer to how natural diamonds form. Natural diamonds form when carbon is trapped deep in Earth’s interior and subjected to the intense heat and pressure there. Scientists think that most natural diamonds formed billions of years ago.

Using the HPHT process, graphite, a soft form of carbon used to make pencil lead, is placed inside a machine that applies intense heat and pressure, similar to the conditions found in Earth’s interior. After just a few days of this treatment, the graphite is changed into a high-quality diamond.

DEVELOP AND USE MODELS TO ILLUSTRATE

Research more about the differences between the CVD and HPHT processes, including costs, characteristics of diamonds produced, and the history of each process. Develop an illustration that describes the differences.

MODULE 3
STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 WHAT IS A MINERAL?

- A mineral is a naturally occurring, inorganic solid with a specific chemical composition and a definite crystalline structure.
- A crystal is a solid in which the atoms are arranged in repeating patterns.
- Minerals form from magma, supersaturated solutions, or the evaporation of solutions in which they are dissolved.
- Minerals can be identified based on physical and chemical properties.
- The most reliable way to identify a mineral is based on a combination of properties.

- mineral
- crystal
- magma
- luster
- hardness
- cleavage
- fracture
- streak
- specific gravity

Lesson 2 TYPES OF MINERALS

- In silicates, one silicon atom bonds with four oxygen atoms to form a tetrahedron.
- Major mineral groups include silicates, carbonates, oxides, sulfides, sulfates, halides, and native elements.
- An ore contains a valuable substance that can be mined at a profit.
- Gems are valuable minerals that are prized for their rarity and beauty.

- silicate
- tetrahedron
- ore
- gem

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

What makes diamonds so special?

CER Claim, Evidence, Reasoning

Explain your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will summarize your evidence and apply it to the project.

GO FURTHER

SEP Data Analysis Lab

What information should you include in a mineral identification chart?

The table shows some of the properties of different minerals.

Data and Observations Copy the data table and use the *Reference Handbook* to complete the table. Expand the table to include the names of the minerals, other properties, and uses.

CER Analyze and Interpret Data

1. **Claim, Evidence** Which of these minerals will scratch glass? Explain.
2. **Claim, Evidence** Which of these minerals might be present in both a painting and your desk? Explain.
3. **Reasoning** What other information could you include in the table? Why?

Mineral Identification Chart

Mineral Color	Streak	Hardness	Breakage Pattern
copper red		3	hackly, fracture
	red and reddish brown	6	irregular fracture
pale to golden yellow	yellow		
	colorless	7.5	conchodial fracture
gray, green, or white			two cleavage planes

*Data obtained from: Klein, C. 2002. *The Manual of Mineral Science.*

MODULE 4
ROCKS

Putt Sakdhnagool/EyeEm/Getty Images

MODULE 4

ROCKS

ENCOUNTER THE PHENOMENON

How did these different types of rock form?

GO ONLINE to play a video about the types of rocks on Earth.

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

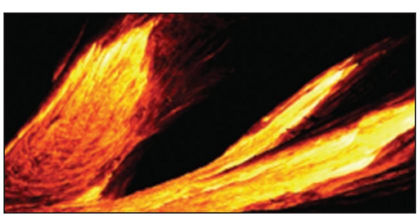
CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about how different types of rocks form. Explain your reasoning.

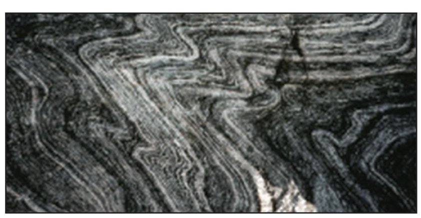
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.



LESSON 1: Explore & Explain: Igneous Rock Formation



LESSON 3: Explore & Explain: Recognizing Metamorphic Rocks

Smithsonian

Additional Resources

LESSON 1

IGNEOUS ROCKS

FOCUS QUESTION

How do rocks form from magma?

Igneous Rock Formation

Igneous rocks form when lava or magma cools and crystallizes. **Lava** is magma that flows out onto Earth's surface. In the laboratory, most rocks must be heated to temperatures of 800°C to 1200°C before they melt. In nature, these temperatures are present in the upper mantle and lower crust. Scientists theorize that the remaining energy from Earth's molten formation and the heat generated from the decay of radioactive elements are the sources of Earth's thermal energy.

Composition of magma

The type of igneous rock that forms depends on the composition of the magma. Magma is often a slushy mix of molten rock, dissolved gases, and mineral crystals. The common elements present in magma are the same major elements that are in Earth's crust: oxygen (O), silicon (Si), aluminum (Al), iron (Fe), magnesium (Mg), calcium (Ca), potassium (K), and sodium (Na). Of all the compounds present in magma, silica is the most abundant and has the greatest effect on magma characteristics. **Table 1** shows that magma is classified as basaltic, andesitic, or rhyolitic, based on the amount of silica it contains. Silica content affects melting temperature and impacts a magma's viscosity, or resistance to flow. Rhyolitic magma has a higher viscosity than basaltic magma. Once magma is free of the overlying pressure of the rock layers around it, dissolved gases are able to escape into the atmosphere. Thus, the chemical composition of lava is slightly different from the chemical composition of the magma from which it developed.

Table 1 Types of Magma

Group	Silica Content	Example Location
Basaltic	45–52%	Hawaiian Islands
Andesitic	52–66%	Cascade Mountains, Andes Mountains
Rhyolitic	more than 66%	Yellowstone National Park

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Mapping Lab: Locating Igneous Rocks on Earth

Develop and use a model to visualize the patterns of global igneous rock locations.

Quick Investigation: Compare Igneous Rocks

Carry out an investigation to compare the properties of igneous rocks from different locations.

Magma formation

Magma can be formed either by melting of Earth's crust or by melting within the mantle. The four main factors involved in the formation of magma are temperature, pressure, water content, and the mineral content of the crust or mantle.

Temperature generally increases with depth in Earth's crust. This temperature increase, known as the geothermal gradient, is plotted in **Figure 1.** Drill bits, such as the one shown in **Figure 2,** can encounter temperatures in excess of 200°C when drilling deep oil wells.

Pressure also increases with depth. This is a result of the weight of overlying rock. Laboratory experiments show that as pressure on a rock increases, its melting point also increases. Thus, a rock that melts at 1100°C at Earth's surface will melt at 1400°C at a depth of 100 km.

The third factor that affects the formation of magma is water content. Rocks and minerals often contain small percentages of water, which changes the melting point of the rocks. As water content increases, the melting point decreases.

Get It?

Explain how water content changes the melting point of rocks.

Mineral content

In order to better understand how the types of elements and compounds present give magma its overall character, it is helpful to discuss this fourth factor in more detail. Different minerals have different melting points. For example, rocks such as basalt, which are formed of olivine, calcium feldspar, and pyroxene (pi RAHK seen), melt at higher temperatures than rocks such as granite, which contain quartz and potassium feldspar. Granite has a melting point that is lower than basalt's melting point because granite contains more water and minerals that melt at lower temperatures. In general, rocks that are rich in iron and magnesium melt at higher temperatures than rocks that contain higher levels of silicon.

Get It?

Explain how levels of iron and magnesium in a rock affect its melting temperature.

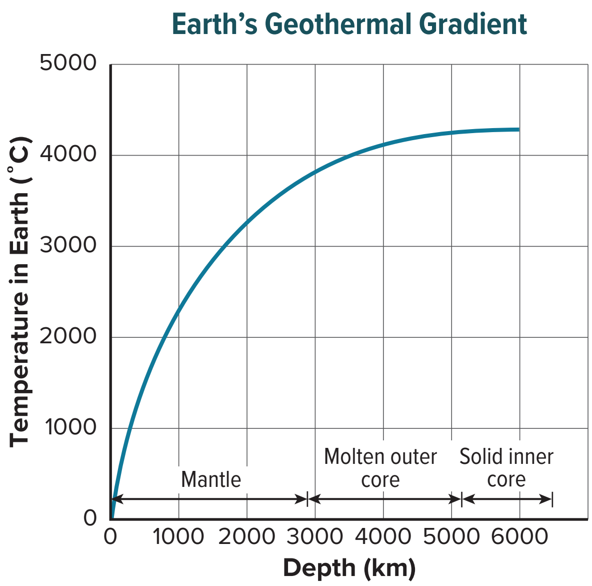


Figure 1 The average geothermal gradient in the crust is about 25°C/km, but scientists think that it drops sharply in the mantle to as low as 1°C/km.

Figure 2 The temperature of Earth's upper crust increases with depth by about 25°C for each 1 km. At a depth of 3 km, this drill bit will encounter rock that is close to the temperature of boiling water.

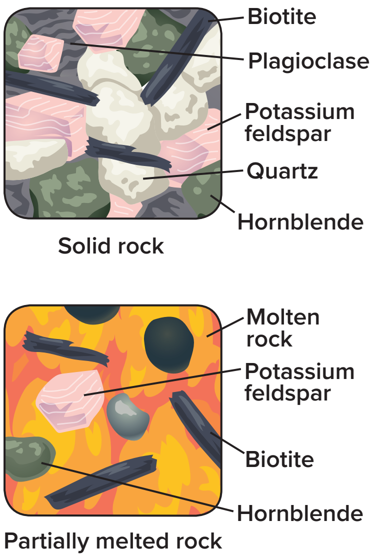


Figure 3 As the temperature increases in an area, minerals begin to melt.

Determine *What can you infer about the melting temperature of quartz based on this diagram?*

Partial melting

Suppose you freeze melted candle wax and water in an ice cube tray. You take the tray out of the freezer and leave it at room temperature. The ice melts, but the candle wax does not. The two substances have different melting points. Rocks melt in a similar way because the minerals they contain have different melting points. Not all parts of a rock melt at the same temperature. This explains why magma is often a slushy mix of crystals and molten rock. The process whereby some minerals melt at relatively low temperatures while other minerals remain solid is called **partial melting.** Partial melting is illustrated in **Figure 3.** As each group of minerals melts, different elements are added to the magma mixture, changing its composition. If temperatures are not high enough to melt the entire rock, the resulting magma will have a different composition from that of the original rock. This is one way in which different types of igneous rocks form.

Get It?

Summarize the formation of magma that has a different chemical composition from the original rock.

Bowen's Reaction Series

In the early 1900s, Canadian geologist N. L. Bowen demonstrated that as magma cools and crystallizes, minerals form in predictable patterns in a process now known as **Bowen's reaction series.** **Figure 4** illustrates the relationship between cooling magma and the formation of minerals that make up igneous rock. Bowen discovered two main patterns, or branches, of crystallization. The left-hand branch is characterized by an abrupt change of mineral type in the iron-magnesium group. A continuous, gradual change of mineral composition characterizes the right-hand branch.

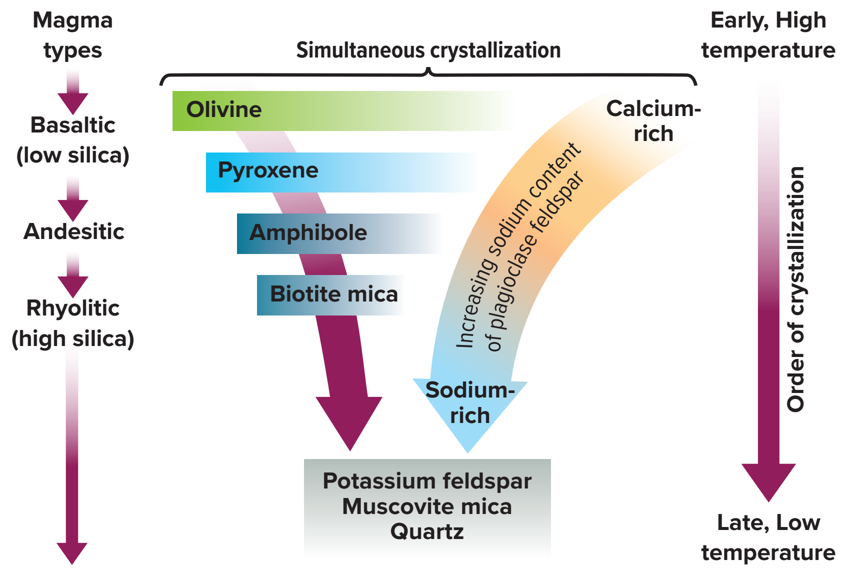


Figure 4 On the left side of Bowen's reaction series, minerals rich in iron and magnesium change abruptly as the temperature of the magma decreases.

Compare *How does this compare to the feldspars on the right side of the diagram?*

Iron-rich minerals

The left branch of Bowen's reaction series represents the iron-rich minerals. These minerals undergo abrupt changes as magma cools and crystallizes. For example, olivine is the first mineral to crystallize when magma that is rich in iron and magnesium begins to cool. When the temperature decreases enough for a completely new mineral, pyroxene, to form, the olivine that previously formed reacts with the magma and is converted to pyroxene. As the temperature decreases further, similar reactions produce the minerals amphibole and biotite mica.

Figure 5 Plagioclase feldspars undergo a continuous change of composition in Bowen's reaction series.

Feldspars

In Bowen's reaction series, the right branch represents the plagioclase feldspars, shown in **Figure 5.** These undergo a continuous change of composition. As magma cools, the first feldspars to form are rich in calcium. As cooling continues, these feldspars react with magma, and their calcium-rich compositions change to sodium-rich compositions. In some instances, such as when magma cools rapidly, the calcium-rich crystals are unable to react completely with the magma. The result is a zoned crystal with a calcium-rich core and sodium-rich outer layers.

Fractional Crystallization

When magma cools, it crystallizes in the reverse order of partial melting. That is, the first minerals that crystallize from magma are the last minerals to melt. This process, called **fractional crystallization,** is similar to partial melting in that the composition of magma can change. In this case, however, early formed crystals are removed from the magma and cannot react with it. As minerals form and their elements are removed from the remaining magma, it becomes concentrated in silica, as shown in **Figure 4.**

As is often the case with scientific inquiry, the discovery of Bowen's reaction series led to more questions. For example, if olivine converts to pyroxene during cooling, why is olivine present in some rocks? Geologists hypothesize that, under certain conditions, newly formed crystals are separated from the cooling magma, and the chemical reactions between the magma and the minerals stop. This can occur when crystals settle to the bottom of the magma body and when liquid magma is squeezed from the crystal mush. This results in the formation of two distinct igneous bodies with different compositions. **Figure 6,** on the next page, illustrates this process and the concept of fractional crystallization with an example from the Hudson River Valley in New York and New Jersey. This is one way in which the magmas listed in **Table 1** are formed.

Figure 7 Quartz veins are deposited from the quartz that was dissolved by hot water from a magma body that cooled and crystallized.

As fractional crystallization continues, and more and more crystals are separated from magma, the magma becomes more concentrated in silica, aluminum, and potassium. For this reason, the last two minerals to crystallize out of a cooling body of magma are potassium feldspar and quartz. Potassium feldspar is one of the most common feldspars in Earth's crust. Quartz often occurs in veins, as shown in **Figure 7,** because hot water dissolved the quartz that crystallizes from the magma. The water then flowed through the cracks, cooled down, and deposited the quartz.

Figure 6 Visualizing Fractional Crystallization and Crystal Settling

The Palisades Sill in the Hudson River Valley of New York and New Jersey is a classic example of fractional crystallization and crystal settling. When magma cools and solidifies before reaching the surface, the rock that forms is called an intrusion. In this basaltic intrusion, small crystals formed in the chill zone as the outer areas of the intrusion cooled more quickly than the interior.

As magma in an intrusion begins to cool, crystals form and settle to the bottom. This layering of crystals is fractional crystallization.

Gabbro

Granite

Diorite

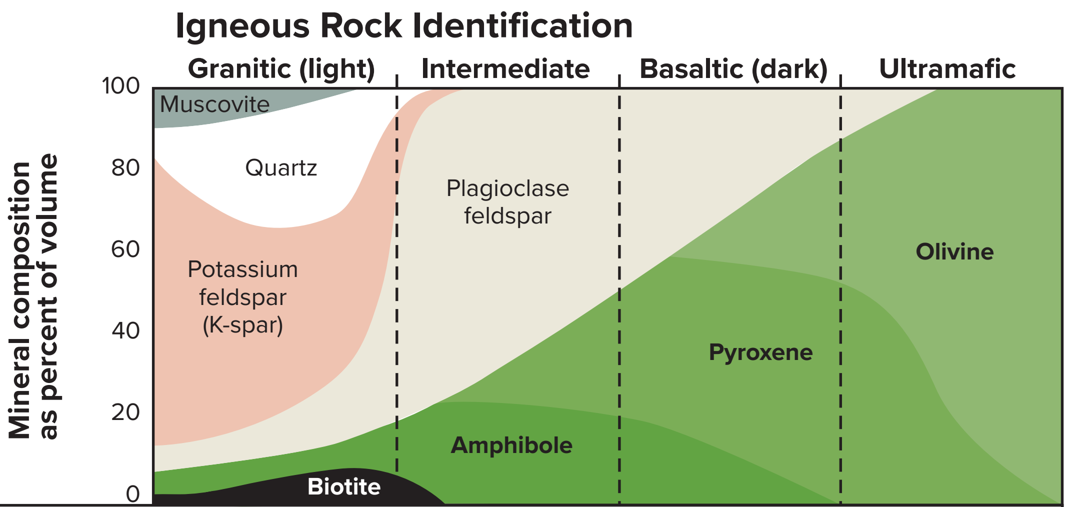
Figure 8 Differences in magma composition can be observed in the rocks that form when the magma cools and crystallizes.

Observe *Describe the differences you see in these rocks.*

Mineral Composition of Igneous Rocks

Igneous rocks are broadly classified as intrusive or extrusive. When magma cools and crystallizes below Earth's surface, **intrusive rocks** form. If the magma is injected into the surrounding rock, it is called an igneous intrusion. Crystals of intrusive rocks are generally large enough to see without magnification. Magma that cools and crystallizes on Earth's surface forms **extrusive rocks.** These are sometimes referred to as lava flows or flood basalts. The crystals that form in these rocks are small and difficult to see without magnification. Geologists classify igneous rocks by their mineral compositions. In addition, physical properties such as grain size and texture serve as clues for the identification of various igneous rocks.

Igneous rocks are classified according to their mineral compositions. **Basaltic rocks,** also called mafic rocks, are dark-colored, have lower silica contents, and contain mostly plagioclase and pyroxene. **Granitic rocks,** or felsic rocks, are light-colored, have high silica contents, and contain mostly quartz and feldspar. Rocks that have a composition of minerals that is somewhere in between basaltic and granitic are called intermediate rocks. They consist mostly of plagioclase feldspar and hornblende. **Figure 8** shows examples from these three main compositional groups of igneous rocks: gabbro is basaltic, granite is granitic, and diorite is intermediate. A fourth category called ultrabasic, or ultramafic, contains rocks with only iron-rich minerals such as olivine and pyroxene and are always dark. **Figure 9** summarizes igneous rock identification.



Origin	Texture	Rock Names			
Intrusive	coarse-grained	granite	diorite	gabbro	peridotite
	porphyritic	porphyritic rhyolite or granite	porphyritic andesite or diorite	porphyritic basalt or gabbro	
Extrusive	fine-grained	rhyolite	andesite	basalt	
	glassy	obsidian			
	vesicular	pumice		scoria (vesicular basalt)	

Figure 9 Rock type can be determined by estimating the relative percentages of minerals in the rocks.

Texture

In addition to differences in their mineral compositions, igneous rocks differ in the sizes of their grains or crystals. **Texture** refers to the size, shape, and distribution of the crystals or grains that make up a rock. For example, as shown in **Figure 10,** the texture of rhyolite can be described as fine-grained, while granite can be described as coarse-grained. The difference in crystal size can be explained by the fact that one rock is extrusive and the other is intrusive.

Figure 10 Rhyolite, granite, and obsidian have different textures because they formed in different ways. Obsidian's glassy texture is a result of rapid cooling.

Figure 11 Rock textures provide information about a rock's formation. Evidence of the rate of cooling and the presence or absence of dissolved gases is preserved in the rocks shown here.

(t)www.sandatlas.org/Shutterstock, (c)theJIPEN/iStockphoto/Getty Images, (b)Jacques Cornell/McGraw-Hill Education

Crystal size and cooling rates When lava flows on Earth's surface, it cools quickly and there is not enough time for large crystals to form. The resulting extrusive igneous rocks, such as rhyolite, which is shown in **Figure 10,** have crystals so small that they are difficult to see without magnification. Sometimes, cooling occurs so quickly that crystals do not form at all. The result is volcanic glass, called obsidian, also shown in **Figure 10.** In contrast, when magma cools slowly beneath Earth's surface, there is sufficient time for large crystals to form. Thus, intrusive igneous rocks, such as granite, diorite, and gabbro, can have crystals larger than 1 cm.

Porphyritic rocks Look at the textures of the rocks shown in **Figure 11.** The top photo shows a rock with different crystal sizes. This rock has a **porphyritic** (por fuh RIH tihk) **texture,** which is characterized by large, well-formed crystals surrounded by finer-grained crystals of the same mineral or different minerals.

What causes minerals to form both large and small crystals in the same rock? Porphyritic textures indicate a complex cooling history during which a slowly cooling magma suddenly began cooling rapidly. Imagine a magma body cooling slowly, deep in Earth's crust. As it cools, the first crystals to form grow large. If this magma were to be suddenly moved higher in the crust, or if it erupted onto Earth's surface, the remaining magma would cool quickly and form smaller crystals.

Vesicular rocks Magma contains dissolved gases that escape when the pressure on the magma lessens. If the lava is thick enough to prevent the gas bubbles from escaping, holes called vesicles are left behind. The rock that forms looks spongy. This spongy appearance is called **vesicular texture.** Pumice and vesicular basalt are examples shown in **Figure 11.**

Get It?

Explain what causes holes to form in igneous rocks.

Thin Sections

It is usually easier to observe the sizes of mineral grains than it is to identify the mineral. To identify minerals, geologists examine samples that are called thin sections. A thin section is a slice of rock, generally 2 cm × 4 cm and only 0.03 mm thick. Because it is so thin, light is able to pass through it.

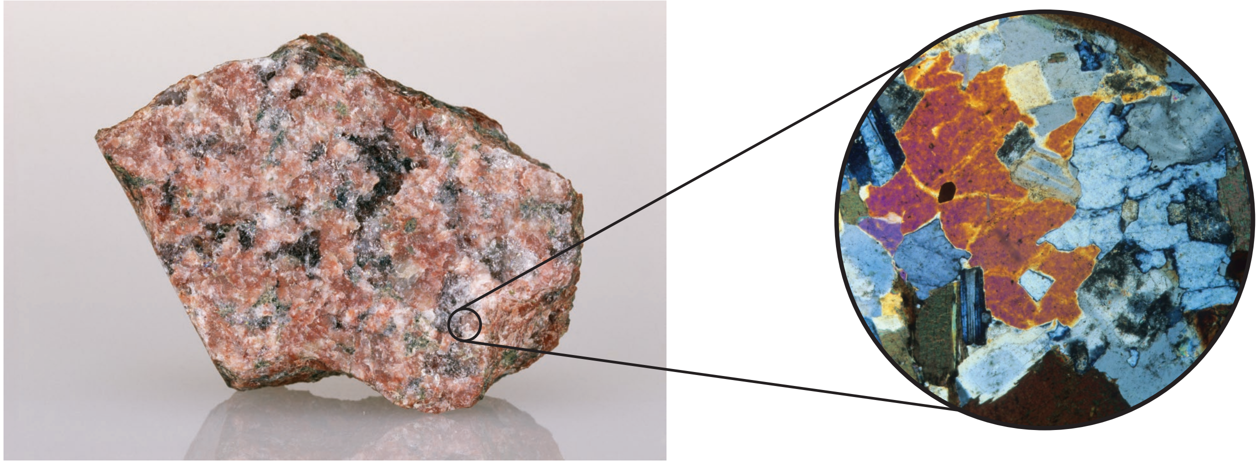


Figure 12 The minerals that make up this piece of granite can be identified in a thin section.

When viewed through a special microscope, called a petrographic microscope, mineral grains exhibit distinct properties. These properties allow geologists to identify the minerals present in the rock. For example, feldspar grains often show a distinct banding called twinning. Quartz grains might appear wavy as the microscope stage is rotated. Calcite crystals become dark, or extinguish, as the stage is rotated. **Figure 12** shows the appearance of a thin section of granite under a petrographic microscope.

Igneous Rocks as Resources

The cooling and crystallization history of igneous rocks sometimes results in the formation of unusual but useful minerals. These minerals can be used in many fields, including construction, energy production, and jewelry making.

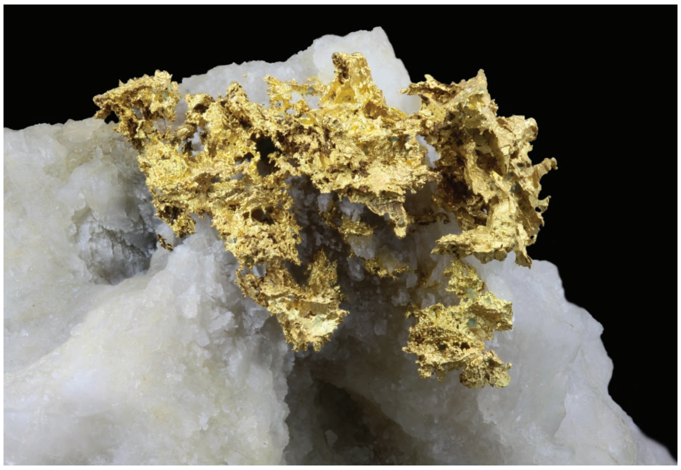


Figure 13 Gold and quartz are extracted from mines together. The two are later separated.

Infer *What can you determine from this photo about the melting temperature of gold?*

Veins

As you have learned, ores are minerals that contain a useful material that can be mined for a profit. Valuable ore deposits often occur within igneous intrusions. In other cases, ore minerals are found in the rocks surrounding intrusions. These types of deposits sometimes occur as veins. Recall from Bowen's reaction series that the fluid left during magma crystallization contains high levels of silica and water. This fluid also contains any leftover elements that were not incorporated into the common igneous minerals. Some important metallic elements that are not included in common minerals are gold, silver, lead, and copper. These elements are released at the end of magma crystallization in a hot, mineral-rich fluid that fills cracks and voids in the surrounding rock. This fluid deposits metal-rich quartz veins, such as the gold-bearing veins in the Sierra Nevada. An example of gold formed in a quartz vein is shown in **Figure 13.**

Get It?

Explain why veins have high amounts of quartz.

Pegmatites

Vein deposits can contain other valuable resources in addition to metals. Igneous rocks that are made of extremely large-grained minerals are called **pegmatites** and are usually found as igneous intrusions or veins. Ores of rare elements, such as lithium (Li) and beryllium (Be), often form in pegmatites. In addition to ores, pegmatites can produce beautiful crystals. Because veins fill cavities and fractures in rock, minerals grow into voids and retain their shapes. Some of the world's most beautiful minerals have been found in pegmatite veins. A famous pegmatite is the source rock for the Mount Rushmore National Memorial, located near Keystone, South Dakota. A close-up view of President Thomas Jefferson, shown in **Figure 14,** reveals the huge mineral veins that run through the rock.

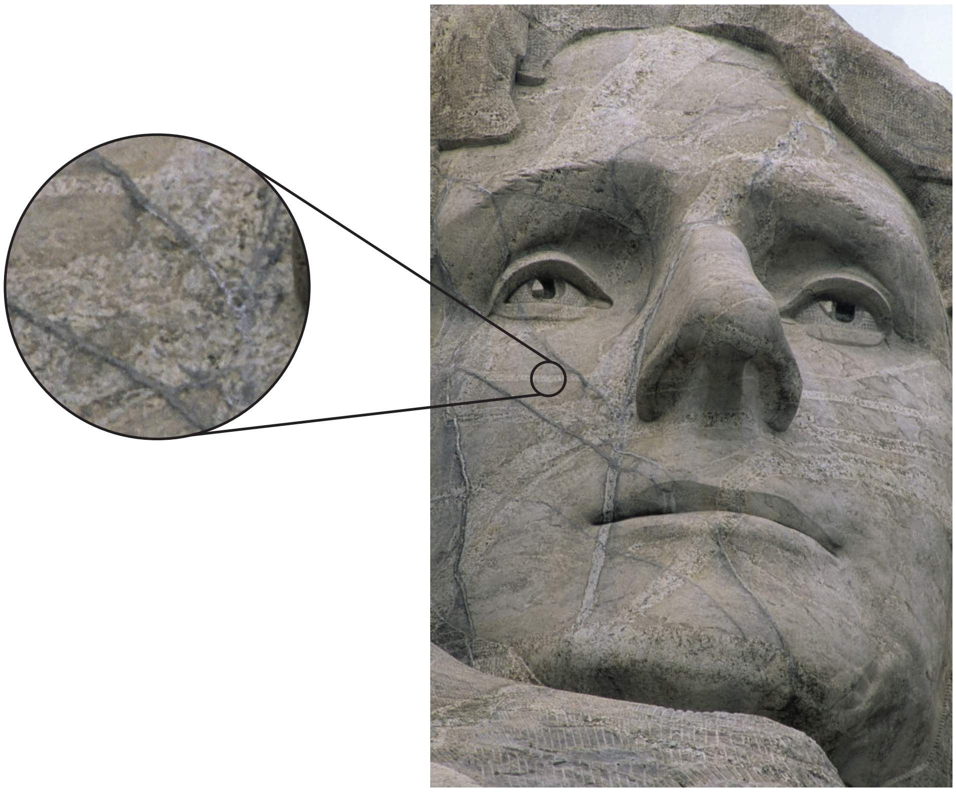


Figure 14 Pegmatite veins cut through much of the rock from which Mount Rushmore National Memorial is carved. You can see the veins running across Thomas Jefferson's face.

Kimberlites

Diamond is a valuable mineral found in rare, ultrabasic rocks known as **kimberlites,** named after Kimberly, South Africa, where the intrusions were first identified. These unusual rocks are a variety of peridotite. They most likely form in the mantle at depths of 150 to 300 km. This is because diamonds and other minerals present in kimberlites can form only under very high pressure.

Geologists hypothesize that kimberlite magma is intruded rapidly upward toward Earth's surface, forming long, narrow, pipelike structures. These structures extend many kilometers into the crust, but they are only 100 to 300 m in diameter. For this reason, they are often called kimberlite pipes.

Most of the world's diamonds come from South African mines, such as the one shown in **Figure 15.** Many kimberlites have been discovered in the United States, but diamonds have been found only in Arkansas and Colorado. The diamond mine in Colorado is the only diamond mine currently in operation in the United States.

Get It?

Explain how kimberlites form and why diamonds are found in kimberlites.

Igneous rocks in construction

Igneous rocks have several characteristics that make them especially useful as building materials. The interlocking grain textures of igneous rocks make them strong. In addition, many of the minerals present in igneous rocks are resistant to weathering.

Granite is among the most durable of igneous rocks. You have probably seen many items, such as countertops, floors, and statues, made from the wide variety of granite that has formed on Earth.

Figure 15 Diamonds are mined from kimberlite in mines like this one in Richtersveld, Northern Cape, South Africa.

Check Your Progress

Summary

- Magma consists of molten rock, dissolved gases, and mineral crystals.
- Magma is classified as basaltic, andesitic, or rhyolitic, based on the amount of silica it contains.
- Different minerals melt and crystallize at different temperatures.
- Bowen's reaction series defines the order in which minerals crystallize from magma.
- Igneous rocks are either ultramafic, basaltic, intermediate, or granitic.
- The rate of cooling determines crystal size.
- Some igneous rocks are used as building materials.

Demonstrate Understanding

1. **Predict** the appearance of an igneous rock that formed as magma cooled quickly and then more slowly.
2. **List** the eight major elements present in most magmas. Include the chemical symbol for each element.
3. **Summarize** the factors that affect the formation of magma.
4. **Identify** mineral resources and how they are used.

Explain Your Thinking

5. **Predict** If the temperature increases toward the center of Earth, why is the inner core solid?
6. **Infer** the silica content of magma derived from partial melting of an igneous rock. Would it be higher, lower, or about the same as the rock itself? Explain.
7. **WRITING Connection** A local rock collector claims that she has found the first example of pyroxene and sodium-rich feldspar in the same rock. Write a commentary about her claim for publication in a rock collector society newsletter.

LEARNSMART® Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

LESSON 2
SEDIMENTARY ROCKS

FOCUS QUESTION

How do rocks become sediment?

Weathering and Erosion

Wherever rock is exposed at Earth's surface, it is continuously being broken down by weathering—a set of physical and chemical processes that breaks rock into smaller pieces. **Sediments** are small pieces of rock that are moved and deposited by water, wind, glaciers, and gravity. When sediments become glued together, they form sedimentary rocks. The formation of sedimentary rocks begins when weathering and erosion produce sediments.

Weathering

Weathering produces rock and mineral fragments, known as sediments, that range in size from huge boulders to microscopic particles. Chemical weathering occurs when the minerals in a rock are dissolved or otherwise chemically changed. What happens to more resistant minerals during weathering? While the less stable minerals are chemically broken down, the more resistant grains are broken off of the rock as smaller grains. During physical weathering, however, minerals remain chemically unchanged. Rock fragments break off of the solid rock along fractures or grain boundaries. The rock in **Figure 16** has been chemically and physically weathered.

Figure 16 When exposed to both chemical and physical weathering, granite eventually breaks apart and might look like the decomposed granite shown here.

Infer *which of the three common minerals—quartz, feldspar, and mica—is most resistant to chemical weathering.*

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Investigation Lab: Comparing Chemical Sedimentary Rocks and Modeling Their Formation

Carry out an investigation into the changes that occur during the formation of sedimentary rocks.

Quick Investigation: Model Sediment Layering

Develop and use a model to visualize the result of sediment settling.

Erosion

The removal and transport of sediment is called erosion. **Figure 17** shows the four main agents of erosion: wind, moving water, gravity, and glaciers. Visible signs of erosion are all around you. You can observe erosion in action when a gust of wind blows soil across the infield at a baseball park. The force of the wind removes the soil and carries it away. In another example, water in streams becomes muddy after a storm because eroded silt and clay-sized particles have been mixed in it. Glaciers are large masses of ice that move across land. As they move, they drag sediments with them.

After rock fragments and sediments have been weathered out of the rock, they often are transported to new locations through the process of erosion. Eroded material is almost always carried downhill. Although wind can sometimes carry fine sand and dust to higher elevations, particles transported by water are almost always moved downhill. Eventually, even windblown dust and fine sand are pulled downhill by gravity.

Get It?

Summarize what occurs during erosion.

Figure 17 Rocks and sediment are weathered and transported by the main agents of erosion—wind, moving water, gravity, and glaciers.

Deposition

When transported sediments are deposited on the ground or sink to the bottom of a body of water, deposition occurs. Sediments in nature are deposited when transport stops. Perhaps the wind stops blowing or a river enters a quiet lake or an ocean. In each case, the particles being carried will settle out, forming layers of sediment, with the largest grains at the bottom and the smallest grains at the top.

Energy of transporting agents

Fast-moving water can transport larger particles better than slow-moving water. As water slows down, the largest particles settle out first, then the next largest, and so on, so that different-sized particles are sorted into layers. Such deposits are characteristic of sediment transported by water and wind. Wind, however, can move only small grains. For this reason, sand dunes are commonly made of fine, well-sorted sand, as shown in **Figure 18.** Not all sediment deposits are sorted. Glaciers, for example, move all materials with equal ease. Large boulders, sand, and mud are all carried along by the ice and dumped in an unsorted pile as the glacier melts. Landslides create similar deposits when sediment moves downhill in a jumbled mass.

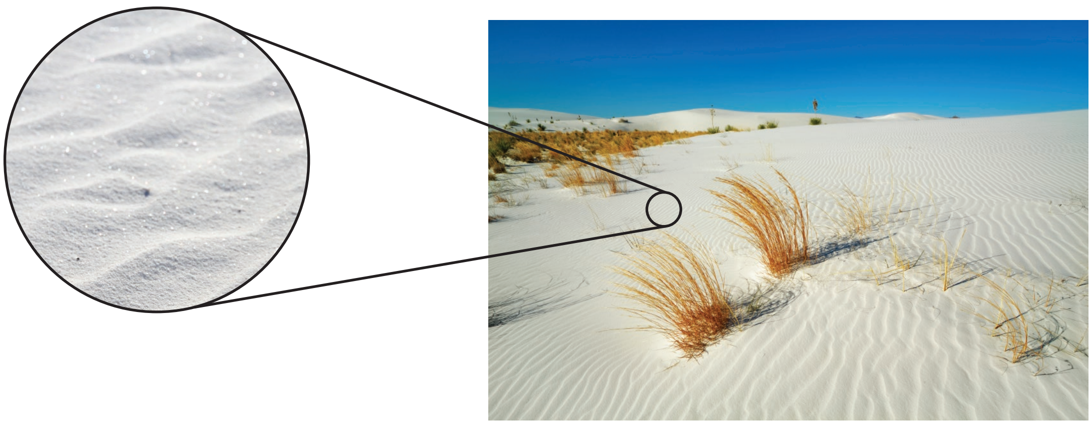


Figure 18 These sand dunes at White Sands National Monument in New Mexico were formed by windblown sand that has been transported and redeposited. Notice the uniform size of the sand grains.

Lithification

Most sediments are ultimately deposited on Earth in low areas such as valleys and ocean basins. As more sediment is deposited in an area, the bottom layers are subjected to increasing pressure and temperature. These conditions cause **lithification,** the physical and chemical processes that transform sediments into sedimentary rocks. *Lithify* comes from the Greek word *lithos*, which means "stone."

STEM CAREER Connection

Sedimentologist

Do you wonder if sediments contain pollutants or other chemicals? Do you like learning about human history by examining layers of sediment? If so, you may enjoy working as a sedimentologist. Sedimentologists work both in the field, where they collect samples, and in the lab, where they analyze samples.

CCC CROSSCUTTING CONCEPTS

Structure and Function Beach dunes are formed when wind blows grains of sand into an area where the sand accumulates. You may have noticed that on the side of a dune facing the wind, the sand grains are blown up the side. The side away from the wind is usually smooth compared to the side facing the wind.

Compaction

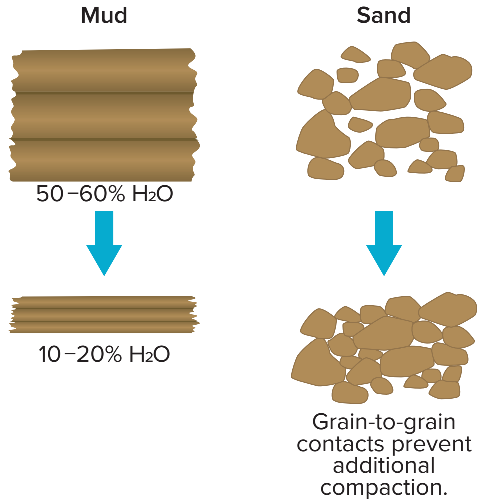


Figure 19 The high water content and flat shape of particles in mud cause it to compact greatly when subjected to the weight of overlying sediments.

Lithification begins with compaction. The weight of overlying sediments forces the sediment grains closer together, causing the physical changes shown in **Figure 19.** Layers of mud can contain up to 60 percent water, and these shrink as excess water is squeezed out. Sand does not compact as much as mud during burial, partly because individual sand grains, usually composed of quartz, do not deform under normal burial conditions. Grain-to-grain contacts in sand form a supporting framework that helps maintain open spaces between the grains. Groundwater, oil, and natural gas are commonly present in these spaces in sedimentary rocks.

Cementation

Compaction is not the only force that binds the grains together. **Cementation** occurs when mineral growth glues sediment grains together into solid rock. This occurs when a new mineral, such as quartz (SiO_2), calcite ($CaCO_3$), or iron oxide (Fe_2O_3), grows between sediment grains as dissolved minerals precipitate out of groundwater. This process is illustrated in **Figure 20.**

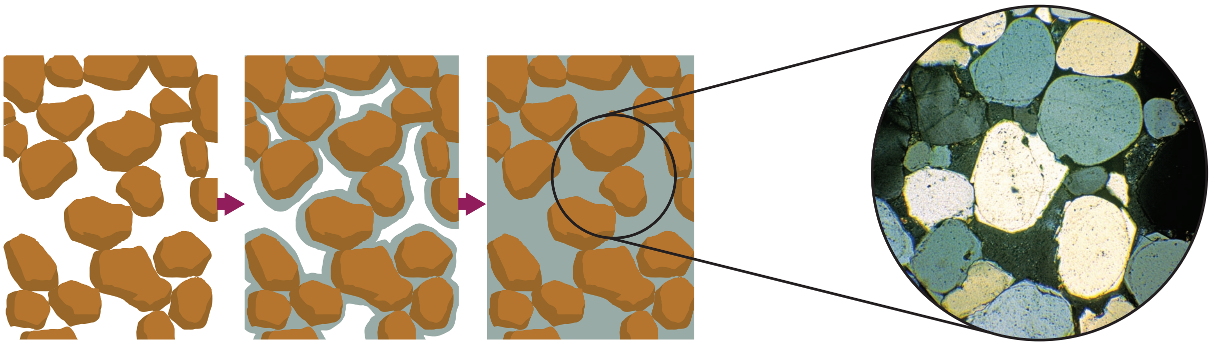


Figure 20 Minerals precipitate out of water as it flows through pore spaces in the sediment. These minerals form the cement that glues the sediments together.

Sedimentary Features

Just as igneous rocks contain information about the history of their formation, sedimentary rocks also have features and characteristics that help geologists interpret how they formed and the history of the area in which they formed.

Bedding

The primary feature of sedimentary rocks is horizontal layering called **bedding.** This feature results from the way sediment settles out of water or wind. Individual beds can range in thickness from a few millimeters to several meters. There are two different types of bedding, each dependent upon the method of transport. However, the size of the grains and the material within the bedding depend upon many other factors.

Graded bedding

Bedding in which the particle sizes become progressively finer and lighter toward the top layers is called **graded bedding.** Graded bedding is often observed in marine sedimentary rocks that were deposited by underwater landslides. As the sliding material slowly came to rest under water, the largest and heaviest material settled out first and was followed by progressively finer material. An example of graded bedding is shown in **Figure 21.**

Cross-bedding

Another characteristic feature of sedimentary rocks is cross-bedding. **Cross-bedding,** shown in **Figure 22,** is formed as layers of sediment are deposited at an incline across a horizontal surface. When these deposits become lithified, the cross-beds are preserved in the rock. Small-scale cross-bedding forms on sandy beaches and along sandbars in streams and rivers. Most large-scale cross-bedding is formed by migrating sand dunes.

Get It?

Contrast graded bedding and cross-bedding.

Ripple marks When sediment is moved into small ridges by wind or wave action or by a river current, ripple marks form. The back-and-forth movement of waves on a shore pushes the sand on the bottom into symmetrical ripple marks, where grain size is evenly distributed. When a current flows in one direction, such as in a river, it pushes the sediment on the bottom into asymmetrical ripple marks. The ripple marks are steeper upstream and contain coarser sediment on the upstream side. If a rippled surface is buried gently by more sediment without being disturbed, it might be preserved in solid rock. The formation of ripple marks is illustrated in **Figure 23.**

Get It?

Explain how the two types of ripple marks form.

Figure 21 The graded bedding (shown between the arrows in this photo) of the Furnace Creek Formation in Death Valley, California, records an episode of deposition during which the water that carried these sediments slowed and lost energy.

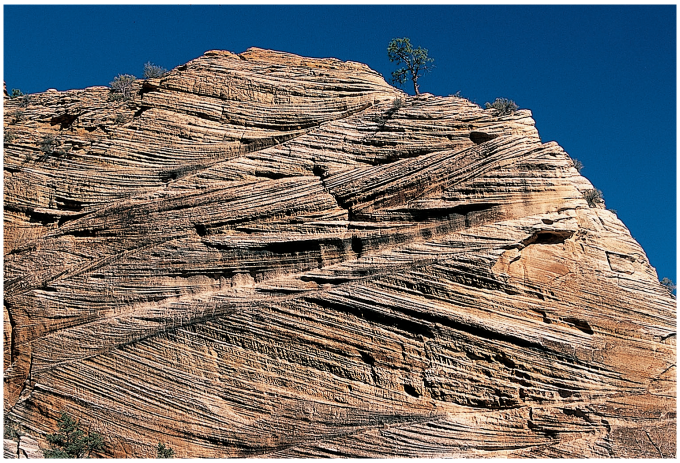


Figure 22 The large-scale cross-beds in these ancient dunes at Zion National Park were deposited by wind.

SCIENCE USAGE v. COMMON USAGE

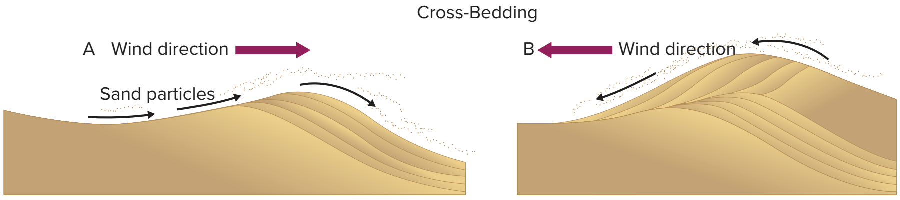
grade

Science usage: a position in a scale of ranks or qualities

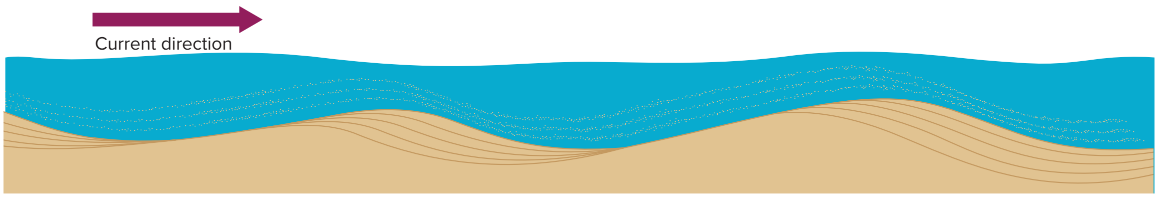
Common usage: a mark indicating a degree of knowledge or completion in school

Figure 23 Visualizing Cross-Bedding and Ripple Marks

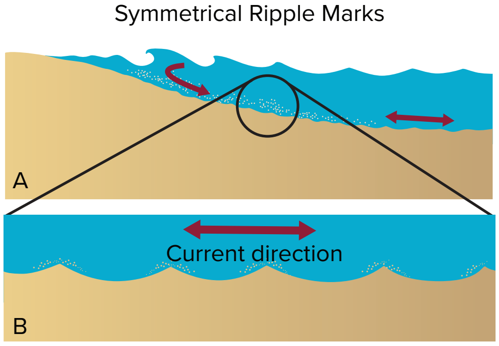
Moving water and loose sediment result in the formation of sedimentary structures such as cross-bedding and ripple marks.



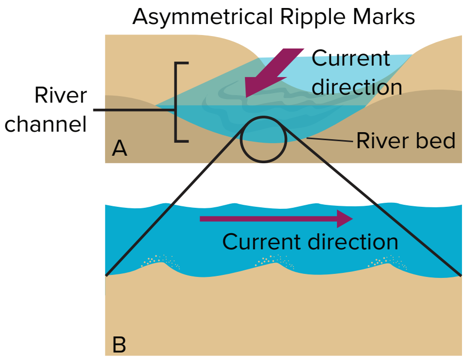
Sand carried by wind gets deposited on the downwind side of a dune. As the wind changes direction, cross-bedding is formed that records this change in direction.



Sediment on the river bottom gets pushed into small hills and ripples by the current. Additional sediment gets deposited at an angle on the downcurrent side of these hills forming cross-beds. Eventually, it levels out or new hills form and the process begins again.



The back-and-forth wave action on a shore pushes the sand on the bottom into symmetrical ripple marks. Grain size is evenly distributed.



Current that flows in one direction, such as that of a river, pushes sediment on the bottom into asymmetrical ripple marks. They are steeper upstream and contain coarser sediment on the upstream side.

Angular vs. rounded

Some individual sediment grains have jagged, angular edges, and some are rounded. When a rock breaks apart, the pieces are initially angular in shape. As the sediment is transported away from its source, individual pieces knock into each other. The edges are broken off and, over time, the pieces become rounded. The amount of rounding is influenced by how long the sediment has been in transport and how far the sediment has traveled. Also, harder minerals with little to no cleavage have a better chance of becoming rounded before they break apart. As shown in **Figure 24,** quartz sand on beaches is nearly round, while carbonate sand, which is made up of seashells and calcite, is usually more angular because it is deposited closer to the source of the sediment.

Figure 24 The carbonate sand has sharp, jagged pieces and is not as rounded and smooth as the quartz sand.

Evidence of past life

Probably the best-known features of sedimentary rocks are fossils. Fossils are the preserved remains or impressions or any other evidence, of once-living organisms. When an organism dies, if its remains are buried without being disturbed, it might be preserved as a fossil. During lithification, parts of the organism can be replaced by minerals and turned into rock, such as shells that have been mineralized.

Clastic Sedimentary Rocks

The most common sedimentary rocks, **clastic sedimentary rocks,** are formed from the abundant deposits of loose sediments that accumulate on Earth's surface. The word **clastic** comes from the Greek word *klastos*, meaning "broken." These rocks are further classified according to the sizes of their particles. As you read about each rock type, refer to **Table 2** on the next page, which summarizes the classification of sedimentary rocks based on grain size, mode of formation, and mineral content.

Coarse-grained rocks Sedimentary rocks consisting of gravel-sized rock and mineral fragments are classified as coarse-grained rocks, samples of which are shown in **Figure 25.** Conglomerates have rounded, gravel-sized particles. Because of its relatively large mass, gravel is transported by high-energy flows of water, such as those generated by mountain streams, flooding rivers, some ocean waves, and glacial meltwater. During transport, gravel becomes abraded and rounded as the particles scrape against one another. This is why beach and river gravels are often well rounded. Lithification turns these sediments into conglomerates.

In contrast, breccias are composed of angular, gravel-sized particles. The angularity indicates that the sediments from which they formed did not have time to become rounded. This suggests that the particles were transported only a short distance and deposited close to their source. Refer to **Table 2** to see how these rocks are named.

Figure 25 Conglomerates and breccias are made of coarse sediments that have been transported by high-energy water.

Infer *the circumstances that might cause the types of transport necessary for each to form.*

Table 2 Classification of Sedimentary Rocks

Classification	Texture/Grain Size	Composition	Rock Name
Clastic	coarse (> 2 mm)	Fragments of any rock type—quartz, chert and quartzite common } rounded / angular	conglomerate breccia
	medium (1/16 mm to 2 mm)	quartz and rock fragments quartz, potassium feldspar and rock fragments	sandstone arkose
	fine (1/256 mm–1/16 mm)	quartz and clay	siltstone
	very fine (< 1/256 mm)	quartz and clay	shale
Biochemical	microcrystalline with conchoidal fracture	calcite ($CaCO_3$) quartz (SiO_2)	micrite chert
	abundant fossils in micrite matrix	calcite ($CaCO_3$)	fossiliferous limestone
	shells and shell fragments loosely cemented	calcite ($CaCO_3$)	coquina
	microscopic shells and clay	calcite ($CaCO_3$)	chalk
	variously sized fragments	highly altered plant remains, some plant fossils	coal
Chemical	ooids (small spheres of calcium carbonate)	calcite ($CaCO_3$)	oolitic limestone
	fine to coarsely crystalline	calcite ($CaCO_3$)	crystalline limestone
	fine to coarsely crystalline	dolomite $(Ca,Mg)CO_3$ (will effervesce if powered)	dolostone
	very finely crystalline	quartz (SiO_2)—light colored; dark colored calcite ($CaCO_3$)	chert; flint micrite
	fine to coarsely crystalline	gypsum ($CaSO_4 \cdot 2H_2O$)	rock gypsum
	fine to coarsely crystalline	halite (NaCl)	rock salt

Medium-grained rocks Stream and river channels, beaches, and deserts often contain abundant sand-sized sediments. Sedimentary rocks that contain sand-sized rock and mineral fragments are classified as medium-grained clastic rocks. Refer to **Table 2** for a listing of rocks with sand-sized particles. Sandstone usually contains several features of interest to scientists. For example, because ripple marks and cross-bedding indicate the direction of current flow, geologists use sandstone layers to map ancient stream and river channels.

Another important feature of sandstone is its relatively high porosity. **Porosity** is the percentage of open spaces between grains in a rock. Loose sand can have a porosity of up to 40 percent. Some of these open spaces are maintained during the formation of sandstone, often resulting in porosities as high as 30 percent. When pore spaces are connected to one another, fluids can move through sandstone. This feature makes sandstone layers valuable as underground reservoirs of oil, natural gas, and groundwater.

ACADEMIC VOCABULARY

reservoir

a subsurface area of rock that has enough porosity to allow for the accumulation of oil, natural gas, or water

The newly discovered reservoir contained large amounts of natural gas and oil.

Fine-grained rocks Sedimentary rocks consisting of silt- and clay-sized particles, such as siltstone and shale, are called fine-grained rocks. These rocks represent environments like swamps, ponds, and deep oceans which have still or slow-moving waters. In the absence of strong currents and wave action, these sediments settle to the bottom where they accumulate in thin horizontal layers. Shale often breaks along thin layers, as shown in **Figure 26.** Unlike sandstone, fine-grained sedimentary rock has low porosity and often forms barriers that hinder the movement of groundwater and oil. **Table 2** shows how these rocks are named.

Figure 26 The very fine-grained sediment that formed this shale was deposited in thin layers in still waters.

Get It?
Identify the types of environments in which fine-grained rocks form.

Chemical and Biochemical Sedimentary Rocks

The formation of chemical and biochemical rocks involves the processes of evaporation and precipitation of minerals. During weathering, minerals can be dissolved and carried into lakes and oceans. As water evaporates from the lakes and oceans, the dissolved minerals are left behind. In arid regions, high evaporation rates can increase the concentration of dissolved minerals in bodies of water. The Great Salt Lake, shown in **Figure 27**, is an example of a lake that has high concentrations of dissolved minerals.

Chemical sedimentary rocks When the concentration of dissolved minerals in a body of water reaches saturation, crystals can precipitate out of solution and settle to the bottom. As a result, layers of chemical sedimentary rocks form, most of which are called **evaporites.** Evaporites primarily form in arid regions, drainage basins on continents that have low water flow, and in coastal settings. Because these areas usually have minimal freshwater input and high rates of evaporation, the concentration of dissolved minerals remains high. Over time, thick layers of evaporite minerals can accumulate on basin floors, as illustrated in **Figure 27**.

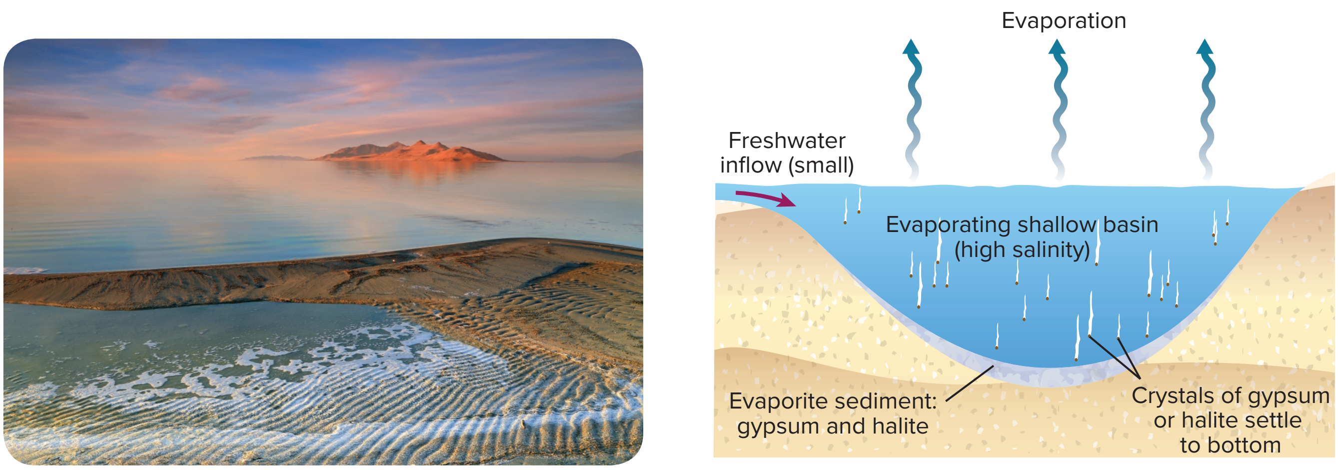


Figure 27 The constant evaporation from a body of salt water results in precipitation of large amounts of salt. This process has been occurring in the Great Salt Lake in Utah for approximately 18,000 years.

Biochemical sedimentary rocks Biochemical sedimentary rocks are formed from the remains of once-living organisms. The most abundant of these rocks is limestone, which is composed primarily of calcite. Some organisms that live in the ocean use the calcium carbonate that is dissolved in seawater to make their shells. When these organisms die, their shells settle to the bottom of the ocean and can form thick layers of carbonate sediment. During burial and lithification, calcium carbonate precipitates out of the water, crystallizes between the grains of carbonate sediment, and forms limestone.

Limestone is common in shallow water environments, such as those in the Bahamas, where coral reefs thrive in 15 to 20 m of water just offshore. The skeletal and shell materials that are currently accumulating there will someday become limestone as well. Many types of limestone contain evidence of their biological origin in the form of abundant fossils. As shown in **Figure 28,** these fossils can range from large-shelled organisms to microscopic, unicellular organisms. However, not all limestone contains fossils or is biochemical in origin. Some limestone has a crystalline texture or consists of tiny spheres of carbonate sand called ooids. These are listed in **Table 2.**

Other organisms make their shells out of silica, or microcrystalline quartz. After these organisms die and settle to the bottom of the ocean, their shells can form sediment that is often referred to as siliceous ooze because it is rich in silica. Siliceous ooze becomes lithified into the sedimentary rock chert, which is also listed in **Table 2.**

Figure 28 Limestone can contain many different fossil organisms. Geologists can interpret where and when the limestone formed by studying the fossils within the rock.

Check Your Progress

Summary

- The processes of weathering, erosion, deposition, and lithification form sedimentary rocks.
- Sediments are lithified into rock by the processes of compaction and cementation.
- Clastic rocks form from sediments and are classified by particle size and shape.
- Chemical rocks form primarily from minerals precipitated from water.
- Biochemical rocks form from the remains of once-living organisms.

Demonstrate Understanding

1. **Describe** how sediments are produced by weathering and erosion.
2. **Sequence** Use a flowchart to show why sediment deposits tend to form layers.
3. **Compare** temperature and pressure conditions at Earth's surface and below Earth's surface, and relate them to the process of lithification.

Explain Your Thinking

4. **Determine** whether you are walking upstream or downstream along a dry mountain streambed if you notice that the shape of the sediment is getting more angular as you continue walking. Explain.
5. **WRITING Connection** Imagine you are designing a museum display based on a sedimentary rock that contains fossils of corals and other marine animals. Draw a picture of what this environment might have looked like, and write the accompanying description that will be posted next to the display.

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LESSON 3

METAMORPHIC ROCKS

FOCUS QUESTION

How can we tell when a rock has been transformed?

Recognizing Metamorphic Rock

The rock layers shown in **Figure 29** have been metamorphosed (meh tuh MOR fohzd)—this means that they have been changed. How do geologists know that this has happened? Pressure and temperature increase with depth. When temperature and pressure become high enough, rocks melt and form magma. But what happens if the rocks do not reach the melting point? When temperature and pressure combine and change the texture, mineral composition, or chemical composition of a rock without melting it, a metamorphic rock forms. The word *metamorphism* is derived from the Greek words *meta*, meaning "change," and *morphé*, meaning "form." During metamorphism, a rock changes form while remaining solid.

The high temperatures required for metamorphism are ultimately derived from Earth's internal heat, either through deep burial or from nearby igneous intrusions. The high pressures required for metamorphism come from deep burial or from compression during mountain building.

Figure 29 Strong forces were required to bend these rock layers into the shape they are today.
Hypothesize *the changes that occurred to the sediments after they were deposited.*

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

GeoLAB: Interpret Changes in Rocks
Construct an explanation of the changes that occur to a rock during metamorphosis.

Revisit the Encounter the Phenomenon Question
What information from this lesson can help you answer the Unit and Module questions?

Metamorphic minerals

How do minerals change without melting? Think back to the concept of fractional crystallization. Bowen's reaction series shows that all minerals are stable at certain temperatures, and they crystallize from magma along a range of different temperatures. Scientists have discovered that these stability ranges also apply to minerals in solid rock. During metamorphism, the minerals in a rock change into new minerals that are stable under the new temperature and pressure conditions. Minerals that change in this way are said to undergo solid-state alterations. Scientists have conducted experiments to identify the metamorphic conditions that create specific minerals. When the same minerals are identified in rocks, scientists are able to interpret the conditions inside the crust during the rocks' metamorphism. **Figure 30** shows some common metamorphic minerals.

Figure 30 Metamorphic minerals, such as mica, staurolite, garnet, and talc (shown above, clockwise from top left), occur in many colors, shapes, and crystal sizes. Colors can be dark or light, and crystal form can be unique.

Get It?

Explain what metamorphic minerals are.

Metamorphic textures

Metamorphic rocks are classified into two textural groups: foliated and nonfoliated. Geologists use metamorphic textures and mineral composition to identify metamorphic rocks. **Figure 31** shows how these two characteristics are used in the classification of metamorphic rocks.

Foliated rocks Layers and bands of minerals characterize **foliated** metamorphic rocks. High pressure during metamorphism causes minerals with flat or needlelike crystals to form with their long axes perpendicular to the pressure, as shown in **Figure 32.** This parallel alignment of minerals creates the layers observed in foliated metamorphic rocks.

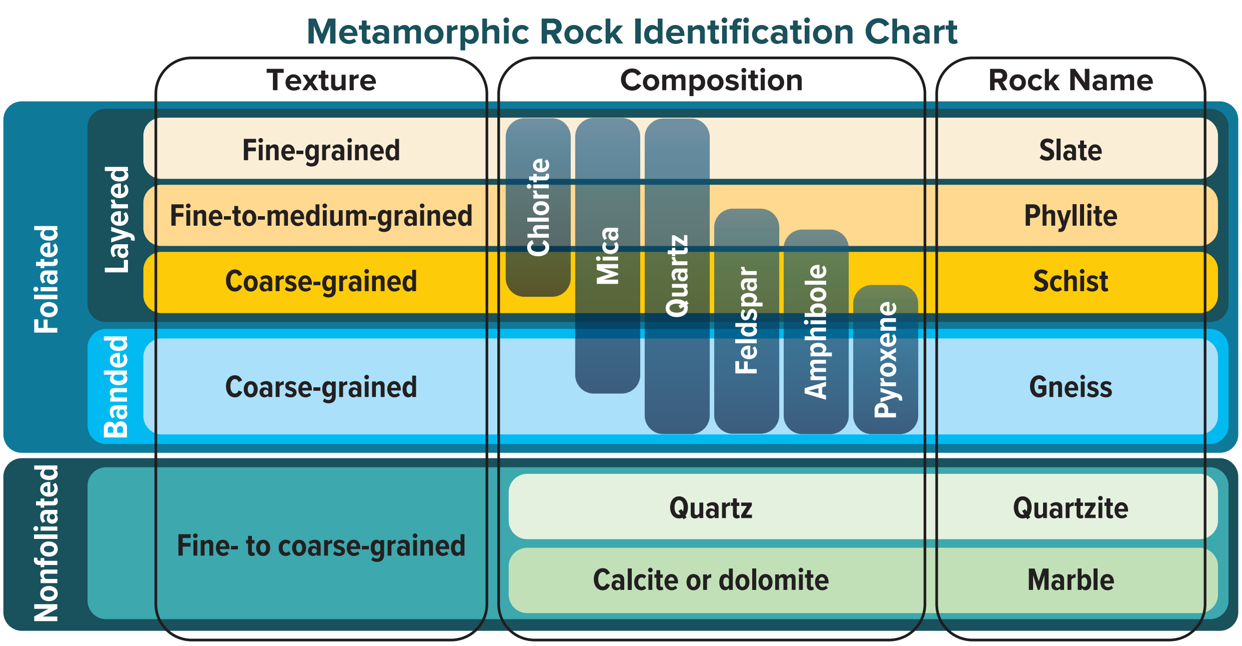

Figure 31 Increasing grain size parallels changes in composition and development of foliation. Grain size is not a factor in nonfoliated rocks.

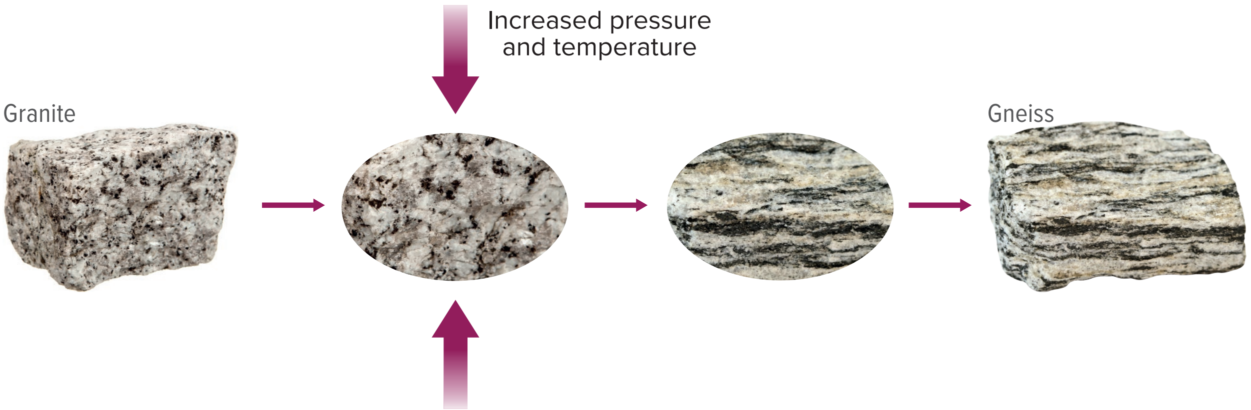

Figure 32 Foliation develops when pressure is applied from opposite directions. The foliation develops perpendicular to the pressure direction.

Nonfoliated rocks

Unlike foliated rocks, **nonfoliated** metamorphic rocks are composed mainly of minerals that form with blocky crystal shapes. Two common examples of nonfoliated rocks, shown in **Figure 33,** are quartzite and marble. Quartzite is a hard, often light-colored rock formed by the metamorphism of quartz-rich sandstone. Marble is formed by the metamorphism of limestone or dolomite. Some marbles have smooth textures that are formed by interlocking grains of calcite. These marbles are often used in sculptures. Fossils are rarely preserved in metamorphic rocks.

Under certain conditions, new metamorphic minerals can grow large while the surrounding minerals remain small. The large crystals, which can range in size from a few millimeters to a few centimeters, are called porphyroblasts. Although these crystals resemble the very large crystals that form in pegmatite granite, they are not the same. Instead of forming from magma, they form in solid rock through the reorganization of atoms during metamorphism. Garnet, shown in **Figure 33,** is a mineral that commonly forms porphyroblasts.

Marble | Quartzite | Garnet porphyroblasts in schist

Figure 33 As a result of the extreme heat and pressure during metamorphism, marble rarely contains fossils. Metamorphism does not, however, always destroy cross-bedding and ripple marks, which can be seen in some quartzites. Garnet porphyroblasts can grow to be quite large in some rocks, as shown by the garnets in this sample of schist.

Grades of Metamorphism

Different combinations of temperature and pressure result in different grades of metamorphism. Low-grade metamorphism is associated with low temperatures and pressures and a particular suite of minerals and textures. High-grade metamorphism is associated with high temperatures and pressures and a different suite of minerals and textures. Intermediate-grade metamorphism is in between low- and high-grade metamorphism.

Figure 34 shows the minerals present in metamorphosed shale. Note the change in composition as conditions change from low-grade to high-grade metamorphism. Geologists can create metamorphic maps by plotting the location of metamorphic minerals. Knowing the temperatures that certain areas experienced when rocks were forming helps geologists locate valuable metamorphic minerals such as garnet and talc. Studying the distribution of metamorphic minerals helps geologists to interpret the metamorphic history of an area.

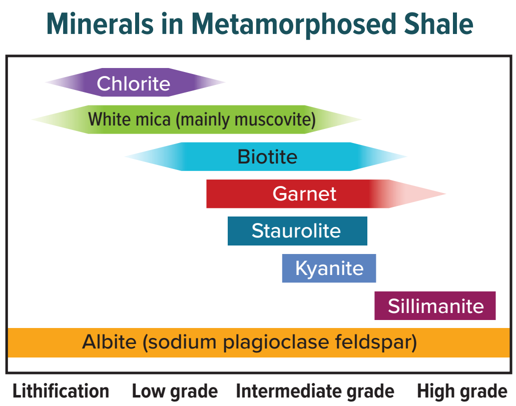

Figure 34 Metamorphism of shale results in the formation of minerals that provide the wide variety of color observed in slate.

Types of Metamorphism

The effects of metamorphism can be the result of contact metamorphism, regional metamorphism, or hydrothermal metamorphism. The minerals that form and the degree of change in the rocks provide information as to the type and grade of metamorphism that occurred.

Regional metamorphism

When temperature and pressure affect large regions of Earth's crust, they produce large belts of **regional metamorphism.** The metamorphism can range in grade from low to high. Results of regional metamorphism include changes in minerals and rock types, foliation, and folding and deforming of the rock layers that make up the area. The folded rock layers shown in **Figure 29** experienced regional metamorphism.

Contact metamorphism

When molten material, such as that in an igneous intrusion, comes in contact with solid rock, a local effect called **contact metamorphism** occurs. High temperature and moderate-to-low pressure form mineral assemblages that are characteristic of contact metamorphism.

SCIENCE USAGE v. COMMON USAGE

intrusion

Science usage: the placement of a body of magma into preexisting rock

Common usage: the act of joining or coming into without being invited

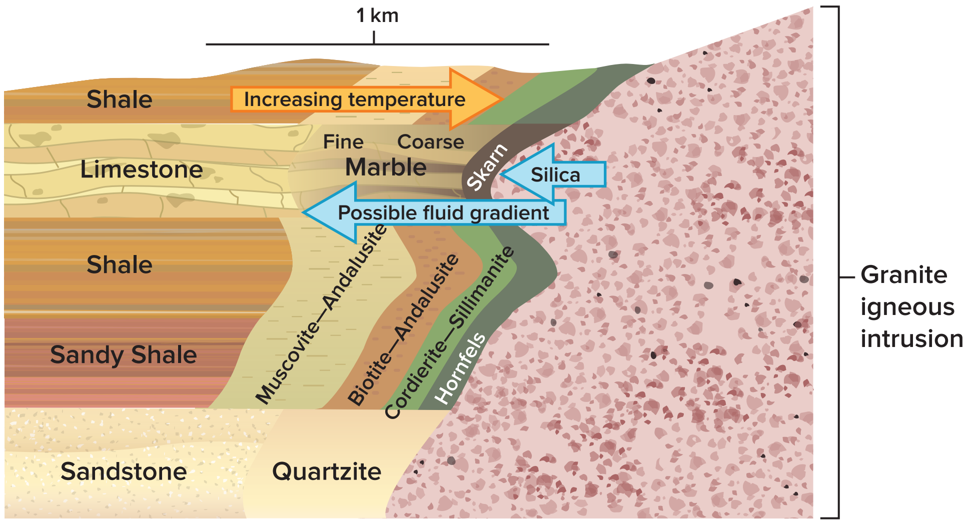

Figure 35 Contact metamorphism from the intrusion of this granite batholith has caused zones of metamorphic minerals to form.

Figure 35 shows zones of different minerals surrounding an intrusion. Because temperature decreases with distance from an intrusion, metamorphic effects also decrease with distance. Recall that minerals crystallize at specific temperatures. Metamorphic minerals that form at high temperatures occur closest to the intrusion, where it is hottest. Because lava cools too quickly for the heat to penetrate far into surface rocks, contact metamorphism from extrusive igneous rocks is limited to thin zones.

Hydrothermal metamorphism

When very hot water reacts with rock and alters its chemical and mineral composition, **hydrothermal metamorphism** occurs. The word *hydrothermal* is derived from the Greek words *hydro*, meaning "water," and *thermal*, meaning "heat." As hot fluids migrate in and out of the rock during metamorphism, the original mineral composition and texture of the rock can change. Chemical changes are common during contact metamorphism near igneous intrusions and active volcanoes. Valuable ore deposits of gold, copper, zinc, tungsten, and lead are formed in this manner.

Economic Importance of Metamorphic Rocks and Minerals

The modern way of life is made possible by a great number of naturally occurring Earth materials. We use salt for cooking; gold for trade; other metals for construction and industrial purposes; fossil fuels for energy; and rocks and various minerals for construction, cosmetics, and more. **Figure 36,** on the next page, shows two examples of how metamorphic rocks are used in construction. Many economic mineral resources are produced by metamorphic processes. Among these are the metals gold, silver, copper, and lead, as well as many significant nonmetallic resources.

Figure 36 Marble and slate are metamorphic rocks that have been used in construction for centuries.

Metallic mineral resources

Metallic resources occur mostly in the form of metal ores, although deposits of pure metals are occasionally discovered. Many metallic deposits are precipitated from hydrothermal solutions and are either concentrated in veins or spread throughout a rock mass. Native gold, silver, and copper deposits tend to occur in hydrothermal quartz veins near igneous intrusions or in contact metamorphic zones. However, most hydrothermal metal deposits are in the form of metal sulfides such as galena (PbS) or pyrite (FeS_2). The iron ores magnetite and hematite are oxide minerals often formed by precipitation from iron-bearing hydrothermal solutions.

Get It?

State the resources that hydrothermal metamorphism produces.

Nonmetallic mineral resources

Metamorphism of ultrabasic igneous rocks produces the minerals talc and asbestos. Talc, with a hardness of 1, is used as a dusting powder, as a lubricant, and to provide texture in paints. Because it is not combustible and has low thermal and electric conductivity, asbestos has been used in fireproof and insulating materials. Prior to the recognition of its cancer-causing properties, it was also widely utilized in the construction industry. Many older buildings still have asbestos-containing materials. Graphite, the main ingredient of the lead in pencils, is formed by the metamorphism of organic material.

Get It?

Explain why asbestos is no longer used in the construction industry.

CCC CROSSCUTTING CONCEPTS

Energy and Matter The rock cycle provides another example of the concept that neither matter nor energy can be created or destroyed. In the rock cycle, older rocks are recycled to form younger rocks. Energy in the rock cycle comes from the Sun and Earth's interior.

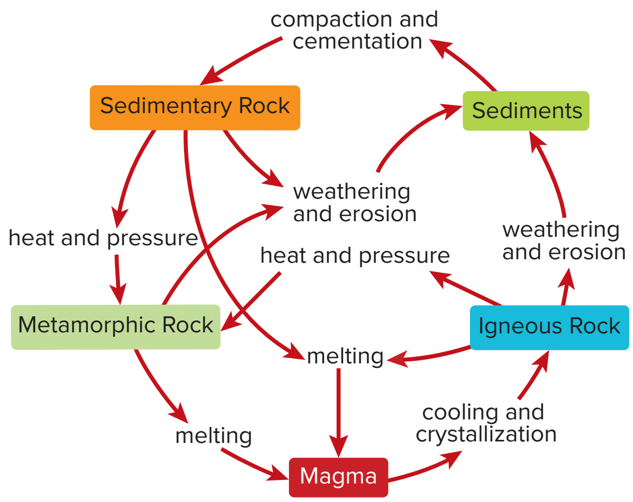

Figure 37 Rocks are continually being changed above and beneath Earth's surface. The rock cycle shows some of the series of changes rocks undergo.

The Rock Cycle

Metamorphic rocks form when other rocks change. The three types of rock—igneous, sedimentary, and metamorphic—are grouped according to how they form. Igneous rocks crystallize from magma underneath Earth's surface or from lava on Earth's surface; sedimentary rocks form from cemented or precipitated minerals and sediments; and metamorphic rocks form from changes in temperature and pressure. Once a rock forms, does it remain the same type of rock always? Possibly, but it most likely will not.

Heat and pressure can change an igneous rock into a metamorphic rock. A metamorphic rock can be changed into another metamorphic rock or melted to form an igneous rock. Alternately, metamorphic rock can be weathered and eroded into sediments that might become cemented into a sedimentary rock. In fact, any rock can be changed into any other type of rock. The continuous changing and remaking of rocks is called the **rock cycle.** The rock cycle is summarized in **Figure 37.** The arrows represent the different processes that change rocks into different types.

Check Your Progress

Summary

- The three main types of metamorphism are regional, contact, and hydrothermal.
- The texture of metamorphic rocks can be foliated or nonfoliated.
- During metamorphism, new minerals form that are stable under the increased temperature and pressure conditions.
- The rock cycle is the set of processes through which rocks continuously change into other types of rocks.

Understand Main Ideas

1. **Summarize** how temperature increases can cause metamorphism.
2. **Summarize** what causes foliated metamorphic textures to form.
3. **Apply** the concept of the rock cycle to explain how the three main types of rocks are classified.
4. **Compare and contrast** the factors that cause the three main types of metamorphism.

Think Critically

5. **Infer** which steps in the rock cycle are skipped when granite metamorphoses to gneiss.
6. **Predict** the location of an igneous intrusion based on the following mineral data. Muscovite and chlorite were collected in the northern portion of the area of study; garnet and staurolite were collected in the southern portion of the area.
7. **MATH Connection** Gemstones often form as porphyroblasts. Gemstones are described in terms of carat weight. A carat is equal to 0.2 g, or 200 mg. A large garnet discovered in New York in 1885 weighs 4.4 kg and is 15 cm in diameter. What is the carat weight of this gemstone?

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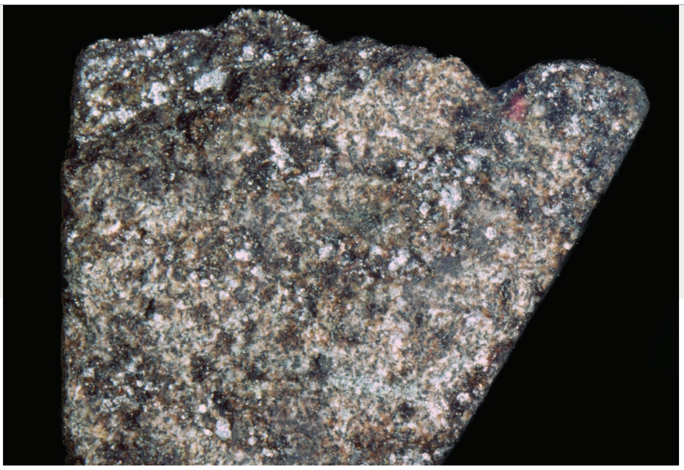
A Rock by Any Other Name

Geologists study Earth, the materials that compose it, and its processes. Many geologists study the different types of rocks on Earth. But did you know that some geologists also study rocks from outer space?



Geologists study Earth rocks as well as rocks of extraterrestrial origin.

Extraterrestrial rocks

The extraterrestrial rocks that geologists study come from the Moon, Mars, and asteroids. These rocks were collected in different ways. Rocks and other materials from the Moon were collected during the Apollo missions. About 124 Martian rocks have landed on Earth as meteorites. Most rocks from asteroids that geologists study—more than 60,000 of them—also fell to Earth in the form of meteorites. However, we do have one sample, taken by Japanese Aerospace Exploration Agency (JAXA), from an asteroid in orbit around the Sun.

Similarities to Earth rocks

Geologists have found that extraterrestrial rocks are similar to Earth rocks in several ways. For example, some Martian rocks show signs of having formed in the presence of water, as many sedimentary rocks on Earth are formed. Mars and Earth both have mudstone, sandstone, shale, and conglomerate rocks. Mars and the Moon also have basalt, a volcanic rock that shows evidence of Earth-like volcanic activity.

Differences from Earth rocks

Geologists have also found a few differences between Earth rocks and extraterrestrial rocks. Moon rocks have tiny pockmarks called zap pits because the Moon's atmosphere is so thin that even micrometeorites impact its surface. Earth's rocks do not have zap pits because its atmosphere burns up most micrometeorites. Most Martian rocks have few zap pits; the planet's atmosphere is thin, but it still protects the surface from micrometeorites.

Another difference relates to oxidation. On Earth, rocks and minerals undergo chemical weathering when oxygen in the atmosphere reacts with them. However, because the Moon's atmosphere does not contain free oxygen, its rocks do not show the effects of oxidation. In years to come, geologists will likely find more similarities and differences between Earth, Martian, and lunar rocks.

ENGAGE IN ARGUMENT FROM EVIDENCE

Work with a small group to find more information on this topic from print or online sources. Then use evidence to construct an argument about which rocks are most similar. Debate the issue with another group.

MODULE 4

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 IGNEOUS ROCKS

- Magma consists of molten rock, dissolved gases, and mineral crystals.
- Magma is classified as basaltic, andesitic, or rhyolitic based on the amount of silica it contains.
- Different minerals melt and crystallize at different temperatures.
- Bowen's reaction series defines the order in which minerals crystallize from magma.
- Igneous rocks are either ultramafic, basaltic, intermediate, or granitic.
- The rate of cooling determines crystal size.
- Some igneous rocks are used as building materials.

- igneous rock
- lava
- partial melting
- Bowen's reaction series
- fractional crystallization
- intrusive rock
- extrusive rock
- basaltic rock
- granitic rock
- texture
- porphyritic texture
- vesicular texture
- pegmatite
- kimberlite

Lesson 2 SEDIMENTARY ROCKS

- The processes of weathering, erosion, deposition, and lithification form sedimentary rocks.
- Sediments are lithified into rock by the processes of compaction and cementation.
- Sedimentary rocks might contain features such as horizontal bedding, cross-bedding, and ripple marks.
- Clastic rocks form from sediments and are classified by particle size and shape.
- Chemical rocks form primarily from minerals precipitated from water.
- Biochemical rocks form from the remains of once-living organisms.

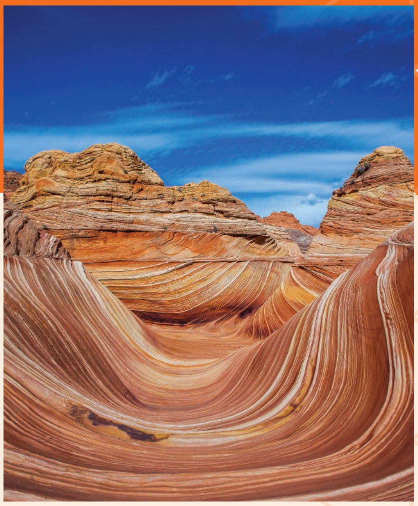
- sediment
- lithification
- cementation
- bedding
- graded bedding
- cross-bedding
- clastic sedimentary rocks
- clastic
- porosity
- evaporite

Lesson 3 METAMORPHIC ROCKS

- The three main types of metamorphism are regional, contact, and hydrothermal.
- The texture of metamorphic rocks can be foliated or nonfoliated.
- During metamorphism, new minerals form that are stable under the increased temperature and pressure conditions.
- The rock cycle is the set of processes through which rocks continuously change into other types of rocks.

- foliated
- nonfoliated
- regional metamorphism
- contact metamorphism
- hydrothermal metamorphism
- rock cycle

Module Wrap-Up



REVISIT THE PHENOMENON

How did these different types of rock form?

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will apply your evidence from this module and complete your project.

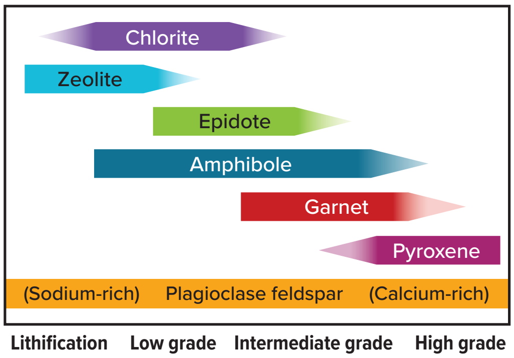
GO FURTHER

SEP Data Analysis Lab

Which metamorphic minerals will form?

The minerals that form in metamorphic rocks depend on the metamorphic grade and composition of the original rock. The diagram on the right and **Figure 23** show the mineral groups that form under different metamorphic conditions. Use both diagrams to answer the questions below.

Minerals in Metamorphosed Basalt



CER Analyze and Interpret Data

1. **Claim, Evidence** What minerals are formed when shale and basalt are exposed to low-grade metamorphism? Use evidence to explain your answer.
2. **Claim, Evidence** Identify the mineral groups that you would expect to form from intermediate-grade metamorphism of shale and basalt. Support your answer with evidence.
3. **Reasoning** Explain the major compositional differences between shale and basalt. How are these differences reflected in the minerals formed during metamorphism?