TOPIC 10

Minerals

People have used minerals for thousands of years. Small, carved artifacts of gold, copper, and silver from 5000 B.C. have been found in the Middle East and Afghanistan. About 3000 years later, Egyptians mined malachite, turquoise, and lapis lazuli and heated these minerals to extract copper. Over the next 2000 years, people learned to cast bronze and iron. These minerals, metals, and alloys and many other Earth substances are still mined and used by people today.

SUBTOPIC A WHAT IS A MINERAL?

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; A.1, A.2; B.2; D.2

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.4	Evolution and equilibrium
UCP.5	Form and function

Science as Inquiry

A.1	Abilities necessary to do scientific inquiry
A.2	Understandings about scientific inquiry

Physical Science

B.2	Structure and properties of matter

Earth and Space Science

D.2	Geochemical cycles

VOCABULARY

mineral	oxides
compound	halides
crystals	sulfates
silicates	sulfides
carbonates	

Diamonds are often used as gemstones but can be used as industrial abrasives as well. Gold is used by jewelers, dentists, and artists. Halite is a very common food preservative and flavoring, which thousands of years ago was also used as money. Copper is a metal used to make electrical wiring and some coins. What do diamonds, gold, halite, and copper have in common? All of these substances are minerals. A **mineral** is a naturally occurring solid that formed through inorganic processes and has a specific chemical composition and a definite crystalline structure.

Characteristics of a Mineral

A substance must meet five requirements to be a mineral. The first stipulation is that the substance is naturally occurring. In other words, it forms in nature. For example, diamonds that form beneath Earth's surface are minerals. However, synthetic diamonds, which are manufactured in laboratories, are not minerals. Rock salt is primarily composed of halite. Its sweet counterpart, sugar, is not a mineral.

Sugar is not a mineral because the second requirement that a substance must meet to be classified as a mineral is that the substance must have formed through inorganic processes. In other words, the formation of a mineral does not involve living things. Halite ($NaCl$) is formed when water evaporates from salt water, allowing dissolved sodium (Na^+) and Chloride (Cl^-) ions to chemically combine with each other. Sugar (sucrose), in contrast, is produced by plants in a series of reactions that begin with photosynthesis.

The third characteristic is that all minerals are solids at room temperature. A solid is a state of matter that has a definite shape and volume. For example, 1 kg of copper occupies a volume of 112 cm^3.

Native Elements

Only about 20 elements are found uncombined in nature. Of these native elements, about a dozen or so are minerals. Most of these elements are metals. Metals are relatively soft, are malleable (have the ability to be stretched), are ductile (have the ability to be pulled into long wires), have low melting points, and are good conductors of heat and electricity. Some of the metal minerals in the native elements group are gold, silver, copper, iron, and platinum.

A few native elements are metalloids. Metalloids are brittle elements that are poor conductors of heat and electricity. Arsenic and bismuth are metalloids that belong to the native elements group of minerals.

A few of the minerals in the native elements group are nonmetals. Unlike the metals and metalloids, which have some similar properties, the nonmetals each have very different properties. Sulfur, diamond, and graphite are some of the nonmetals in the native elements group of minerals.

Silicates

Oxygen (O) is the most abundant element in Earth's crust. Silicon (Si) is the second-most abundant element in the crust. Minerals that contain these two elements, and usually one or more other elements, are called **silicates.** Silicates make up approximately 96 percent of the minerals found in Earth's crust. The most common minerals in Earth's crust, quartz and the feldspars, are silicates.

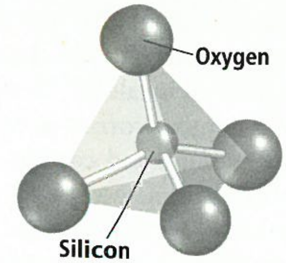
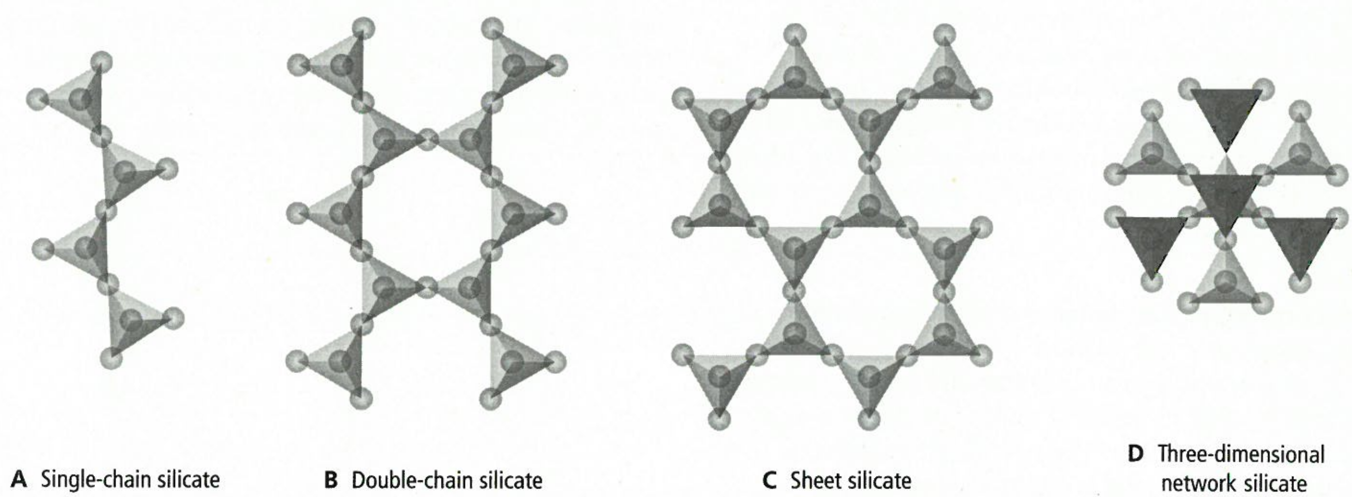


Figure 10-2 The silicon tetrahedron is a pyramid-shaped structure composed of one atom of silicon joined to four oxygen atoms.

All silicates contain the silicon tetrahedron, a pyramid-shaped structure that contains one silicon atom joined to four oxygen atoms. This building block of silicate minerals is shown in Figure 10-2. The silicon tetrahedron has the ability to share its oxygen atoms with other tetrahedron molecules in different ways. Oxygen atoms can be shared to form single chains, as shown in Figure 10-3A. Augite, (CaNa)(Mg, Fe, Al)(Al, Si)$_2$O$_6$, is a single-chain silicate. Oxygen atoms can also be shared to form double chains, as shown in Figure 10-3B. Hornblende, $Ca_2Na(Mg, Fe^{2+})_4(Al, Fe^{3+}, Ti)_3 Si_8O_{22}(O, OH)_2$, is a common double-chain silicate. Silicon tetrahedrons can also join to form sheets as shown in Figure 10-3C. The micas—biotite, $K(Mg,Fe)_3(Al,Si_3O_{10})(OH)_2$, and muscovite, $KAl_2(Al,Si_3O_{10})(OH)_2$, are sheet silicates. Some silicates, such as quartz (SiO_2) and the feldspars, are three-dimensional networks composed of silicon tetrahedrons, as shown in Figure 10-3D.

Figure 10-3 The silicon tetrahedron can share oxygen atoms to form single-chain silicates (A), double-chain silicates (B), sheets (C), and three-dimensional networks (D).



SUBTOPIC B
IDENTIFYING MINERALS

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; A.1, A.2; B.2; D.2

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Earth and Space Science

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VOCABULARY

luster	density
streak	specific gravity
hardness	crystal shape
cleavage	acid test
fracture	

Minerals have physical properties that are the result of their chemical composition and crystal structure. Minerals can be identified by physical and chemical properties such as cleavage, fracture, color, density, hardness, streak, luster, crystal shape, and reaction with acid. The chemical composition and physical properties of minerals determine how humans use these Earth materials.

Mineral Identification

All minerals can be identified using X-ray diffraction or microscopic methods. Such methods, however, require expensive and sophisticated equipment. Most minerals can be quickly identified by inspection or by relatively simple tests.

Color

Color is the most obvious property used to identify a mineral. For some minerals, color is directly related to the composition of the minerals and therefore is constant and diagnostic. For example, azurite is always blue, malachite is always green, pyrite is always yellow-gold, and chalcopyrite is always brass-yellow.

For many minerals, however, color can be the least diagnostic property. Some minerals can change color when they are exposed to the atmosphere. In other minerals, color is determined largely by the presence of impurities. Pure quartz, for example, is colorless, but quartz containing trace amounts of other substances can have a variety of colors: red jasper, amethyst (purple), and citrine (yellow or orange) contain traces of iron; smoky quartz (yellow, brown, or almost black) contains free silicon; and rose quartz (pink) contains titanium or manganese.

Luster

Luster is the general appearance of a mineral surface in reflected light. There are two main types of luster: metallic and nonmetallic. A mineral that shines like a metal in reflected light has a metallic luster. Silver, gold, copper, pyrite, and galena (PbS) are minerals with metallic luster.

A mineral that does not shine like a metal is said to have a nonmetallic luster. A variety of luster types are included in this category. Minerals that shine like glass, such as quartz and tourmaline, have a vitreous luster. Minerals that resemble plant resin, including sulfur and sphalerite, have a resinous luster. Talc is said to have a pearly luster because it shines like the surface of a pearl. Fibrous gypsum and malachite have a silky luster. Minerals with a dull, powdery appearance, such as some types of hematite, have an earthy luster. Minerals that shine brilliantly, including diamond and transparent lead minerals, have an adamantine luster.

Texture

Texture describes how a mineral feels to the touch. Many minerals have smooth textures. Talc can have a greasy texture, and some fibrous minerals have a silky texture. Texture can also be described as ragged, rough, soapy, or glassy. Like luster and color, texture can be used in combination with other properties to identify an unknown mineral.

Streak

The color of a finely powdered mineral is known as the mineral's **streak.** Streak can be observed by rubbing a mineral over an unglazed piece of porcelain, or a streak plate. While the color of some minerals may vary, a mineral's streak is usually constant. Therefore, streak is sometimes referred to as a mineral's true color. For some minerals, color and streak are identical. A gold nugget, for example, is yellow and so is its streak. For other minerals, color and streak are different. Calcite, which can be transparent, white, or pink, always leaves a white streak. Fluorite (CaF_2) can be purple, green, yellow, or blue, but its streak is always white. Pyrite is yellowish gold, but its streak is greenish black. A variety of hematite called specularite is silver-colored but leaves a reddish-brown streak.

Density

Two minerals with the same volume can have different masses and thus different densities. **Density** is the mass per unit volume of any object. The equation for density can be found on the first page of the *Earth Science Tables and Charts.* The density of most mineral samples is expressed in grams per cubic centimeter, or g/cm^3. Pyrite, or fool's gold, has a density of 5.2 g/cm^3. Real gold, on the other hand, has a density of 19.3 g/cm^3.

Specific Gravity

Geologists often compare the density of a mineral to the density of water. **Specific gravity,** or relative density, is the ratio of the density of a mineral to the density of water at 4°C.

The first step in determining a mineral's specific gravity is to weigh the mineral in air. Then the mineral is immersed in water and weighed again. The weight of the mineral in air divided by the weight of the mineral in air minus the weight of the mineral in water equals the specific gravity of the mineral, as given in the formula below. Note that specific gravity is a unitless value.

$$\textit{Specific Gravity} = \textit{Weight}_{air} \div (\textit{Weight}_{air} - \textit{Weight}_{water})$$

An accurate measure of specific gravity requires a mineral sample that is homogeneous; the sample should contain only the mineral being tested. Also, the sample must be compact. Air bubbles, fractures, and cavities in the sample will result in an inaccurate value of specific gravity.

Crystal Shape

The shape of a mineral crystal can also help in the identification of the mineral. **Crystal shape** (or crystal habit) is the shape in which a mineral tends to grow in nature. Crystal shapes are often named after objects that minerals resemble, such as plates, blades, fibers, and pyramids. Quartz crystals are sometimes said to be pyramidal (shaped like a pyramid).

Other Mineral Properties

Some minerals have additional properties that aid in their identification. For example, a variety of calcite called Iceland spar bends, or refracts, light in two directions. This property, called double refraction, creates two images of an object when the object is viewed through the calcite, as shown in Figure 10-6. Zircon ($ZrSiO_4$), a common metamorphic mineral, also exhibits double refraction.

Another property related to the behavior of light is iridescence. Minerals such as limonite, hematite, and sphalerite exhibit surface iridescence. Light reflected from their surfaces produces a play of colors similar to what you see on a thin film of oil. Opal ($SiO_2 \cdot nH_2O$), on the other hand, scatters light internally to produce its striking play of colors.

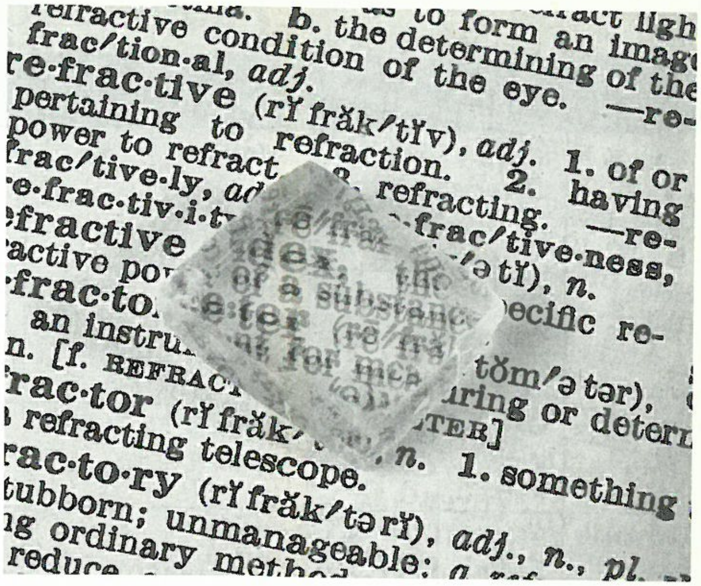


Figure 10-6 Minerals that bend light in two directions exhibit double refraction.

Some minerals have electrical and magnetic properties that not only aid in their identification but also make them quite useful. Minerals made only of native metallic elements—gold, silver, and copper, for example—are excellent conductors of electricity. Some quartz crystals exhibit a special electric property that allows them to be used in digital watches. Magnetite (Fe_3O_4) is a naturally magnetic mineral used to make magnets.

Some minerals are easily identified because they react with acids. Most carbonate minerals, for example, react with dilute hydrochloric acid (HCl). Calcite effervesces, or bubbles, when cold HCl is dropped on its surface. This test is known as the **acid test.** The bubbles are carbon dioxide gas, which is produced during the chemical reaction between hydrochloric acid and calcite. The chemical equation for this process is $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$. Dolomite is another carbonate mineral that reacts with hydrochloric acid. However, dolomite effervesces only if it is powdered or has been recently cleaved.

Some Common Minerals, Their Properties, and Their Uses

Only a few dozen of the 3000 known minerals are common. Table 10-2 lists some of the more common minerals, their chemical formulas, and some of their properties and uses. Some of the information contained in this table can also be found in *Properties of Common Minerals* in *Earth Science Tables and Charts.*

Mineral formula	Color	Streak	Luster	Hardness	Specific gravity	Crystal system	Breakage pattern	Uses and other properties
Graphite C	black to gray	black to gray	metallic or dull earthy	1–2	2.3	hexagonal	basal cleavage	used in pencil "lead," lubricants, some nuclear reactor rods, and battery poles
Gypsum $CaSO_4 \cdot 2H_2O$	varies	white	vitreous, pearly, silky	2	2.3	monoclinic	perfect cleavage	used to make plaster of paris, which is used to make wallboard, molds, and casts
Hematite (specular) Fe_2O_3	silver, black, or reddish brown	red or reddish brown	metallic	6	5.3	hexagonal	irregular fracture	source of iron; used in the steelmaking industry
Hornblende $Ca_2Na(Mg, Fe^{2+})_4, (Al,Fe^{3+}, Ti)_3, Si_8O_{22} (O,OH)_2$	green to black	gray to white	varies, often vitreous to fibrous	5–6	3.4	monoclinic	cleavage in two directions	consists of crystals with a six-sided cross section
Magnetite Fe_3O_4	black	black	metallic	6	5.2	cubic	conchodial fracture	source of iron; naturally magnetic
Muscovite $KAl_2 (Al,Si_3O_{10}) (OH)_2$	colorless	colorless	vitreous to silky to pearly	2–2.5	2.76–2.88	monoclinic	perfect cleavage in one direction	used in insulating materials and electrical appliances; also used as a lubricant and fireproofing material
Olivine $(Mg, Fe)_2 SiO_4$	olive green	colorless	vitreous	6.5	3.5	ortho-rhombic	conchoidal fracture	used as gemstones and in refractory sands
Pyrite FeS_2	light brassy yellow	greenish black	metallic	6.5	5.0	cubic	uneven fracture	source of iron; also known as fool's gold; alters to limonite
Quartz SiO_2	varies	colorless	vitreous	7	2.65	hexagonal	conchoidal fracture	used in glass, electronic equipment, radios, computers, and watches; also used as gemstone
Silver Ag	silvery white	light gray to silver	metallic	2.5	10–12	cubic	hackly fracture	used in coins, dentistry, jewelry, silver-plating, and wires; is malleable and ductile; tarnishes to black
Sulfur S	yellow	yellow	resinous	1.5–2.5	2.05–2.09	ortho-rhombic	conchoidal to uneven fracture	used to make sulfuric acid; also used in fertilizers, rubber, and insecticides
Talc $Mg_3Si_4O_{10} (OH)_2$	apple green, gray, white	white	pearly to greasy	1	2.7–2.8	monoclinic	cleavage	used in paints, ceramics, cosmetics, and some paper
Topaz $Al_2SiO_4 (F, OH)_2$	varies	colorless	vitreous	8	3.5	ortho-rhombic	basal cleavage	used as gemstone

Type B

Base your answers to questions 10–14 on the information in the table below.

Mineral/formula	Percent of rock A	Percent of rock B
Quartz SiO_2	40	0
Augite $(Ca,Na)(Mg,Fe,Al)(Al,Si_2)O_6$	0	25
Plagioclase feldspar $NaAlSi_3O_8$	20	0
Orthoclase feldspar $KAlSi_3O_8$	20	0
Biotite $K(Mg,Fe)_3(Al,Si_3O_{10})(OH)_2$	10	0
Hornblende $Ca_2Na(Mg,Fe^{2+})_4,(Al,Fe^{3+},Ti)_3 Si_8O_{22}(O,OH)_2$	10	0
Olivine $(Mg,Fe)_2SiO_4$	0	75

10. Which characteristic of rock B could be caused by the minerals augite and olivine?

a. green color
b. felsic composition
c. metallic luster
d. radioactivity

11. What percentage of rock A is made of silicates?

a. 20% **c.** 60%
b. 40% **d.** 100%

12. Which of the minerals in the table do not exhibit cleavage?

a. quartz and olivine
b. plagioclase feldspar and orthoclase feldspar
c. quartz and biotite
d. olivine and augite

13. Which of the minerals in the table are used in the glassmaking industry?

a. the feldspars and biotite
b. biotite and hornblende
c. quartz and orthoclase feldspar
d. augite and hornblende

14. Which of the minerals in rock A are the most common minerals in Earth's crust?

a. hornblende and biotite
b. biotite and quartz
c. the feldspars and quartz
d. augite and hornblende

Type C

Base your answers to questions 15 and 16 on the information in the paragraph below.

> Emery is used as an industrial abrasive and a component of nonslip flooring. Deposits of emery form when schist is altered by heat, pressure, and thermal solutions. Minerals found in emery include magnetite, spinel, corundum, ilmenite, garnet, sillimanite, and cordierite.

15. Which of the following best describes how the minerals found in emery deposits form?

a. precipitation from shallow seawater
b. metamorphism
c. volcanism
d. evaporation of supersaturated water

16. The chemical formula of cordierite is $(Mg,Fe)_2Al_4 Si_5O_{18}$. To which mineral group does cordierite belong?

a. silicates
b. carbonates
c. native elements
d. sulfates

17. Corals are tiny marine organisms that secrete skeletons made of calcite. The hardness of these skeletons measures 3 on the Mohs scale. The skeletons also effervesce in hydrochloric acid. Are coral skeletons minerals? Why or why not?

18. Olivine is often the first mineral to form when magma cools. Augite and hornblende form next, followed by feldspars and micas. Quartz is the last mineral to form. Which of these minerals is the most stable at Earth's surface? Why?

31. What was the predominant mineral of the sandstones prior to metamorphism?

a. calcite **c.** halite

b. fluorite **d.** quartz

32. What process resulted in the formation of the yellowish-brown layer of minerals at the base of the sill?

a. metamorphism

b. evaporation from solution

c. igneous intrusion

d. precipitation from seawater

33. To which mineral group does the yellowish-brown mineral belong?

a. carbonate group

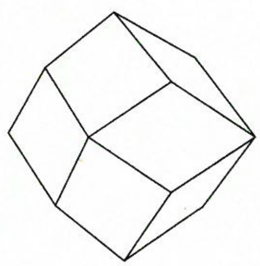
b. silicate group

c. halide group

d. sulfide group

Type C

Base your answers to questions 34–36 on the diagram of a common mineral shown below.



34. The mineral can scratch olivine but not topaz. What is the mineral's hardness?

a. 6.0 **c.** 7.0

b. 6.5 **d.** 8.0

35. The mineral has a vitreous to resinous luster. How can the luster of this mineral be classified?

a. nonmetallic **c.** magnetic

b. metallic **d.** earthy

36. The mineral contains three atoms of iron, two atoms of aluminum, twelve atoms of oxygen, and three atoms of silicon. What is the formula of this mineral?

a. $3SiO_{12}3FeAl_2$ **c.** $3Fe2AlO_{12}Si_3$

b. $Fe_3Al_2Si_3O_{12}$ **d.** $(Fe,Mg)_23SiO_4$

Base your answers to questions 37–38 on the table below.

The information in the table below shows different varieties of garnet.

Variety of garnet	Formula	Specific gravity
Pyrope	$Mg_3Al_2Si_3O_{12}$	3.58
Almandine	$Fe_3Al_2Si_3O_{12}$	4.32
Spessartite	$Mn_3Al_2Si_3O_{12}$	4.19
Grossularite	$Ca_3Al_2Si_3O_{12}$	3.59
Andradite	$Ca_3Fe_2Si_3O_{12}$	3.86
Uvarovite	$Ca_3Cr_2Si_3O_{12}$	3.90

37. Which variety of garnet has the highest specific gravity?

a. spessartite **c.** uvarovite

b. almandine **d.** grossularite

38. What accounts for the difference in specific gravity between the garnet variety with the highest specific gravity and the variety with the lowest specific gravity?

a. the presence of calcium rather than magnesium

b. the presence of iron rather than magnesium

c. the presence of chromium rather than magnesium

d. the presence of iron rather than aluminum

39. You are asked to identify an unknown crystal, which is black and has a vitreous luster. You observe cleavage in the sample. When you test the hardness of the sample, you find that it scratches fluorite and apatite but not quartz. You also note that the crystal has a square cross section. Identify this mineral. To which crystal system does it belong? What is its specific gravity?

40. Suppose you are given a bag of 100 transparent, colorless minerals. Only one of the minerals is a diamond; the others are calcite. You are told that if you can find the diamond in less than a minute, it is yours. How could you find the diamond?