EXERCISE TWO

Mineral Properties, Uses, and Identification

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PURPOSE

People use many different minerals in different ways, because of their beneficial properties. Some minerals are used in their natural forms. Others are industrially *refined,* or separated, into their constituent elements. The most commonly refined mineral compounds are the ores of metals. For example, the metal lead is refined from the mineral galena (lead sulfide) by separating the lead from the sulfur. Indeed, we use so many minerals and mineral products daily that you would have difficulty listing them all!

Some minerals can produce adverse effects upon people's lives. For example, refining of sulfide minerals (such as refining galena for lead) may release large amounts of sulfur into the atmosphere. There it can combine with rainwater to form sulfuric acid, creating a type of acid rain that deteriorates Earth materials and disrupts the life cycles of organisms. The burning of coal that contains sulfate minerals has a similar result.

This exercise presents systematic procedures for identifying minerals by their physical properties. Your ability to determine these properties by careful *observation* and *testing* is more important than merely being able to recognize and name minerals. Later exercises will show how *minerals* combine to form *rocks.* Thus it is essential for you to learn the common minerals and their properties so that you will be able to complete the rock identification exercises.

MATERIALS

Pencil, eraser, steel knife or steel masonry nail, wire nail, glass plate, streak plate, copper penny, small magnet, dilute (1–3%) hydrochloric acid (HCl) in a dropper bottle, and mineral samples provided by your instructor.

INTRODUCTION

A **mineral** is a naturally occurring, inorganic substance with crystalline structure, a characteristic chemical composition, and characteristic physical properties. Crystalline structure refers to an orderly, predictable arrangement, or pattern, of the atoms in a substance (Figure 2.13). Substances possessing crystalline structure are called **crystals.** Chemical composition and crystalline structure determine the physical properties of a mineral: its color, hardness, shape, feel, and how it reflects or refracts light. Different minerals therefore have different properties, and these can be used to distinguish one mineral from another.

A **mineraloid** is a naturally occurring, inorganic substance with a characteristic chemical composition and physical properties. However, mineraloids lack crystalline structure (i.e., they are amorphous). For example, opal (Figure 2.23) and limonite (Figure 2.24) are mineraloids. Some common minerals and mineraloids are shown in Figures 2.1 through 2.25.

MINERAL PROPERTIES

Crystal form is the external, geometrical appearance of a perfectly formed crystal. The flat external surfaces of the crystal are called *crystal faces* (Figures 2.1, 2.2, 2.3). Individual crystals that are perfectly bounded by all of their natural faces are called *euhedral* crystals, and are rare. Mineral grains that exhibit some of their natural faces are called *subhedral* crystals, and are common. Some mineral grains do not exhibit any of their natural crystal faces (i.e., they lack external crystal form), and are called *anhedral* crystals.

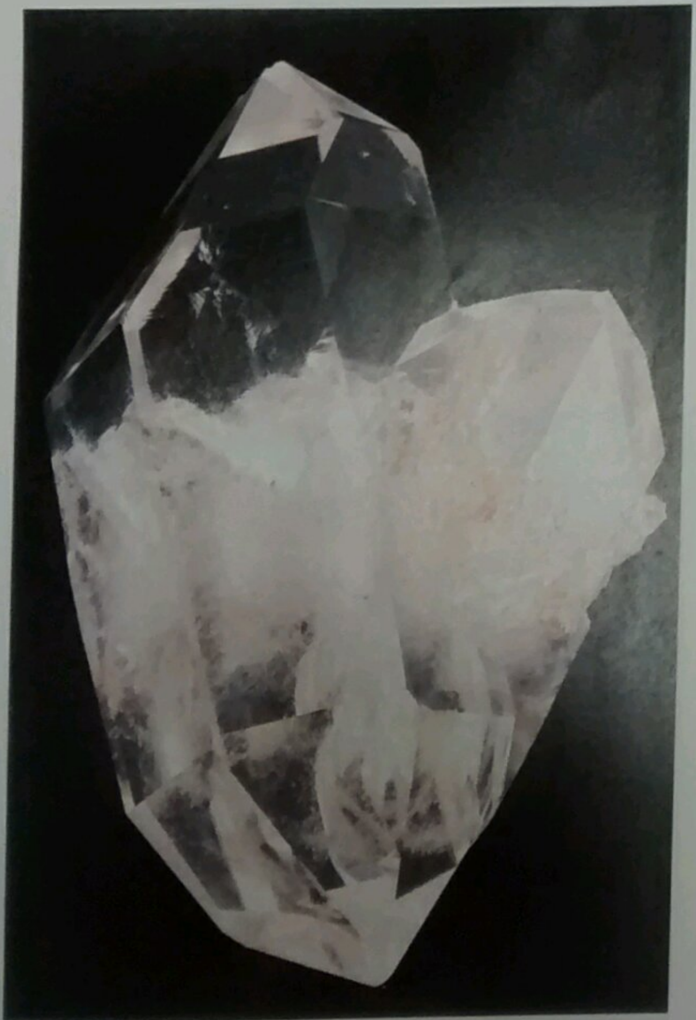


FIGURE 2.1 Quartz crystals. Because quartz consists of the two most abundant elements of Earth's crust, silicon (Si) and oxygen (O), it is one of the most common minerals in the crust. Angles between crystal faces of individual quartz crystals are always the same.

FIGURE 2.2 Amethyst quartz. This quartz variety has a violet-to-purple color caused by small amounts of *ferric iron* as an impurity. These crystals formed in a very large bubble of gas trapped within a solidifying body of molten rock material (magma) inside Earth. The amethyst formed secondary crystals on top of primary crystals of transparent-to-milky quartz.

Color of a mineral, usually its most noticeable property, may be one of the least-accurate diagnostics in mineral identification. For example, quartz can be colorless (Figure 2.1), violet (Figure 2.2), white (Figure 2.4), rose (Figure 2.5), gray, blue, green, red, yellow, brown, and more. However, most minerals do have a typical color that can be used as a clue in identification. For example, the majority of quartz specimens are colorless, white, or gray. The color of a mineral also may be a clue to its chemical composition.

Streak is the color of a mineral after it has been ground to a fine powder. The easiest way to do this is simply to scratch the mineral across the surface of a square of unglazed porcelain (called a *streak plate*). Then, blow away the excess powder and broken fragments. The color of the powder remaining on the plate is the streak (Figure 2.7).

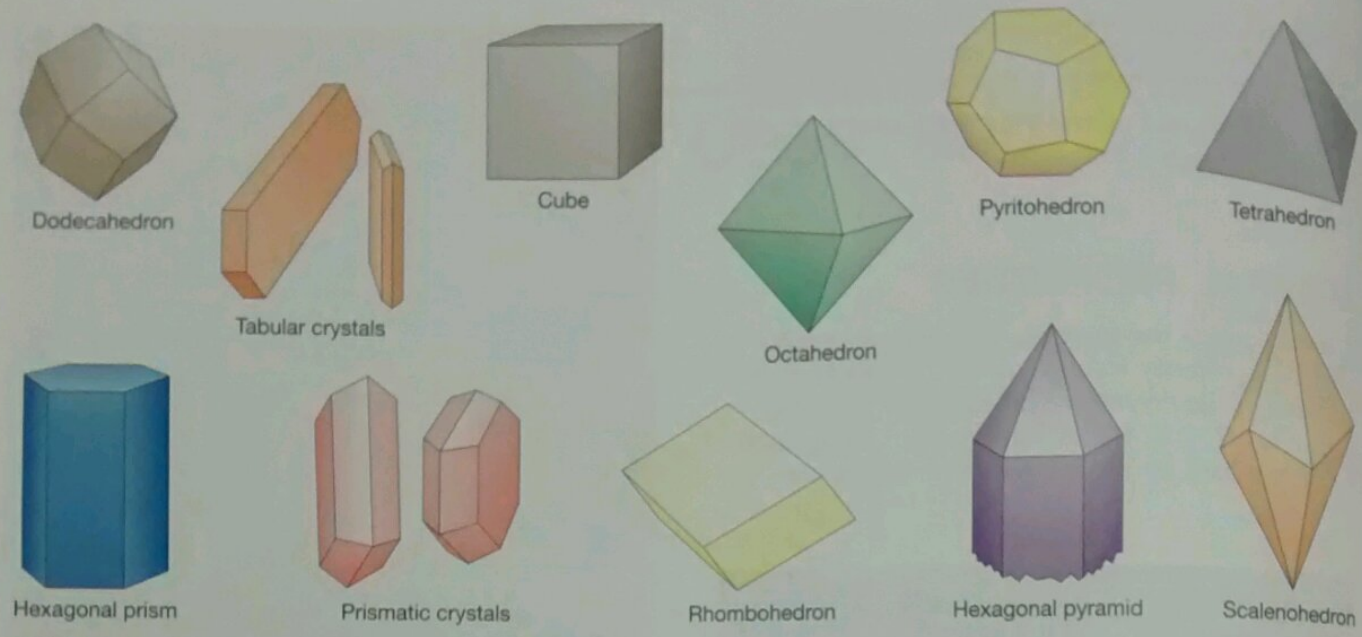


FIGURE 2.3 Some external forms of mineral crystals.

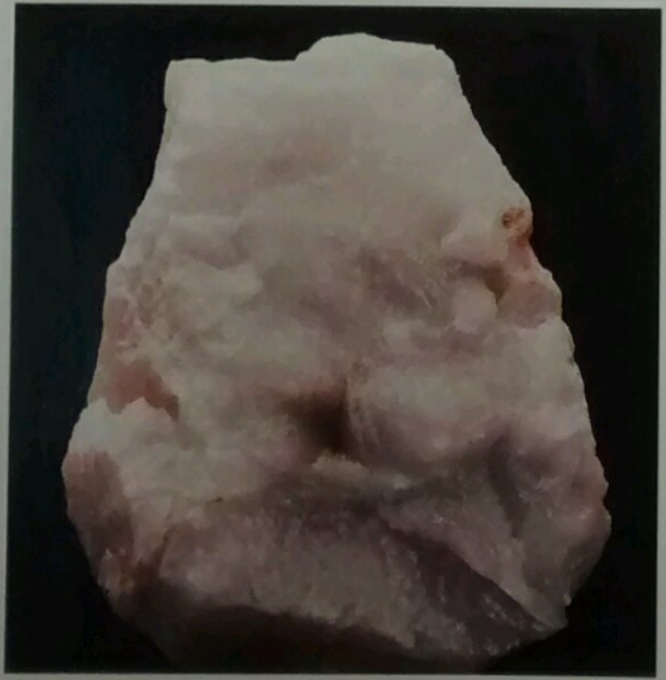


FIGURE 2.4 Milky quartz. This quartz variety forms when quartz contains microscopic fluid inclusions, commonly water. The sample displays essentially no crystal faces, because many crystals developed simultaneously in a crowded area, resulting in this "massive" form. Note the greasy luster of the fracture surfaces.

FIGURE 2.5 Rose quartz. This quartz variety is rose-to-pink because it contains small amounts of the element *titanium* as an impurity. Rose quartz generally occurs in massive form like this example.

FIGURE 2.6 Agate. This quartz variety may contain chert (white to gray), opal (any color), flint (black), jasper (yellow, brown, red), or chalcedony (any color) in alternating bands, blotches, stripes, or mosslike patterns. It is commonly found lining fractures and solution cavities in the bedrock of arid regions.

FIGURE 2.7 Hematite. This mineral is an oxide of iron that takes several forms. Hematite always has a characteristic red-brown *streak* (its color in powdered form) as shown here for four samples of hematite having different lusters and textures. (Photo by R. Busch)

FIGURE 2.8 Pyrite (left) and chalcopyrite (right). Both of these iron sulfide minerals are informally known as "fool's gold" because they are pale brassy-yellow and have a metallic luster. Pyrite often has striated crystal faces, but not always. It lacks the iridescent play of colors so typical of chalcopyrite. (Compare to the unstriated pyrite crystals in Figure 2.25.) (Photo by R. Busch)

Streak color is representative of a mineral's true color, which often is different from the apparent color of an unground specimen.

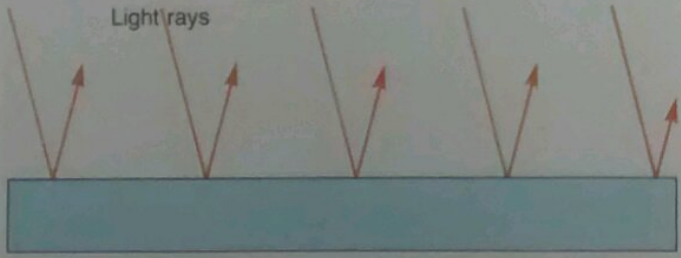
Luster is the manner in which the surface of a substance reflects light. Terms used to describe luster include earthy (like concrete), glossy (like auto paint), metallic (like silver, gold, or copper), pearly (like a pearl), greasy (like grease), waxy (like a candle), and vitreous (like glass). Sphalerite (Figure 2.9) has metallic luster only when viewed in certain directions, so its luster is described as submetallic.

Cleavage planes are flat surfaces along which some crystalline substances break because of weakness in their crystalline structure. That is, they are parallel surfaces of weak chemical bonding (attraction) between repeating, parallel layers of atoms in the crystal. Each different set of parallel cleavage planes has an orientation relative to the crystalline structure, and is referred to as a *cleavage direction* (Figure 2.10). For example, muscovite mica (Figure 2.12) has one cleavage direction. Galena (Figure 2.11) and halite (Figure 2.14) have three prominent cleavage directions developed at right angles to

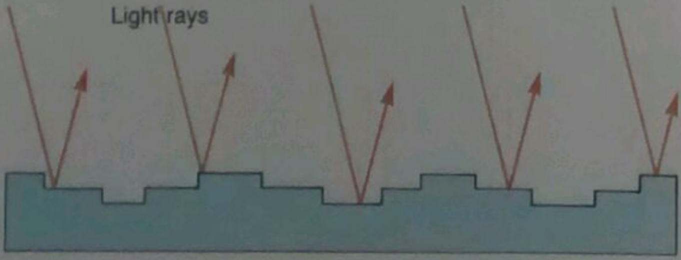
FIGURE 2.9 Sphalerite. This mineral is zinc sulfide, and it is commonly mined as zinc ore. Sphalerite has a characteristic luster called submetallic, as in the sample shown. It also has dodecahedral cleavage (see Figure 2.10), a white-to-yellow-brown streak, and is commonly yellow, red, brown, or black.

one another, so they break either into cubes (cubic cleavage), or into fragments that have sides at right angles to one another. Other common cleavage patterns are described in Figure 2.10.

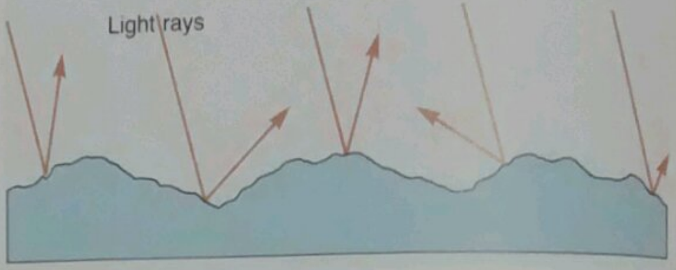
A mineral with *good cleavage* reflects light from very obvious, parallel flat surfaces that are extensive on large crystals:



A mineral with *poor cleavage* reflects light from many flat, parallel surfaces that are not so obvious because the flat surfaces are relatively small:



Fracture surfaces are nonplanar, nonparallel surfaces along which minerals and other substances may break in addition to cleavage, or in the absence of cleavage. Quartz and volcanic glass are examples of materials that fracture and lack cleavage. They break along smoothly curved surfaces called *conchoidal fractures*. "Splintery" (like wood) and "irregular" (like concrete) are other terms that describe the fracture appearance of particular minerals. Unlike cleavage surfaces, fracture surfaces reflect light in many different directions:



Feldspar is a mineral that has both cleavage and fracture (Figures 2.20, 2.21, 2.22). It has two directions of cleavage at nearly right angles, plus a fracture direction.

Striations are straight "hairline" grooves on the cleavage faces of some minerals. This can be helpful in mineral identification. For example, we will use the striations of plagioclase feldspar to distinguish it from potassium feldspar:

Plagioclase feldspars (Figures 2.20, 2.22) have striations, which appear as straight parallel lines or grooves on the faces of one cleavage direction, and which are parallel to the faces of the second cleavage direction.

Potassium feldspars (Figures 2.21, 2.22) may have lines on their surfaces that resemble striations. However, these are thin, discontinuous, subparallel lamellae (thin, discontinuous layers) of plagioclase, called exsolution lamellae.

Tenacity is the manner in which a substance resists breakage. Terms such as brittle (like glass), malleable (like modeling clay), flexible (like a plastic comb), and elastic (like a rubber band) are all used to describe tenacity.

Reaction to acid differs among minerals. Cool, dilute (1–3%) hydrochloric acid (HCl) applied from a dropper bottle is a common "acid test." Many carbonate minerals such as calcite (Figure 2.15) will effervesce ("fizz") when a drop of such dilute HCl is applied to a freshly exposed surface. Another carbonate mineral, dolomite, appears al-

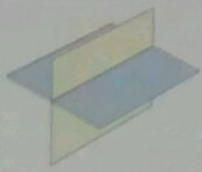
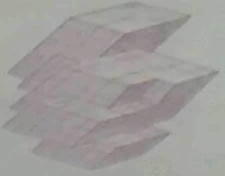
Number of Cleavage Directions	Shapes that Crystal Breaks Into	Sketch	Ilustration of Cleavage Directions
0 No cleavage, only fracture	Irregular masses with no flat surfaces		None
1	"Books" that split apart along flat sheets		
2 at 90°	Elongated form with rectangular cross sections (prisms) and parts of such forms		
2 not at 90°	Elongated form with parallelogram cross sections (prisms) and parts of such forms		
3 at 90°	Shapes made of cubes and parts of cubes		
3 not at 90°	Shapes made of rhombohedrons and parts of rhombohedrons		
4	Shapes made of octahedrons and parts of octahedrons		
6	Shapes made of dodecahedrons and parts of dodecahedrons		

FIGURE 2.10 Common *cleavage patterns* of minerals, which cause minerals to break into preferred shapes.

most identical to calcite, but it will effervesce in dilute HCl only if the mineral is first powdered. (It can be powdered for this test by simply scratching the mineral's surface with the tip of a rock pick or pocket knife.) If HCl is not available, undiluted vinegar can be used for the acid test, for it contains acetic acid.

Magnetism is exhibited by some minerals, such as magnetite. The test is simple: magnetite is attracted to a magnet. Lodestone is a variety of magnetite that is itself a natural magnet. It will attract steel paperclips.

Double refraction occurs when light passes through the crystalline structure of some minerals.

The light is refracted (bent) into two rays, so that a double image is produced. Clear calcite displays excellent double refraction (Figure 2.15).

Specific gravity (SG) is the ratio of the weight of a substance to the weight of an equal volume of water. For example, the mineral quartz (SG = 2.65) is 2.65 times heavier than an equal volume of water. *Hefting* is an easy way to judge the specific gravity of one mineral relative to another. This is done by holding a piece of the first mineral in one hand and holding an equal-sized piece of the second mineral in your other hand. Feel the difference in weight between the two samples (i.e., heft the samples). The sample that feels heavier has a higher specific gravity than the other. Most metallic minerals have higher specific gravities than nonmetallic minerals.

Hardness (H) is a measure of resistance to scratching. A harder substance will scratch a softer one. A German mineralogist, Friedrich Mohs (1773–1839), developed a quantitative scale of mineral hardness on which the softest mineral (talc) has a hardness of 1 and the hardest mineral (diamond) has a hardness of 10. Higher-numbered minerals will scratch lower-numbered minerals (e.g., diamond will scratch talc, but talc cannot scratch diamond). *Mohs Scale of Hardness* (Figure 2.26) is now widely used by geologists and engineers.

There are many other properties of minerals that we have not described here. Keep this in mind as you continue this exercise, so that you can increase your understanding of mineral identification and uses. Refer to Figures 2.13–2.26 before you proceed.

FIGURE 2.12 Muscovite mica. Micas are aluminum silicate minerals which form stout crystals that split easily into paper-thin, flexible sheets, parallel to the flat base of the crystals. This splitting is called *basal cleavage*. Muscovite is a light-colored, silvery-brown mica, in contrast to biotite mica, which is black.

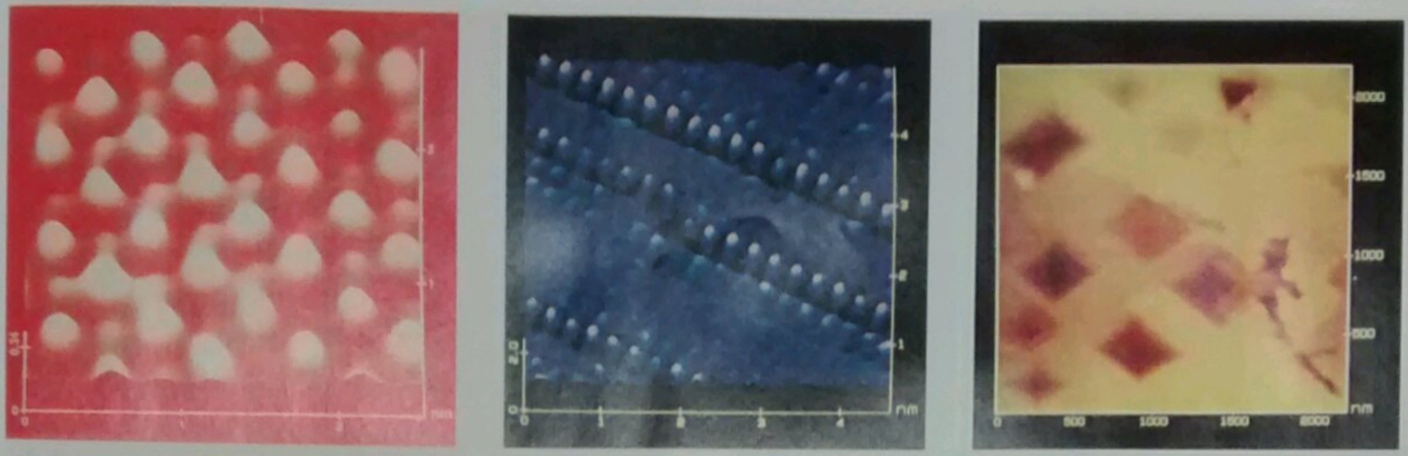
FIGURE 2.11 Galena is lead sulfide, so it has a notably high specific gravity. It forms cubic crystals, has cubic cleavage (see Figure 2.10), and its metallic luster resembles that of lead, for which galena is an ore.

MINERAL IDENTIFICATION

The ability to identify minerals is one of the most fundamental skills of an Earth scientist. It also is fundamental to identifying rocks, for you must first identify the minerals composing them. Only after minerals and rocks have been identified can their origin, classification, and alteration be adequately understood.

To identify a mineral, you must first list as many of its properties as you can determine, using available tools and your senses. Then, identify the mineral using the mineral identification tables (Figures 2.27, 2.28) or flow charts (Figures 2.29, 2.30).

Use this procedure for each mineral:



A. Galena
B. Hematite
C. Calcite

FIGURE 2.13 *Atomic-resolution images* of galena, hematite, and calcite. Scales are in nanometers (nm). There are 1000 nanometers in 1 micron, and 1000 microns in 1 millimeter, so 1 nanometer is 1 millionth of a millimeter (or 1 billionth of a meter). (Images courtesy of Stanford University)
A. Scanning tunneling microscope (STM) image of galena (PbS), tilted back 30° to give better perspective. High bumps are electrons tunneling from sulfur atoms, and low bumps represent fewer electrons tunneling from the individual lead atoms. Nevertheless, the surface is atomically flat. Each *sulfur* atom is bonded to four lead atoms in the image, plus another lead atom beneath it. Similarly, each *lead* atom is bonded to four sulfur atoms in the image, plus a sulfur atom beneath it. (Image collected by C. M. Eggleston, Stanford University)
B. STM image of hematite (Fe_2O_3) fracture surface, also tilted back 30° for perspective. Because of the conditions under which electrons were tunneled onto the surface, only the oxygen atoms (and not the iron atoms) are visible in the image. The blue bumps represent oxygen atoms on atomically flat surfaces. The pink bumps highlight oxygen atoms located at the edges of steps that are one atom high. (Image collected by C. M. Eggleston, Stanford University)
C. Scanning force microscope (SFM) image of a surface of calcite ($CaCO_3$). It has been immersed in water and partly dissolved by hydrolysis, a decomposition reaction involving water. This image is not tilted and was collected from a relatively large area; however, the vertical scale is small. The highest point on the image (lightest color) is only about 15 nm above the lowest point (darkest color). The two markers on the image are on the top and bottom of a step that is only one atom high. (Image collected by M. F. Hochella, Jr., Stanford University)

A. Separate metallic from nonmetallic minerals. If you are uncertain about a mineral's luster, then it is probably nonmetallic.

B. For the *metallic* minerals, determine:
   1. hardness
   2. color
   3. cleavage qualities, quantities, and angles between cleavage directions
   4. streak
   5. other properties as needed
   6. name from Figure 2.27

C. For the *nonmetallic* minerals:
   1. separate light from dark colors
   2. determine hardness
   3. determine cleavage qualities, quantities, and angles between cleavage directions
   4. determine streak
   5. determine other properties as needed
   6. determine name from Figure 2.28

Mineral tables and flow charts are extremely helpful, but they are cumbersome in the field, and their use is time consuming. Therefore, the ability to identify common minerals without tables and charts is an important asset to the field-oriented Earth scientist.

FIGURE 2.14 Halite has a characteristic cubic cleavage, meaning that it breaks into cubes (blocks) or pieces with numerous flat surfaces that are all perpendicular to one another (see Figure 2.10). Halite is common table salt.

FIGURE 2.15 Calcite has a characteristic rhombohedral cleavage (see Figure 2.10), meaning that it breaks into rhombohedra (leaning blocks) or shapes composed of rhombohedra. Also note the golden colored crystal of calcite (lower left) that is easily scratched by an iron nail; it exhibits external crystal faces rather than cleavage surfaces. Calcite is a carbonate mineral that *effervesces* (fizzes) in dilute, cool hydrochloric acid (HCl) squeezed from a dropper bottle (upper left). It also exhibits double refraction; note how the X behind the top-center sample appears as two overlapping letters. Calcite is the chief mineral in the rocks limestone and marble. (Photo by R. Busch)

FIGURE 2.16 Fluorite is calcium fluoride. It commonly forms cubic crystals that are purple, blue, yellow, green, or colorless. Fluorite has very well-developed octahedral cleavage, as shown (see Figure 2.10). Its common crystal form is a cube (Figure 2.3). (Photo by R. Busch)

FIGURE 2.17 Garnet is a hard mineral (H = 6.5–7.5). It is used as an abrasive (in garnet paper, a form of sandpaper) and as a gemstone. It is commonly red, black, or green, but its streak is white. Garnet is brittle and has no cleavage, instead commonly breaking along slightly curved, subparallel surfaces called *parting surfaces* (as in this sample showing the broken end of a large crystal).

FIGURE 2.18 Augite pyroxene. Pyroxenes are a group of complex silicates. Because they contain some proportion of iron (Fe) and magnesium (Mg), they are *ferromagnesian silicates*. Augite is a pyroxene containing both iron and magnesium. It forms short, stout crystals which are dark green to black and have a pearly luster. Augite also has two prominent cleavage directions, which intersect at 87° and 93° and are difficult to detect in hand samples.

FIGURE 2.19 Hornblende amphibole. Amphiboles are another group of complex silicates containing some proportion of iron (Fe) and magnesium (Mg), so they too are *ferromagnesian silicates*. Hornblende is generally green to black and has two prominent cleavage directions, intersecting at 56° and 124°.

FIGURE 2.20 Albite feldspar. Albite is a sodium plagioclase feldspar. Like other feldspars, it has two obvious directions of cleavage, one of which has parallel, closely spaced *hairline striations* (also see Figure 2.22). The striations are caused by twinning, which is the intergrowth of symmetrically paired microcrystalline portions of the large crystal. Albite is usually colorless, white, or gray.

FIGURE 2.21 Microcline feldspar. Microcline is a potassium-rich feldspar (or "K-spar"), so it is commonly pink or red. However, green-to-blue-green microcline is encountered, and is called amazonite. Like other feldspars, microcline has two obvious cleavage directions (also see Figure 2.10). It typically contains thin, discontinuous, subparallel lamellae of plagioclase feldspar, called *exsolution lamellae*. They are visible on the front cleavage surface of this sample.

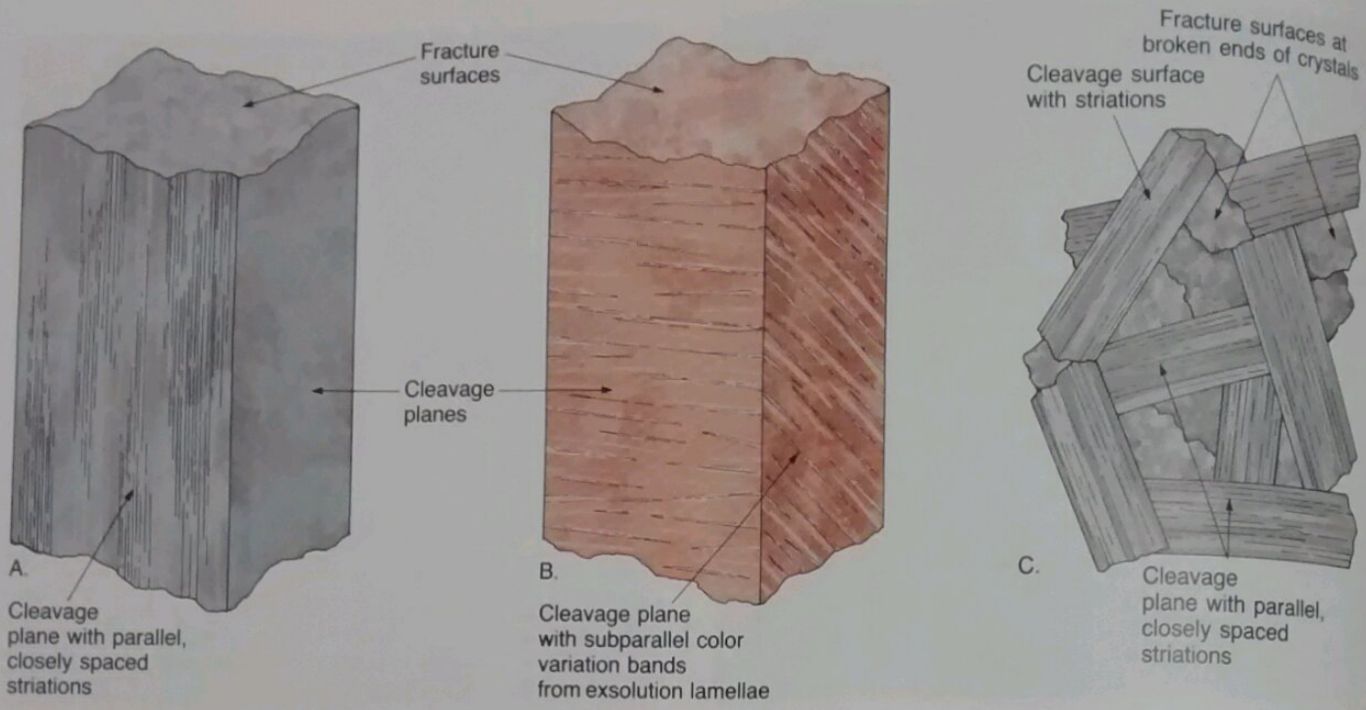


FIGURE 2.22 Common feldspars and rock.
A. This piece of plagioclase feldspar crystal shows *hairline striations* on a cleavage surface. These striations are caused by *twinning*. Twinning occurs when microscopic intergrowths develop between symmetrically paired microcrystalline portions of the larger crystal. The striations occur only along one of the two cleavage directions.
B. This piece of potassium feldspar (K-spar) crystal shows intergrowths of thin, discontinuous, subparallel lamellae of plagioclase, called *exsolution lamellae*. Such texture is called *perthitic* texture.
C. This hand specimen formed as an aggregate of intergrown plagioclase mineral crystals. Individual mineral crystals are discernible within the rock, particularly the cleavage surfaces of plagioclase with their characteristic hairline striations.

FIGURE 2.23 Opal is a *mineraloid*, a mixture of quartz molecules and water molecules that forms massive opal without crystalline structure. Opal has a characteristic conchoidal fracture, waxy luster, and low specific gravity. It also can have a play of colors, called *opalescence*, in which case it is called "precious opal." The opal shown formed on brown rock, and it has been fractured throughout.

FIGURE 2.24 Limonite is an amorphous, hydrous oxide of iron (mineraloid), commonly known as the "rust" that forms on iron objects. It generally forms earthy masses, although it also may replace iron-bearing minerals that are in contact with air (containing oxygen).

FIGURE 2.25 Pyrite crystals and limonite pseudomorphs after pyrite.

QUESTIONS

1. Examine Figures 2.1 and 2.2 (or laboratory examples, if available). How many crystal faces form the end (terminus) of each quartz crystal? What kind of crystal form is it (See Figure 2.3)?

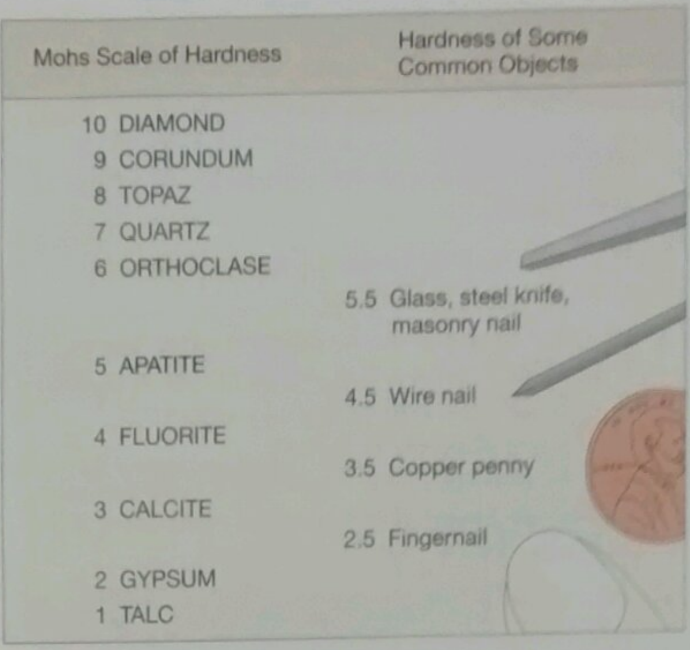


FIGURE 2.26 Mohs Scale of Hardness and the hardness of some common objects.

2. Biotite mica and muscovite mica have the same crystalline structure. (Examine laboratory samples of both, if available.)
   a. Why are they different materials?
   b. What physical properties distinguish biotite from muscovite?
3. Other than the properties already discussed in this exercise, name two properties of halite that can be used to distinguish it from colorless calcite. (Examine laboratory samples of both, if available.)
4. What products in your house or dormitory might be made from these minerals? (Examine laboratory samples of them, if available. Also refer to Figure 2.31 as needed for information about the uses of some common minerals.)
   a. muscovite
   b. gypsum
   c. hematite, magnetite, or limonite
   d. graphite
   e. galena
   f. feldspar
   g. garnet
   h. talc
5. Which property is more reliable in mineral identification, color or streak? Why?
6. Both magnetite and pyrite can be ores for iron. Based upon their chemical composition, which

one of these minerals would you choose for this purpose? Why?

7. Describe the chemical changes that take place to form limonite pseudomorphs after pyrite (Figure 2.25). (Examine laboratory samples, if available.)
8. Why are so many minerals pseudomorphic after the mineral halite?
9. Imagine that you have found a large vein of white calcite in a quarry that mines limestone (a type of rock composed of calcite).
   a. Why is the calcite white?
   b. Describe how the white calcite formed at that location. (Hint: normal rainwater is a weak acid.)
10. What kind(s) of crystal form do the pyrite crystals and limonite pseudomorphs have in Figure 2.25? (Also see Figure 2.3.)
11. Obtain a set of minerals from your instructor, if available. Identify each of the minerals using the information provided in this exercise.

ATOMIC-RESOLUTION MINERALOGY

Two modern technologies now allow mineralogists to obtain images of the atoms and atomic structures of minerals and other Earth materials. These new technologies are described here, along with images of three minerals for you to interpret.

Scanning tunneling microscopy (STM) was invented in IBM's laboratory at Zurich, Switzerland, between 1979 and 1981 by Gerd Binnig and Henrich Rohrer. This revolutionary discovery earned Binnig and Rohrer the Nobel Prize in physics in 1986.

STM works by scanning a sharp metal tip over the surface of a sample. If the sample can conduct electricity and the tip is brought to within a few atomic diameters of the surface, then applying a small voltage allows electrons to "tunnel" across this extremely small gap. Most tunneling electrons are exchanged only between the last atom on the end of the tip and the first atom on the sample surface directly beneath it. As the tip scans over the surface, the variation in tunneling current is measured, in effect mapping the position of each atom (Figure 2.13A).

In most cases, however, not all surface atoms contribute to the image. Atoms that contribute to tunneling depend on the applied voltage and their exact electronic structure (Figure 2.13B). At atomic resolution, images are most easily interpreted when the surface composition is known and the types of chemical bonds are understood. At lower resolution (larger scan areas), surface shape can be mapped precisely by requiring a constant tunneling current between the tip and sample. This keeps the gap constant. The image then is formed by the up-and-down motion of the tip as it scans over the surface.

Scanning force microscopy (SFM), also called atomic force microscopy (AFM), is a direct descendant from STM technology. It was first built and used in 1985 by Gerd Binnig and Calvin Quate, respectively of IBM and Stanford University. SFM is similar to STM, except the image is produced by moving the sample laterally under a hard, sharp tip that is free to move up and down.

Unlike STM, the tip is in actual physical contact with the surface. However, the force holding it down is approximately a billion times less than the force used to hold a stylus against a phonographic record. These extremely light tracking forces keep the sharp tip from damaging the surface. The motion of the tip usually is measured by an optical laser system that is sensitive to movement on the atomic scale. Consequently, images with nearly atomic resolution can be obtained. Because this type of microscopy does not require electrical current, insulating surfaces can be imaged as well as those that are conducting (Figure 2.13C).

STM and SFM have become important tools for studying mineral growth and breakdown. Atomic structure and bonding can be studied (Figures 2.13A, 2.13B), along with minute surface topographic features (Figures 2.13B, 2.13C). Structure, bonding, and topography determine what may or may not adsorb to a mineral (this is the process by which ions in water attach to a mineral's surface). If the attachment reaction is strong, the attracted ions may be effectively removed from solution. Or, if attachment is weak, they may stay in solution. These processes are extremely important in water purification. They also may be important in ore deposit formation and hazardous waste migration.

ADDITIONAL QUESTIONS

12. In Figure 2.13A, what is the approximate distance between sulfur and lead atoms? (Note that this is the length of the sulfur-lead atomic bond.)

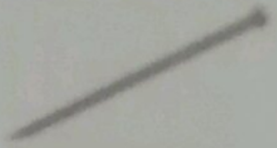
	METALLIC MINERALS			
	Hardness	Streak	Other Properties	Mineral
Not scratched by steel nail or knife	6–6.5	Dark gray	brass yellow, may tarnish brown; brittle, no cleavage, cubic crystals common, S.G. = 5.0	PYRITE ("fool's gold") FeS_2 iron sulfide
	6–6.5	Dark gray	pale brass yellow to whitish gold; brittle, no cleavage, radiating masses and "cockscombs," S.G. = 4.9	MARCASITE FeS_2 iron sulfide
	6	Dark gray	dark gray to black; magnetic; no obvious cleavage, S.G. = 5.2	MAGNETITE Fe_3O_4 iron oxide
	5.5–6.5	Red to red-brown	silver to gray; may be tiny glittery flakes; may tarnish red, S.G. = 4.9–5.3	HEMATITE Fe_2O_3 iron oxide
Scratched by steel nail or knife 	5–5.5	Yellow-brown	dark brown to black, in radiating layers, S.G. = 4.3	GOETHITE FeO(OH) hydrous iron oxide
	5–5.5	Yellow-brown	yellow-brown to dark brown, amorphous, but may be pseudomorphic after pyrite, S.G. = 2.7–4.3	LIMONITE $Fe_2O_3 \cdot nH_2O$ hydrous iron oxide
Scratched by wire nail 	3.5–4	Dark gray	golden yellow; may tarnish purple; brittle, no cleavage, S.G. = 4.1–4.3	CHALCOPYRITE $CuFeS_2$ copper iron sulfide
	3.5–4	White to yellow-brown	brown to yellow, or black; submetallic, dodecahedral cleavage, S.G. = 3.9–4.1	SPHALERITE ZnS zinc sulfide
Scratched by penny 	2.5–3	Copper	copper to dark brown; may oxidize green; malleable, S.G. = 8.8–8.9	NATIVE COPPER Cu copper
	2.5	Gray to dark gray	shiny gray, tarnishes dull gray; cubic cleavage, not scratched by fingernail, S.G. = 7.4–7.6	GALENA PbS lead sulfide
Scratched by fingernail 	1	Dark gray	gray to black; marks paper easily; greasy feel, S.G. = 2.1–2.3	GRAPHITE C carbon

FIGURE 2.27 Characteristics of metallic minerals. SG = specific gravity.

13. In Figure 2.13B, why might the oxygens at the step edges produce different height bumps in the STM image than oxygens on the terraces?
14. Cleavage or parting planes on mineral surfaces often look perfectly flat to the unaided eye. How do you think they look on the nanometer scale (e.g., Figure 2.13A, 2.13B)?
15. What features in Figure 2.13C show that this mineral surface has been dissolving?

Mineral	Formula	Uses
Calcite	$CaCO_3$	In the form of limestone, used as fertilizer, soil conditioner, a source of lime, and in Portland cement In the form of limestone, marble, travertine, and Mexican onyx, used as ornamental stone
Chalcopyrite	$CuFeS_2$	Ore of copper
Feldspar	Aluminosilicates of K, Na, Ca	Major use in manufacture of porcelain, glass, ceramics Minor use as gemstones: amazonite, moonstone, sunstone
Galena	PbS	Chief ore of lead
Garnet	Ca, Fe, Mg, Al silicate	Abrasive powder and sandpaper; gem variety is January birthstone
Graphite	C	Machinery lubricant; heat-resistant material in foundries; pencil "lead"
Gypsum	$CaSO_4 \cdot 2H_2O$	Wallboard, plaster of Paris, drywall, sheetrock, some ornamental use in form called alabaster
Halite	$NaCl$	Table salt, road salt, and source of sodium and chlorine chemicals; old salt mines used as storage sites
Hematite	Fe_2O_3	Major ore of iron; minor use as a pigment (cave paintings often were done with hematite)
Limonite	$Fe_2O_3 \cdot nH_2O$	Ore of iron; minor use as pigment
Magnetite	Fe_3O_4	Ore of iron
Muscovite	$KAl_2(AlSi_3)O_{10}(OH)_2$	Used in sheets as electrical insulation; ground for use in wallpaper and paint; computer chip substrate
Olivine	$(Fe, Mg)_2SiO_4$	Gem variety called peridot is August birthstone; source of silicon for computer chips
Pyrite	FeS_2	"Fool's gold"; ore of sulfur used to make sulfuric acid; also mined for iron, and for associated real gold or copper
Quartz	SiO_2	In form of pure sand, used in making glass; minor importance as gemstones: amethyst, tiger's eye, agate, onyx

FIGURE 2.31 Economic significance of some common minerals and mineraloids.