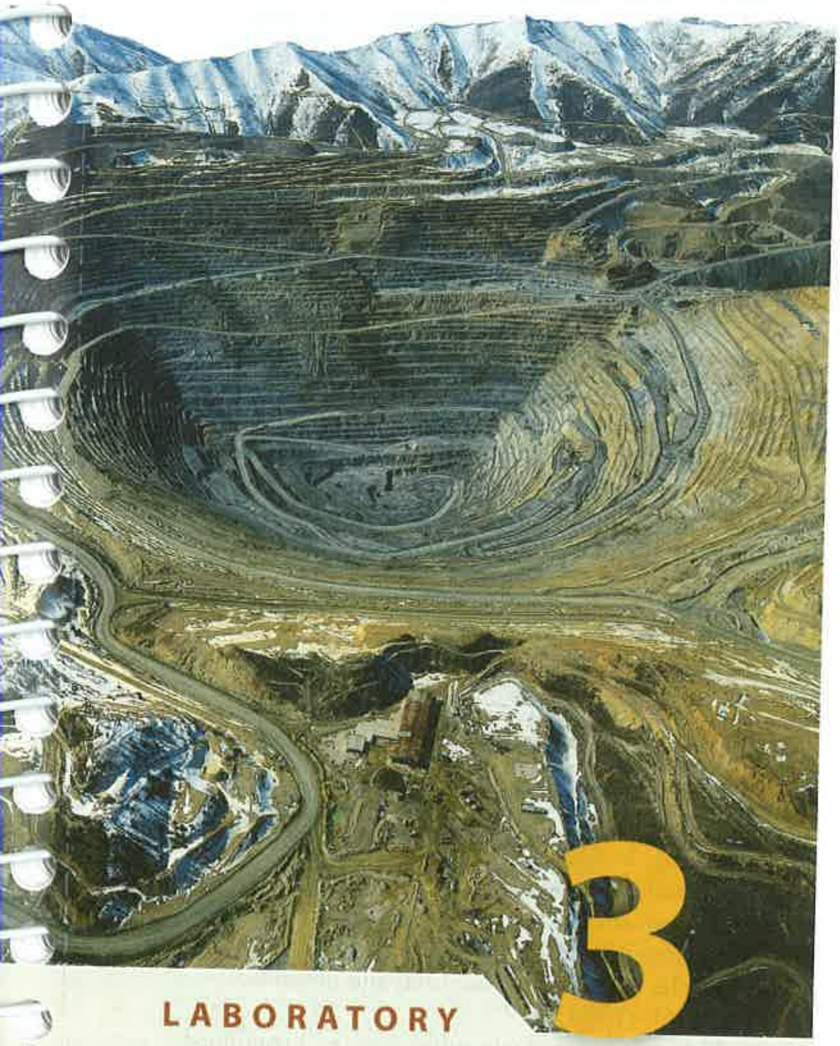


LABORATORY 3

Mineral Properties, Identification, and Uses

CONTRIBUTING AUTHORS

Jane L. Boger • *SUNY, College at Geneseo*

Philip D. Boger • *SUNY, College at Geneseo*

Roseann J. Carlson • *Tidewater Community College*

Charles I. Frye • *Northwest Missouri State University*

Michael F. Hochella, Jr. • *Virginia Polytechnic Institute*

Bingham Canyon Mine, southwest of Salt Lake City, Utah. It is primarily a copper mine, but gold, silver, and other metals have also been extracted from the ore here for over a century. (Michael Collier)

BIG IDEAS

Minerals comprise rocks and are described and classified on the basis of their physical and chemical properties. Every person depends on minerals and elements refined from them, but the supply of minerals is nonrenewable, and the magnitude of their use may be unsustainable.

FOCUS YOUR INQUIRY

THINK About It | What are minerals and crystals, and how are they related to rocks and elements?

ACTIVITY

3.1 Mineral and Rock Inquiry

THINK About It | **What are minerals and crystals, and how are they related to rocks and elements?**

OBJECTIVE Analyze rock samples, and infer how minerals are related to and distinguished from rocks, crystals, and chemical elements.

PROCEDURES

1. **Before you begin,** do not look up definitions and information. Use your current knowledge, and complete the worksheet with your current level of ability. Also, this is **what you will need** to do the activity:

   ____ Activity 3.1 Worksheet (p. 101) and pencil

2. **Then answer every question on the worksheet in a way that makes sense to you** and be prepared to compare your ideas with others.
3. **After you complete the worksheet,** read about minerals and rocks below and be prepared to discuss your observations, interpretations, and inferences with others.

Minerals and Rocks

Many people think of minerals as the beautiful natural crystals mined from the rocky body of Earth and displayed in museums or mounted in jewelry. But table salt, graphite in pencil leads, and gold nuggets are also minerals.

What Are Minerals?

According to geologists, **minerals** are inorganic, naturally occurring solids that have a definite chemical composition, distinctive physical properties, and crystalline structure. In other words, each mineral

- occurs in the solid, rocky body of Earth, where it formed by processes that are inorganic (not involving life).
- has a definite chemical composition of one or more chemical elements that can be represented as a chemical formula (like NaCl for halite, FeS_2 for pyrite, and Au for pure "native gold").
- has physical properties (like hardness, how it breaks, and color) that can be used to identify it.
- has crystalline structure—an internal patterned arrangement or geometric framework of atoms that can be revealed by external crystal faces (FIGURES 3.1A, B), the way a mineral breaks (FIGURE 3.2B), and in atomic-resolution images (FIGURE 3.2C).

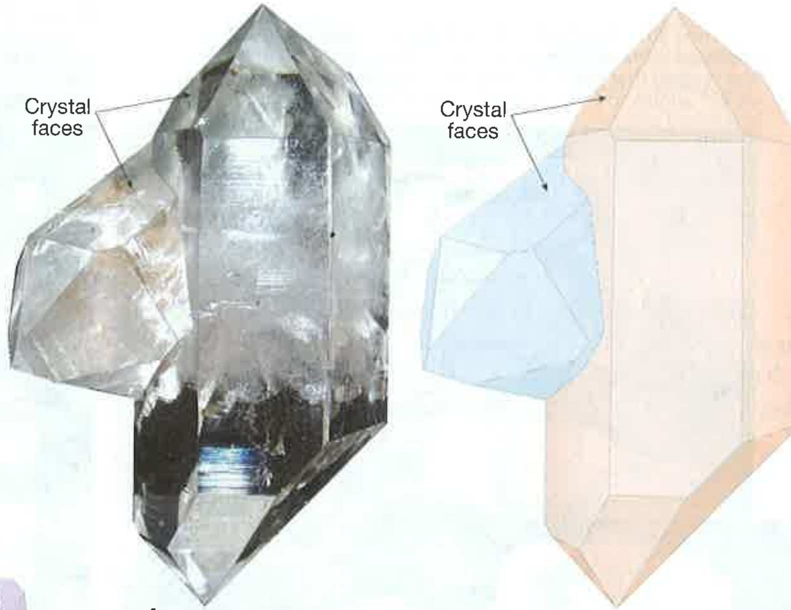
A few "minerals," such as limonite (rust) and opal (FIGURE 3.3) never form crystals, so they do not have crystalline structure. They are mineral-like materials (*mineraloids*) rather than true minerals. And even though all true minerals normally form by inorganic processes, some organisms make them as shells or other parts of their bodies. These so-called *biominerals* are of obvious organic origin (made by plants and animals). Examples include aragonite mineral crystals in clam shells and tiny magnetite crystals in the human brain. People make *cultured* mineral crystals in laboratories. Their chemical and physical properties are identical to naturally-formed mineral crystals, but they are not true minerals because they are *synthetic* (man-made, not natural).

How Are Minerals Classified?

Geologists have identified and named thousands of different kinds of minerals, but they are often classified into smaller groups according to their importance, use, or chemistry. For example, a group of only about twenty are known as **rock-forming minerals,** because they are the minerals that make up most of Earth's crust. Another group is called the **industrial minerals**, because they are the main non-fuel raw materials used to sustain industrialized societies like ours. Some industrial minerals are used in their raw form, such as quartz (quartz sand), muscovite (used in computer chips), and gemstones. Most are refined to obtain specific elements such as iron, copper, and sulfur. All minerals are also classified into the following chemical classes:

- **Silicate minerals** are composed of pure silicon dioxide (SiO_2, called quartz) or silicon-oxygen ions $(SiO_4)^{4-}$ combined with other elements. Examples are olivine: $(Fe, Mg)_2SiO_4$, potassium feldspar: $KAlSi_3O_8$, and kaolinite: $Al_2(Si_4O_{10})(OH)_8$.
- **Oxide minerals** contain oxygen (O^{2-}) combined with a metal (except for those containing silicon, which are silicate minerals). Examples are hematite: Fe_2O_3, magnetite: Fe_2O_3, and corundum: Al_2O_3.
- **Hydroxide minerals** contain hydroxyl ions $(OH)^-$ combined with other elements (except for those containing silicon, which are silicate minerals). Examples are goethite: FeO(OH) and limonite: $FeO(OH) \cdot nH_2O$.
- **Sulfide minerals** contain sulfur ions (S^{2-}) combined with metal(s) and no oxygen. Examples are pyrite: FeS_2, galena: PbS, and sphalerite: ZnS. When they are scratched or crushed, one can usually smell the sulfur in these minerals.
- **Sulfate minerals** contain sulfate ions $(SO_4)^{2-}$ combined with other elements. Examples include gypsum: $CaSO_4 \cdot H_2O$ and barite: $BaSO_4$.
- **Carbonate minerals** contain carbonate ions $(CO_3)^{2-}$ combined with other elements. Examples include calcite: $CaCO_3$ and dolomite: $CaMg(CO_3)_2$. These minerals react with acid, the way baking soda (which is the mineral named nahcolite and the chemical compound named sodium bicarbonate: $NaHCO_3$) reacts with acetic acid (CH_3COOH) in vinegar. Geologists use dilute hydrochloric acid (HCl) to detect carbonate minerals because the reaction makes larger bubbles. If a mineral reacts with the dilute HCl, then it is a carbonate mineral.

Top view: Crystal growth was unobstructed so crystal faces are developed (x1).



A.
A rock made of two large, visible, quartz mineral crystals. *Crystal faces* (flat outside surfaces) merge into three dimensional *crystal forms* (geometric shapes). Crystal growth was unobstructed, except where the two crystals touched and grew together (x1).

Side view: Deformed crystal faces among crowded intergrown crystals (x1).

B.
Rock made of many quartz mineral crystals. Note how crystal growth was obstructed as the sides of many crystals grew together (side view), but tips of the crystals (top view) grew unobstructed into six-sided pyramids. Iron impurity gives the purple amethyst variety of quartz its color.

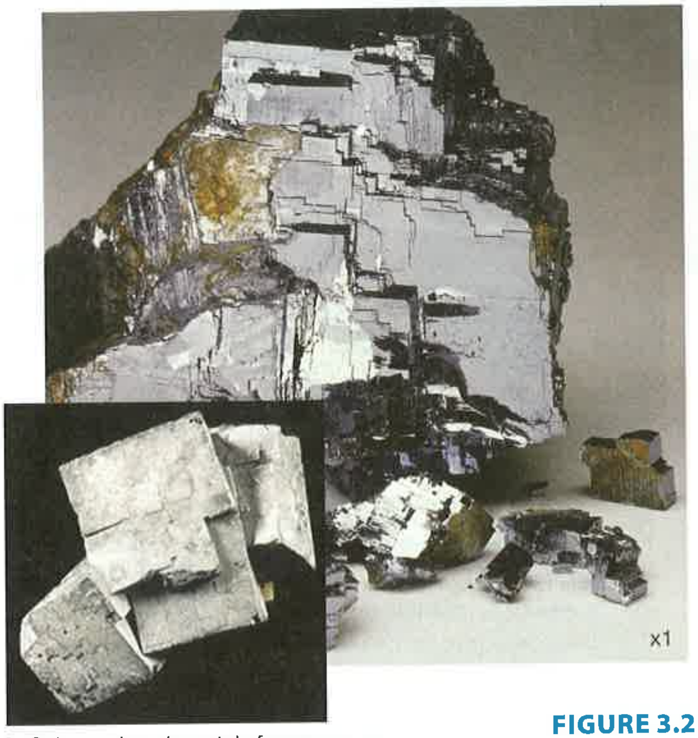
C.
Crystal growth of the calcite mineral crystals in this rock (marble) was obstructed in every direction. The crystals grew together as a dense mass of odd-shaped crystals instead of perfect crystal forms.

Thin section (x30). The layers of agate are made of long intergrown quartz mineral crystals.

D.
Slice of rock (agate) cut with a diamond saw and polished. The layers are made of quartz mineral crystals that are *cryptocrystalline* (not visible in hand sample). They can only be seen in a thin section (thin transparent slice of the rock mounted on a glass slide) magnified with a microscope to 30 times larger than their actual size (x30).

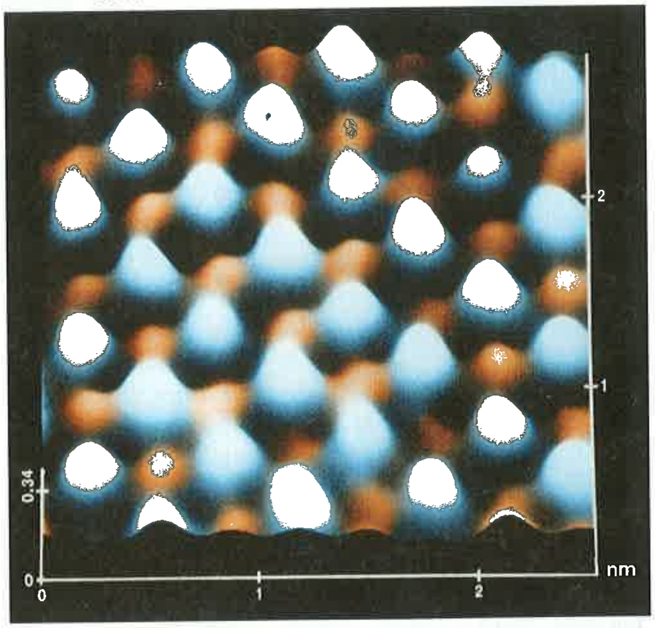
FIGURE 3.1 Minerals and rocks. Most rocks are made of one or more mineral crystals.

B. When struck with a hammer, galena breaks along flat *cleavage surfaces* (planes of weak chemical bonding within the crystal) that have a silvery color, like metal, and intersect at 90° angles to form shapes made of cubes.



A. Galena mineral crystals form cubic shapes that tarnish to a dull gray color.

C. Scanning tunneling microscope (STM) image of galena showing the orderly arrangement of its lead and sulfur atoms. Each sulfur atom is bonded to four lead atoms in the image, plus a lead atom beneath it. Similarly, each lead atom is bonded to four sulfur atoms in the image, plus a sulfur atom beneath it.



Blue = S (sulfur) atoms, Orange = Pb (lead) atoms
nm = nanometer = 1 millionth of a millimeter

FIGURE 3.2 Crystal shape, cleavage, and atomic structure. Galena is lead sulfide—PbS. It is an ore mineral from which lead (Pb) and sulfur (S) are extracted. (STM image by C.M. Eggleston, University of Wyoming)

- **Halide minerals** contain a halogen ion (F^-, Cl^-, Br^-, or I^-) combined with a metal. Examples are halite: NaCl and fluorite: CaF_2.
- **Phosphate minerals** contain phosphate ions $(PO_4)^{3-}$ combined with other elements. An example is apatite: $Ca_5F(PO_4)_3(OH, F, Cl)$.
- **Native elements** are elements in pure form, not combined with different elements. Examples include graphite: C, copper: Cu, sulfur: S_2, gold: Au, and silver: Ag.

How Are Minerals Related to Rocks?

Most **rocks** are aggregates of one or more mineral crystals. For example, mineral crystals comprise all of the rocks in **FIGURE 3.1**. Notice that you can easily detect the mineral crystals in **FIGURES 3.1A** and **3.1B** by their flat **faces**, which are an external feature of the internal geometric framework of their atoms. However, the crystals in many rocks have grown together in such a crowded way that few faces are visible (**FIGURES 3.1C**). Some rocks are also **cryptocrystalline**, made of crystals that are only visible under a microscope (**FIGURE 3.1D**).

Earth is sometimes called the "third rock" (rocky planet) from the Sun, because it is mostly made of rocks. But rocks are generally made of one or more minerals, which are the natural materials from which every inorganic item in our industrialized society has been manufactured. Therefore, minerals are the physical foundation of both our rocky planet and our human societies.

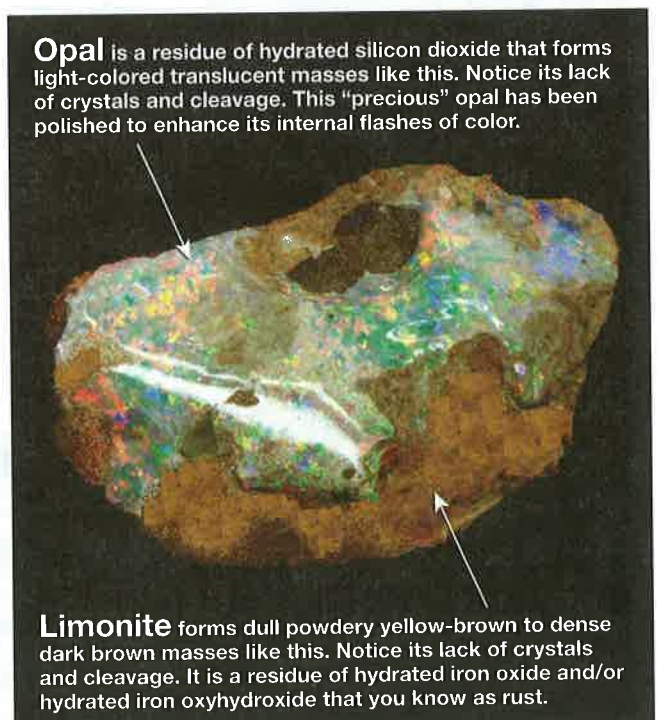


FIGURE 3.3 Mineraloids. Opal and limonite are naturally-occurring inorganic materials, but they are *amorphous* (non-crystalline; they never form crystals). This makes them *mineraloids* (amorphous mineral-like materials), rather true minerals, but they are described, identified, and listed as minerals.

ACTIVITY

3.2 Mineral Properties

THINK About It | **How and why do people study minerals?**

OBJECTIVE Analyze and describe the physical and chemical properties of minerals.

PROCEDURES

1. **Before you begin**, read the following background information. This is **what you will need**:
   ____ Activity 3.2 Worksheets (pp. 102–103) and pencil
   ____ set of mineral samples (obtained as directed by your instructor)
   ____ set of mineral analysis tools (obtained as directed by your instructor)
   ____ cleavage goniometer cut from GeoTools Sheet 1 at the back of the manual
2. **Then follow your instructor's directions** for completing the worksheets.

What Are a Mineral's Chemical and Physical Properties?

The **chemical properties** of a mineral are its characteristics that can only be observed and measured when or after it undergoes a chemical change due to reaction with another material. This includes things like if or how it tarnishes (reacts with air or water) and whether or not it reacts with acid. For example, calcite and other carbonate (CO_3-containing) minerals react with acid, and native copper tarnishes to a dull brown or green color when it reacts with air or water.

The **physical properties** of a mineral are its characteristics that can be observed (and sometimes measured) without changing its composition. This includes things like how it looks (color, luster, clarity) before it tarnishes or weathers by reacting with air or water, how well it resists scratching (hardness), how it breaks or deforms under stress (cleavage, fracture, tenacity), and the shapes of its crystals. For example, quartz crystals are hard to scratch, glassy, and transparent, while talc is easily scratched, opaque, and feels greasy.

In this activity, you will use the properties of color and clarity (before and after tarnishing), crystal form, luster (before and after tarnishing), streak, hardness, cleavage, and fracture to describe mineral samples. Additional properties—such as tenacity, reaction with acid, magnetic attraction, specific gravity, striations, and exsolution lamellae—can also be helpful in analyzing particular minerals.

Color and Clarity. A mineral's **color** is usually its most noticeable property and may be a clue to its identity. Minerals normally have a typical color, like gold. A rock made up of one color of mineral crystals is usually made up of one kind of mineral, and a rock made of more than one color of mineral crystals is usually made up of more than one kind of mineral. However, there are exceptions, like the agate in FIGURE 3.1D. It has many colors, but they are simply *varieties* (var.)—different colors—of the mineral quartz. This means that a mineral cannot be identified solely on the basis of its color. The mineral's other properties must also be observed, recorded, and used collectively to identify it. Most minerals also tend to exhibit one color on freshly broken surfaces and a different color on tarnished or weathered surfaces. Be sure to note this difference, if present, to aid your identification.

Mineral crystals may vary in their **clarity**: degree of transparency or their ability to transmit light. They may be *transparent* (clear and see-through, like window glass), *translucent* (foggy, like looking through a steamed-up shower door), or *opaque* (impervious to light, like concrete and metals). It is good practice to record not only a mineral's color, but also its clarity. For example, the crystals in FIGURE 3.1B are purple in color and have transparent to translucent clarity. Galena mineral crystals (FIGURE 3.2) are opaque.

Crystal Forms and Mineral Habits. The geometric shape of a crystal is its **crystal form**. Each form is bounded by flat **crystal faces** that intersect at specific angles and in symmetrical relationships (FIGURE 3.1A and B). The crystal faces are the outward reflection of the way that atoms or groups of atoms bonded together in a three-dimensional pattern as the crystal grew under specific environmental conditions. There are many named crystal forms (FIGURE 3.4). Combinations of two or more crystals can also form named patterns, shapes, or twins (botryoidal, dendritic, radial, fibrous: FIGURE 3.4). A mass of mineral crystals lacking a distinctive pattern of crystal growth is called *massive*.

Development of Crystal Faces. The terms euhedral, subhedral, and anhedral describe the extent to which a crystal's faces and form are developed. *Euhedral crystals* have well developed crystal faces and clearly defined and recognizable crystal forms (FIGURE 3.1A). They develop only if a mineral crystal is unrestricted as it grows. This is rare. It is more common for mineral crystals to crowd together as they grow, resulting in a massive network of intergrown crystals with deformed crystal faces and odd shapes or imperfect crystal forms (FIGURE 3.1B). *Subhedral* crystals are imperfect but have enough crystal faces that their forms are recognizable. *Euhedral* crystals have no crystal faces, so they have no recognizable crystal form (FIGURE 3.1C). Most of the laboratory samples of minerals that you will analyze do not exhibit their crystal forms because they are small broken pieces of larger crystals. But whenever the form or system of crystals in a mineral sample can be detected, then it should be noted and used as evidence for mineral identification.

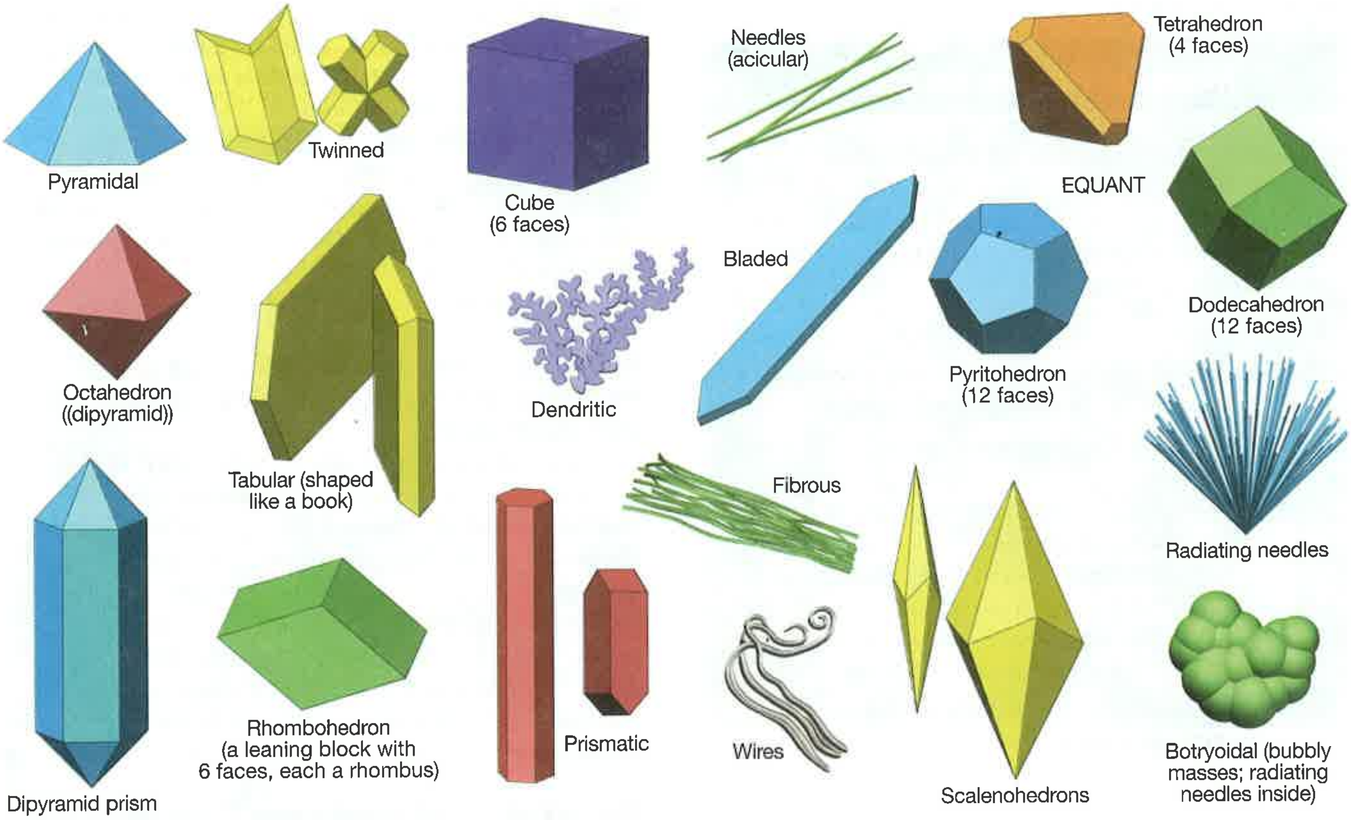


FIGURE 3.4 Crystal forms and combinations. *Crystal form* is the geometric shape of a crystal, and is formed by intersecting flat outer surfaces called *crystal faces*. Combinations of two or more crystals can form patterns, shapes, or twins that also have names. *Massive* refers to a combination of mineral crystals so tightly inter-grown that their crystal forms cannot be seen in hand sample.

Crystal Systems. Each specific crystal form can be classified into one of six *crystal systems* (FIGURE 3.5) according to the number, lengths, and angular relationships of imaginary geometric axes along which its crystal faces grew. The crystal systems comprise 32 classes of crystal forms, but only the common crystal forms are illustrated in FIGURE 3.5.

Mineral Habit. A mineral's **habit** is the characteristic crystal form(s) or combinations (clusters, coatings, twinned pairs) that it habitually makes under a given set of environmental conditions. Pyrite forms under a variety of environmental conditions so it has more than one habit. Its habit is cubes, pyritohedrons, octahedrons, or massive (FIGURE 3.4).

Luster. A mineral's **luster** is a description of how light reflects light from its surfaces. Luster is of two main types—metallic and nonmetallic—that vary in intensity from bright (very reflective, shiny, polished) to dull (not very reflective, not very shiny, not polished). For example, if you make a list of objects in your home that are made of metal (e.g., coins, knives, keys, jewelry, door hinges, aluminum foil), then you are already familiar with metallic luster. Yet the metallic objects can vary from bright (very reflective—like polished jewelry, the polished side of aluminum foil, or new coins) to dull (non-reflective—like unpolished jewelry or the unpolished side of aluminum foil).

Metallic Luster. Minerals with a **metallic luster (M)** reflect light just like the metal objects in your home—they have opaque, reflective surfaces with a silvery, gold, brassy, or coppery sheen (FIGURES 3.2B, 3.6A, 3.7A).

Nonmetallic Luster. All other minerals have a **nonmetallic luster (NM)**—a luster unlike that of the metal objects in your home (FIGURES 3.1, 3.2A, 3.3). The luster of nonmetallic minerals can also be described with the more specific terms below:

- Vitreous—very reflective luster resembling freshly broken glass or a glossy photograph
- Waxy—resembling the luster of a candle
- Pearly—resembling the luster of a pearl
- Earthy (dull)—lacking reflection, like dry soil
- Greasy—resembling the luster of grease, oily

Tarnish and Submetallic Luster. Most metallic minerals will normally tarnish (chemically weather) to a more dull nonmetallic luster, like copper coins. Notice how the exposed metallic copper crystals in FIGURE 3.6 and the galena crystals in FIGURE 3.2A have tarnished to a nonmetallic luster. Always observe freshly broken surfaces of a mineral (e.g., FIGURE 3.2B) to determine whether it has a metallic or nonmetallic luster. It is also useful to note a mineral's luster on fresh versus tarnished

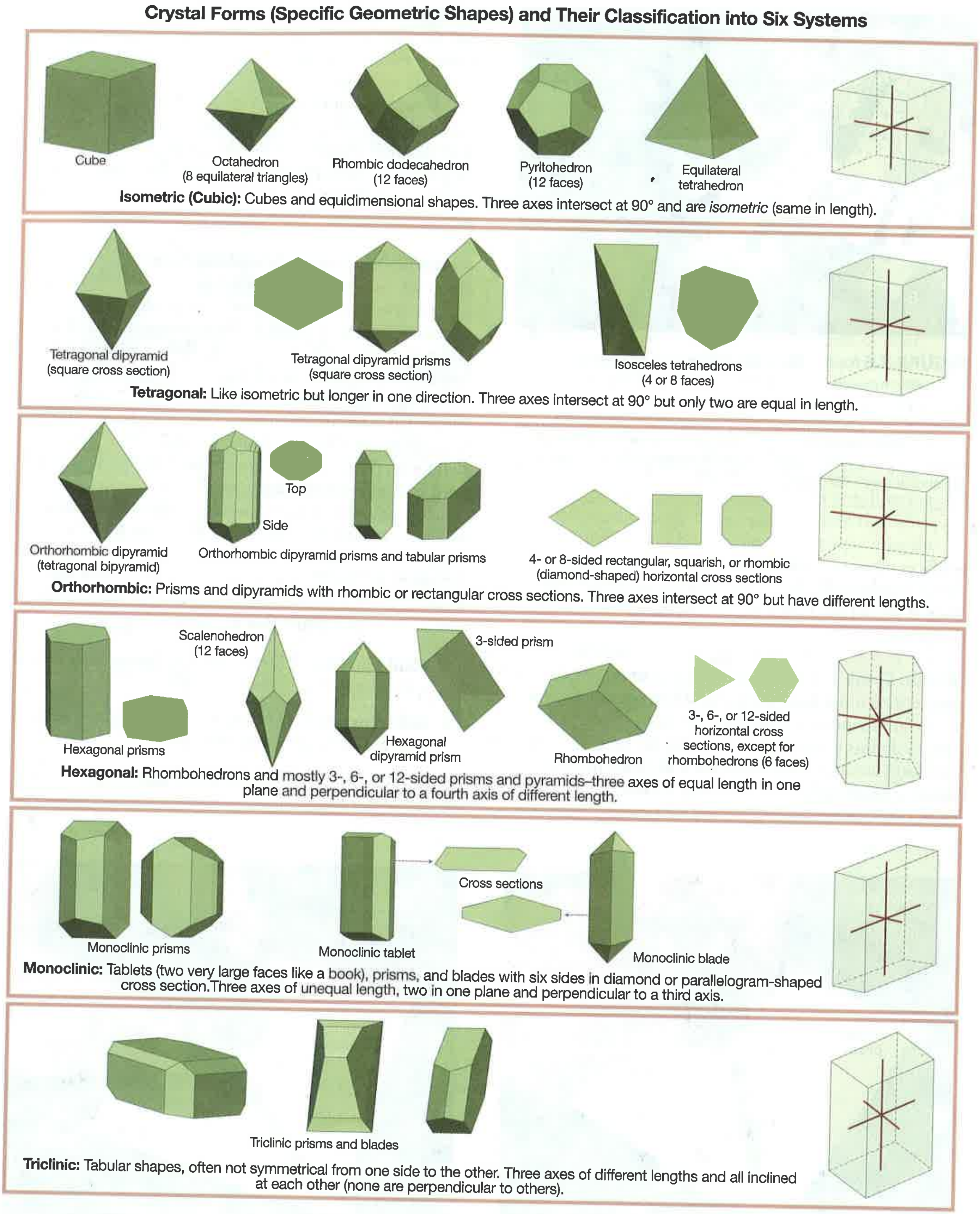


FIGURE 3.5 Crystal systems. Each specific crystal form can be classified into one of six *crystal systems* (major groups) according to the number, lengths, and angular relationships of imaginary geometric axes along which its crystal faces grew (red lines in the right-hand models of each system above). Only the common crystal forms of each class are illustrated and named above.

FIGURE 3.6 Native elements. The native elements are minerals composed of just one element, like gold nuggets. **A.** When freshly formed or broken, native copper (Cu, naturally-occurring pure copper) has a reflective metallic luster like this freshly-minted copper coin. However, these dendritic clusters of native copper crystals have tarnished to nonmetallic dull brown (A) and/or green (B) colors.

surfaces when possible. If you think that a mineral's luster is *submetallic*, between metallic and nonmetallic, then it should be treated as metallic for identification purposes.

Streak. Streak is the color of a mineral or other substance after it has been ground to a fine powder (so fine that you cannot see the grains of powder). The easiest way to do this is simply by scratching the mineral back and forth across a hard surface such as concrete, or a square of unglazed porcelain (called a *streak plate*). The color of the mineral's fine powder is its streak. Note that the brassy mineral in **FIGURE 3.7** has a dark gray streak, but the reddish silver mineral has a red-brown streak. A mineral's streak is usually similar even among all of that mineral's varieties.

If you encounter a mineral that is harder than the streak plate, it will scratch the streak plate and make a white streak of powder from the streak plate. The streak of such hard minerals can be determined by crushing a tiny piece of them with a hammer (if available). Otherwise, record the streak as unknown.

Hardness (H). A mineral's **hardness** is a measure of its resistance to scratching. A harder substance will scratch a softer one (**FIGURE 3.8**). German mineralogist Friedrich Mohs (1773–1839) developed a quantitative scale of relative mineral hardness on which the softest mineral (talc) has an arbitrary hardness of 1 and the hardest mineral (diamond) has an arbitrary 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 3.9**) is widely used by geologists and engineers. When identifying a mineral, you should mainly be able to distinguish minerals that are relatively hard (6.0 or higher on Mohs Scale) from minerals that are relatively soft (less than or equal to 5.5 on Mohs Scale). You can use common objects such as a glass plate (**FIGURE 3.9**), pocket knife, or steel masonry nail to make this distinction as follows.

- **Hard minerals:** Will scratch glass; cannot be scratched with a knife blade or masonry nail.
- **Soft minerals:** Will not scratch glass; can be scratched with a knife blade or masonry nail.

You can determine a mineral's hardness number on Mohs Scale by comparing the mineral to common objects

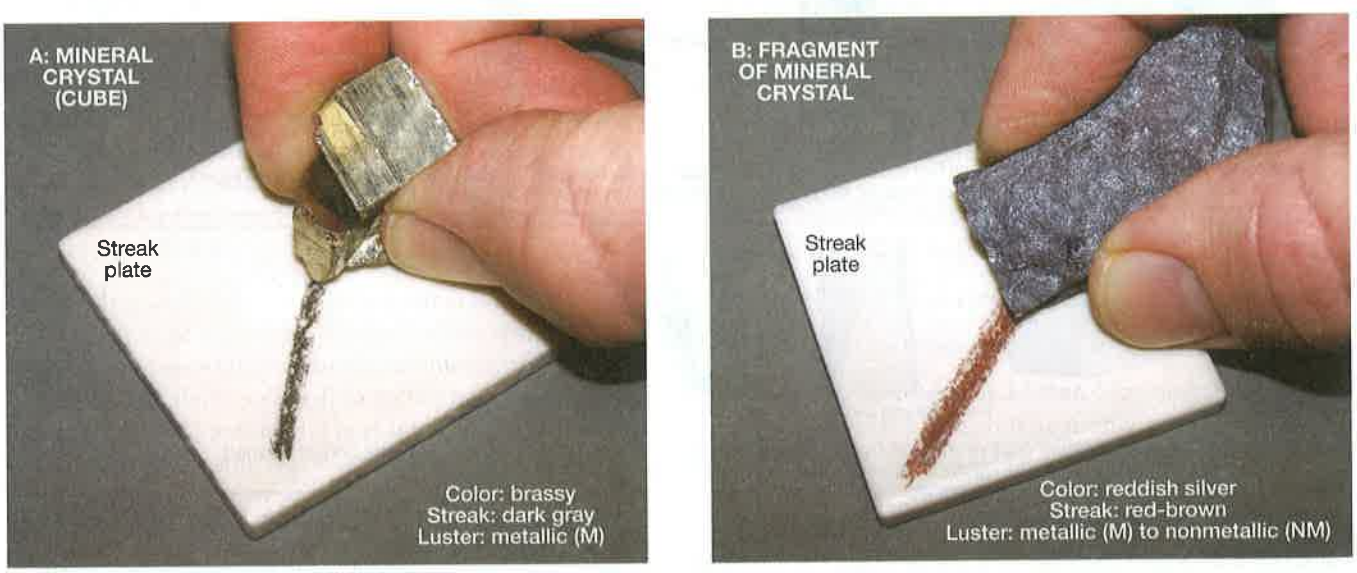


FIGURE 3.7 Streak tests. Determine a mineral's streak (color in powdered form) by scratching it across a streak plate with significant force, then blowing away larger pieces of the mineral to reveal the color of the powder making the streak. If you do not have a streak plate, then determine the streak color by crushing or scratching part of the sample to see the color of its powdered form.

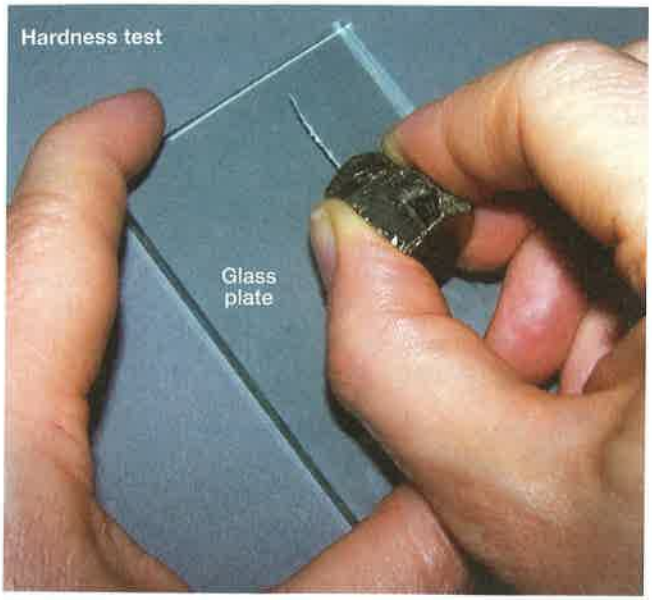
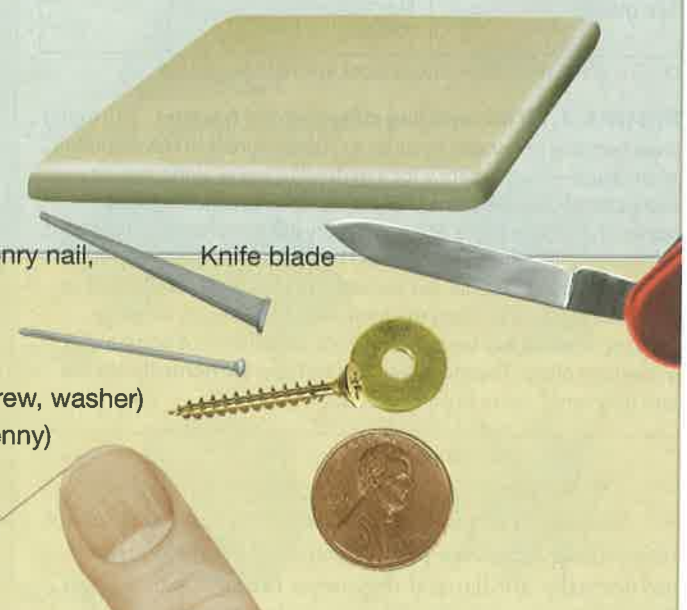


FIGURE 3.8 Hardness test. You can test a mineral's hardness (resistance to scratching) using a glass plate, which has a hardness of 5.5 on Mohs Scale of Hardness (**FIGURE 3.9**). Be sure the edges of the glass have been dulled. If not, then wrap the edges in masking tape or duct tape. Hold the glass plate firmly against a flat table top, then forcefully try to scratch the glass with the mineral sample. A mineral that scratches the glass is a *hard* mineral (i.e., harder than 5.5). A mineral that does not scratch the glass is a *soft* mineral (i.e., less than or equal to 5.5).

shown in **FIGURE 3.9** or pieces of the minerals in Mohs Scale. Commercial *hardness kits* contain a set of all of the minerals in **FIGURE 3.9** or a set of metal scribes of known hardnesses. When using such kits to make hardness comparisons, remember that the harder mineral/object is the one that scratches, and the softer mineral/object is the one that is scratched.

Cleavage and Fracture. Cleavage is the tendency of some minerals to break (*cleave*) along flat, parallel surfaces (**cleavage planes**) like the flat surfaces on broken pieces of galena (**FIGURE 3.2B**). Cleavage planes are surfaces of weak chemical bonding (attraction) between repeating, parallel layers of atoms in a crystal. Each different set of parallel cleavage planes is referred to as a *cleavage direction*. Cleavage can be described as excellent, good, or poor (**FIGURE 3.10**). An *excellent cleavage* direction reflects light in one direction from a set of obvious, large, flat, parallel surfaces. A *good cleavage* direction reflects light in one direction from a set of many small, obvious, flat, parallel surfaces. A *poor cleavage* direction reflects light from a set of small, flat, parallel surfaces that are difficult to detect. Some of the light is reflected in one direction from the small cleavage surfaces, but most of the light is scattered randomly by fracture surfaces separating the cleavage surfaces.

	Mohs Scale of Hardness*	Hardness of Some Common Objects (Harder objects scratch softer objects)
HARD	10 Diamond	
	9 Corundum	
	8 Topaz	
	7 Quartz	
		6.5 Streak plate
	6 Orthoclase Feldspar	
		5.5 Glass, Masonry nail, Knife blade
SOFT	5 Apatite	
		4.5 Wire (iron) nail
	4 Fluorite	
		3.5 Brass (wood screw, washer)
	3 Calcite	
		2.9 Copper coin (penny)
		2.5 Fingernail
	2 Gypsum	
	1 Talc	



* A scale for measuring relative mineral hardness (resistance to scratching).

FIGURE 3.9 Mohs Scale of Hardness (resistance to scratching). *Hard minerals* have a Mohs hardness number greater than 5.5, so they scratch glass and cannot be scratched with a knife blade or masonry (steel) nail. *Soft minerals* have a Mohs hardness number of 5.5 or less, so they do not scratch glass and are easily scratched by a knife blade or masonry (steel) nail. A mineral's hardness number can be determined by comparing it to the hardness of other common objects or minerals of Mohs Scale of Hardness.

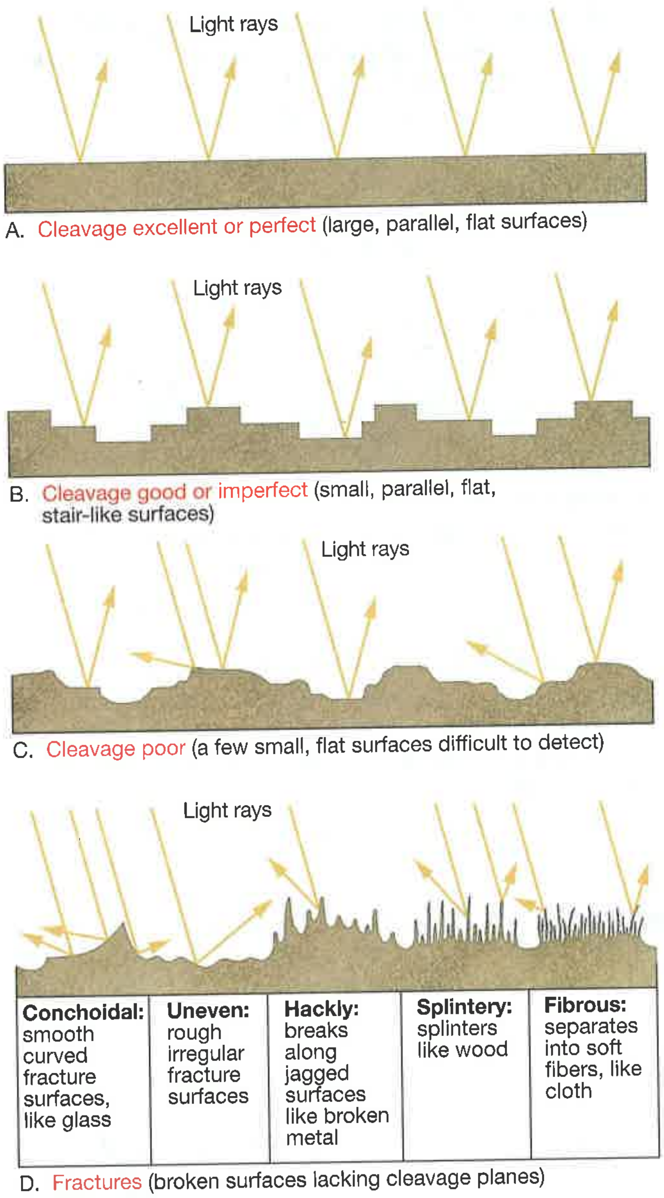


FIGURE 3.10 Recognizing cleavage and fracture. Illustrated cross sections of mineral samples to show degrees of development of cleavage—the tendency for a mineral to break along one or more sets of parallel, planar, reflective surfaces called *cleavage planes*. If a broken piece of a mineral crystal is rotated in bright light, its cleavage planes will be revealed by periodic flashes of light from one large, or many small, flat parallel surfaces. If no such reflective flashes of light occur, then the mineral sample has no cleavage. *Fracture* refers to any break in a mineral that does not occur along a cleavage plane. Therefore, fracture surfaces are normally not flat and they never occur in parallel sets.

Fracture refers to any break in a mineral that does not occur along a cleavage plane. Therefore, fracture surfaces are normally not flat and they never occur in parallel sets. Fracture can be described as *uneven* (rough and irregular, like the milky quartz in FIGURE 3.11B), *splintery* (like splintered wood), or *hackly* (having jagged edges, like broken metal). Pure quartz (FIGURE 3.11A) and mineraloids like opal (FIGURE 3.3) tend to fracture like glass—along ribbed, smoothly curved surfaces called *conchoidal fractures*.

Cleavage Direction. Cleavage planes are parallel surfaces of weak chemical bonding (attraction) between repeating parallel layers of atoms in a crystal, and more than one set of cleavage planes can be present in a crystal. Each different set has an orientation relative to the crystalline structure and is referred to as a **cleavage direction** (FIGURE 3.12). For example, muscovite (FIGURE 3.13) has one excellent cleavage direction and splits apart like pages of a book (book cleavage). Galena (FIGURE 3.2) breaks into small cubes and shapes made of cubes, so it has three cleavage directions developed at right angles to one another. This is called cubic cleavage (FIGURE 3.12).

Cleavage Direction in Pyriboles. Minerals of the pyroxene (e.g., augite) and amphibole (e.g., hornblende) groups generally are both dark-colored (dark green to black), opaque, nonmetallic minerals that have two good

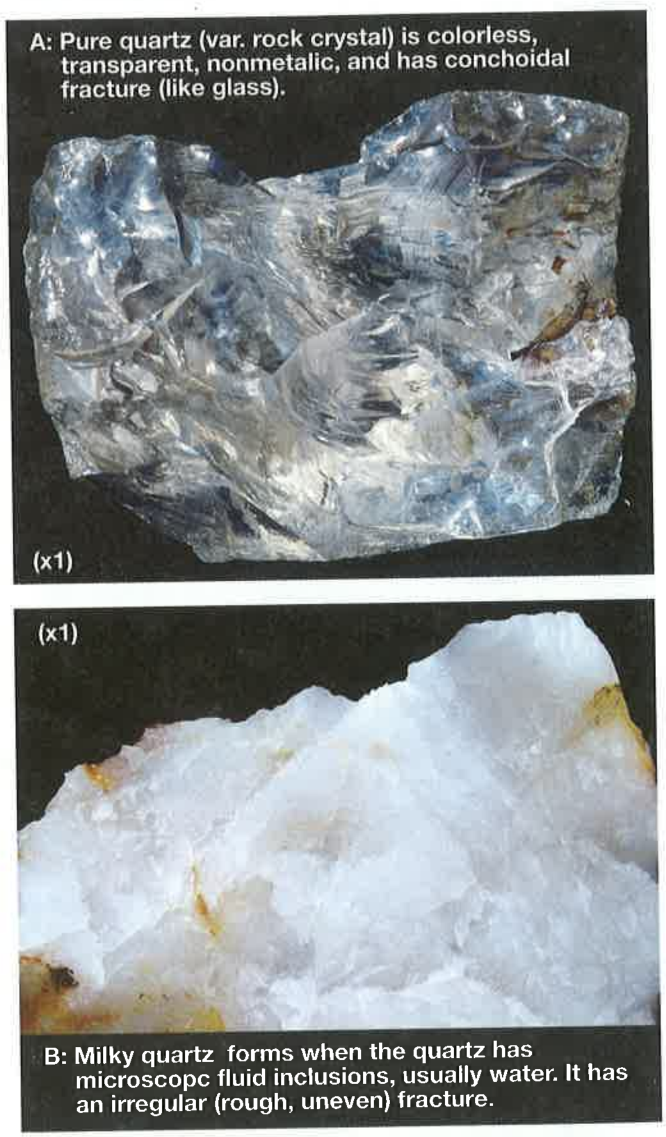


FIGURE 3.11 Fracture in quartz—SiO_2 (silicon dioxide). These hand samples are broken pieces of quartz mineral crystals so no crystal faces are present. Note the absence of cleavage and the presence of conchoidal (like glass) to uneven fracture.

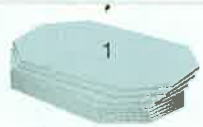
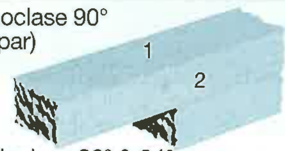
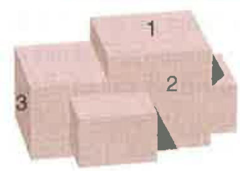
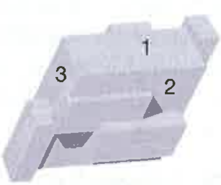
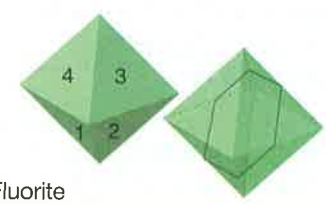
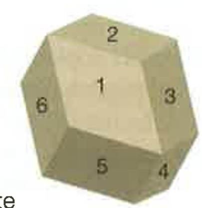
Number of Cleavages and Their Directions	Name and Description of How the Mineral Breaks	Shape of Broken Pieces (cleavage directions are numbered)	Illustration of Cleavage Directions
No cleavage (fractures only)	No parallel broken surfaces; may have conchoidal fracture (like glass)	 Quartz	None (no cleavage)
1 cleavage	**Basal (book) cleavage** "Books" that split apart along flat sheets	 Muscovite, biotite, chlorite (micas)	
2 cleavages intersect at or near 90°	**Prismatic cleavage** Elongated forms that fracture along short *rectangular* cross sections	Orthoclase 90° (K-spar)  Plagioclase 86° & 94°, pyroxene (augite) 87° & 93°	
2 cleavages do not intersect at 90°	**Prismatic cleavage** Elongated forms that fracture along short *parallelogram* cross sections	 Amphibole (hornblende) 56° & 124°	
3 cleavages intersect at 90°	**Cubic cleavage** Shapes made of cubes and parts of cubes	 Halite, galena	
3 cleavages do not intersect at 90°	**Rhombohedral cleavage** Shapes made of rhombohedrons and parts of rhombohedrons	 Calcite and dolomite 75° & 105°	
4 main cleavages intersect at 71° and 109° to form octahedrons, which split along hexagon-shaped surfaces; may have secondary cleavages at 60° and 120°	**Octahedral cleavage** Shapes made of octahedrons and parts of octahedrons	 Fluorite	
6 cleavages intersect at 60° and 120°	**Dodecahedral cleavage** Shapes made of dodecahedrons and parts of dodecahedrons	 Sphalerite	

FIGURE 3.12 **Cleavage in minerals.**

FIGURE 3.13 Cleavage in mica. Mica is a group of silicate minerals that form very reflective (vitreous) tabular crystals with one excellent cleavage direction. The crystals split easily into thin sheets, like pages of a book. This is called *book cleavage*. Muscovite mica is usually silvery brown in color. Biotite mica is always black.

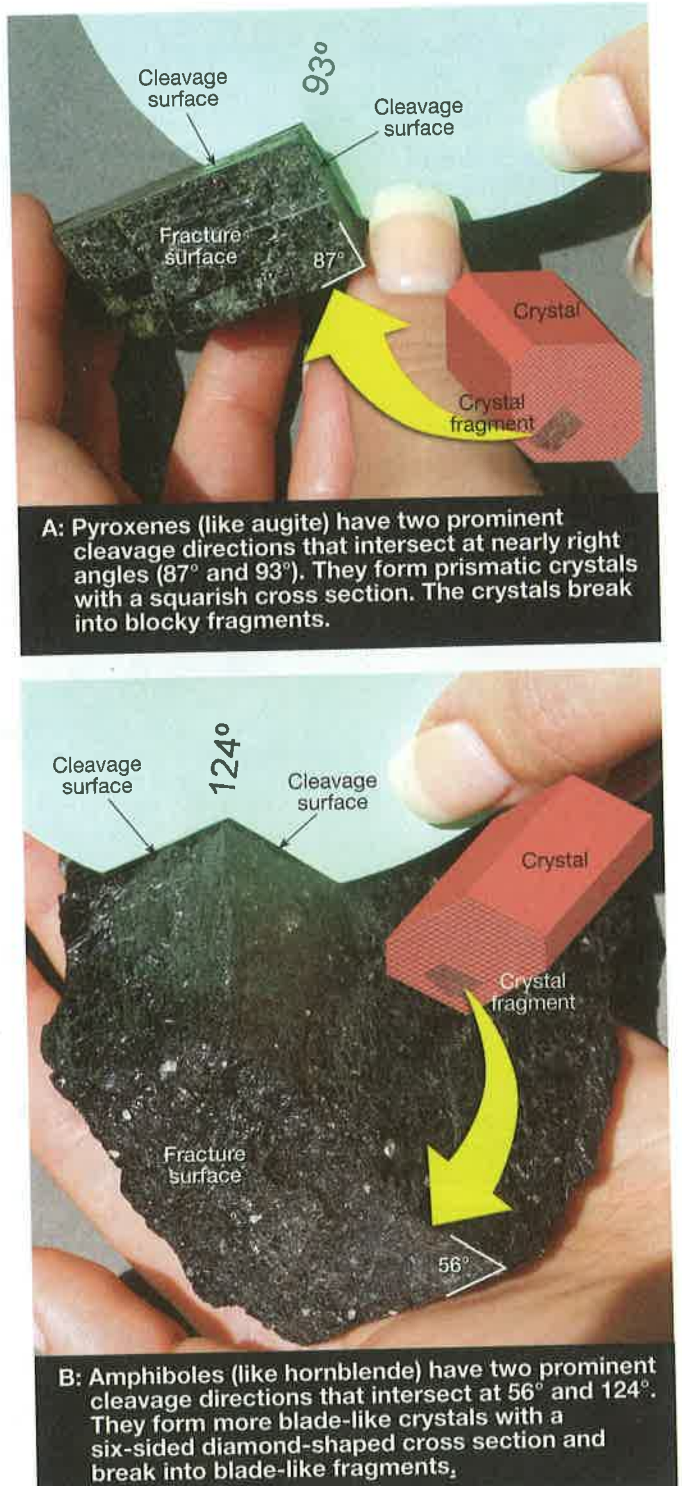


FIGURE 3.14 Cleavage in pyroxenes and amphiboles. Pyroxenes and amphiboles are two groups of dark colored silicate minerals with many similar properties. The main feature that distinguishes them is their cleavage.

cleavage directions. The two groups of minerals are sometimes difficult to distinguish, so some people identify them collectively as *pyriboles*. However, pyroxenes can be distinguished from amphiboles on the basis of their cleavage. The two cleavages of pyroxenes intersect at 87° and 93°, nearly at right angles (**FIGURE 3.14A**). The two cleavages of amphiboles intersect at angles of 56° and 124° (**FIGURE 3.14B**). These angles can be measured in hand samples using the cleavage goniometer from GeoTools Sheet 1 at the back of this manual. Notice how a green cleavage goniometer was used to measure angles between cleavage directions in **FIGURE 3.14**.

Cleavage Direction in Feldspars. Feldspars have two excellent to good cleavage directions, plus uneven fracture (**FIGURE 3.15**). The cleavage goniometer from GeoTools Sheet 1 can be used to distinguish potassium feldspar (orthoclase) from plagioclase (**FIGURE 3.15**).

Other Properties. There are additional mineral properties, too numerous to review here. However, the following other properties are typical of specific minerals or mineral groups:

Tenacity is the manner in which a substance resists breakage. Terms used to describe mineral tenacity include *brittle* (shatters like glass), *malleable* (like modeling clay or gold; can be hammered or bent permanently into new shapes), *elastic* or *flexible* (like a plastic comb; bends but returns to its original shape), and *sectile* (can be carved with a knife).

Reaction to acid differs among minerals. Cool, dilute hydrochloric acid (1–3% HCl) applied from a dropper bottle is a common "acid test." All of the so-called *carbonate minerals* (minerals with a chemical composition including carbonate, CO_3) will effervesce ("fizz") when a drop of such dilute HCl is applied to one of their freshly exposed surfaces (**FIGURE 3.16**). Calcite ($CaCO_3$) is the most commonly encountered carbonate mineral and effervesces in the acid test. Dolomite [$Ca,Mg(CO_3)_2$] is

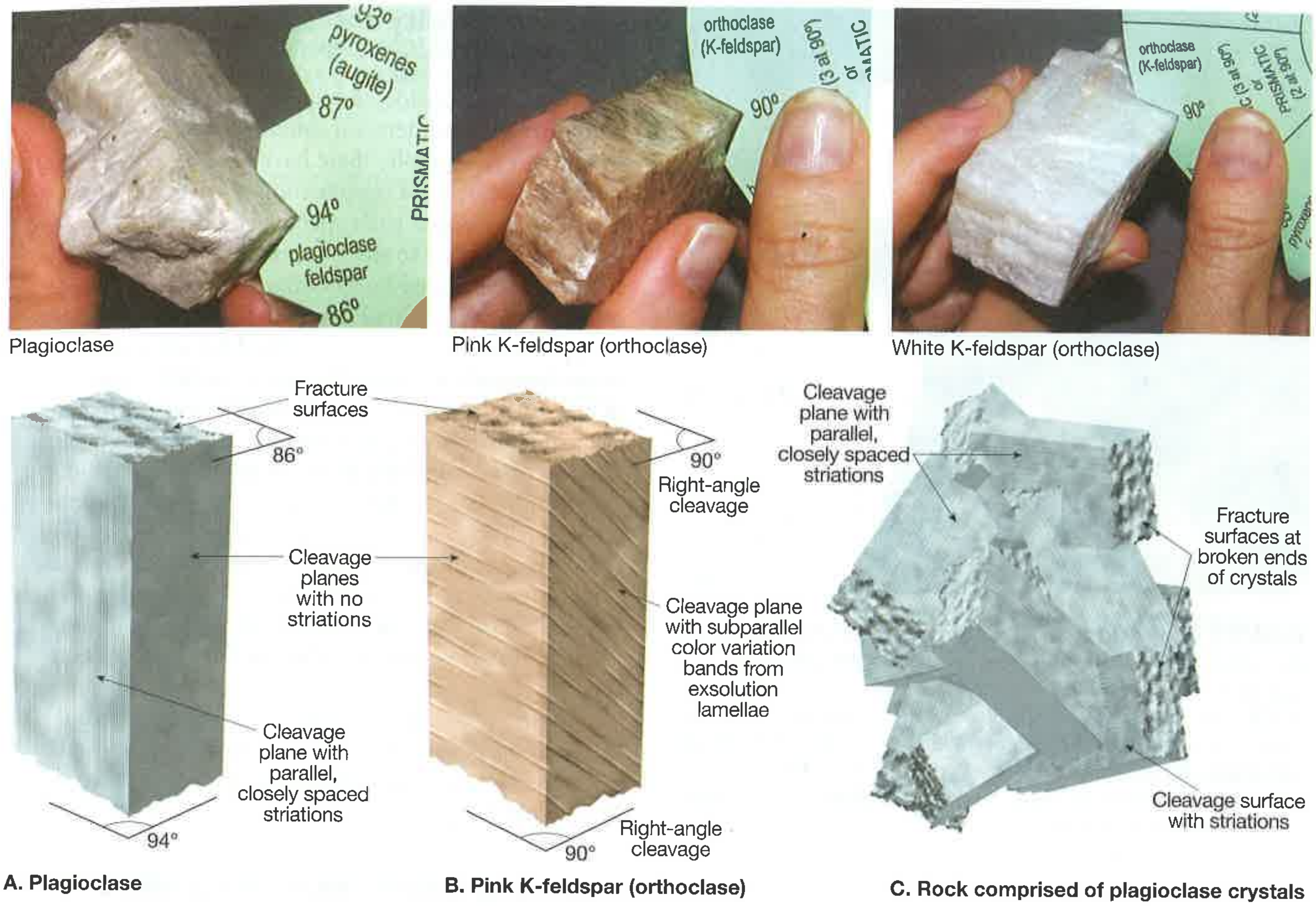


FIGURE 3.15 Common feldspars. Note how the cleavage goniometer can be used to distinguish potassium feldspar (K-spar, orthoclase) from plagioclase. The K-spar or orthoclase (Greek, *ortho*—right angle and *clase*—break) has perfect right-angle (90°) cleavage. Plagioclase (Greek, *plagio*—oblique angle and *clase*—break) does not. A. Plagioclase often exhibits *hairline striations* on some of its cleavage surfaces. They are caused by *twinning*: microscopic intergrowths between symmetrically-paired microcrystalline portions of the larger crystal. B. K-par (orthoclase) crystals may have intergrowths of thin, discontinuous, *exsolution lamellae*. They are actually microscopic layers of plagioclase that form as the K-spar cools, like fat separates from soup when it is refrigerated. C. Hand sample of a rock that is an aggregate of intergrown plagioclase mineral crystals. Individual mineral crystals are discernible within the rock, particularly the cleavage surfaces that have characteristic hairline striations.

another carbonate mineral that resembles calcite, but it will fizz 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, pocket knife, or nail.) If HCl is not available, then undiluted vinegar can be used for the acid test. It contains acetic acid (but the effervescence will be much less violent).

Striations are straight "hairline" grooves on the cleavage surfaces or crystal faces of some minerals. This can be helpful in mineral identification. For example, you can use the striations of plagioclase feldspar (**FIGURE 3.15A**) to distinguish it from potassium feldspar (K-feldspar, **FIGURE 3.15B**). *Plagioclase feldspar* has faint hairline striations on surfaces of one of its two cleavage directions. In contrast, *K-feldspar* (orthoclase) sometimes has internal *exsolution lamellae,* which are faint streaks of plagioclase that grew inside of it.

Magnetism influences some minerals, such as magnetite. The test is simple: check to see if the mineral is attracted to a magnet. Lodestone is a variety of magnetite that is itself a natural magnet. It will attract steel paperclips. Some other minerals may also be weakly attracted to a magnet (e.g., hematite, bornite, and pyrrhotite).

Specific Gravity (SG). Density is a measure of an object's mass (weighed in grams, g) divided by its volume (in cubic centimeters, cm^3). **Specific gravity** is the ratio of the density of a substance divided by the density of water. Since water has a density of 1 g/cm^3 and the units cancel out, specific gravity is the same number as density but without any units. For example, the mineral quartz has a density of 2.65 g/cm^3 so its specific gravity is 2.65 (i.e., SG $=$ 2.65). **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.

FIGURE 3.16 Acid test. Place a drop of weak hydrochloric acid (HCl) on the sample. If it effervesces (reacts, bubbles), then it is a carbonate (CO_{3-} containing) mineral. Please wipe the sample dry with a paper towel after doing this test! Note that the mineral in this example occurs in several different colors and can be scratched by a wire (iron) nail. The yellow sample is a crystal of this mineral, but the other samples are broken pieces of crystals that reveal the mineral's characteristic cleavage angles.

ACTIVITY

3.3 Determining Specific Gravity (SG)

THINK About It | How and why do people study minerals?

OBJECTIVE Measure the volume and mass of minerals, calculate their specific gravities, and use the results to identify them.

PROCEDURES

1. **Before you begin,** read the following background information. Your instructor will provide laboratory equipment, but this is **what you will need** to bring to lab:

   ___ Activity 3.3 Worksheet (p. 104) and pencil

   ___ calculator

2. **Then follow your instructor's directions** about where to obtain laboratory equipment and mineral samples, how to work safely, and how to complete the worksheet.

Why Are Density and Specific Gravity Important?

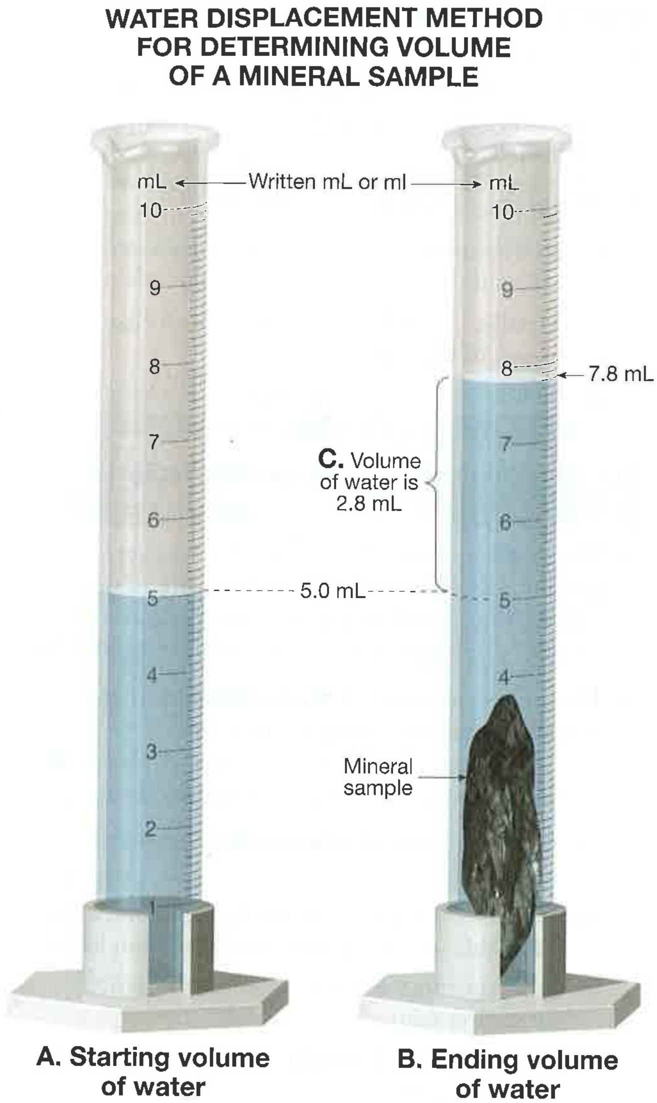
Have you ever considered buying silver coins as an investment? If so, then you should be wary of deceptive sales. For example, there have been reports of less valuable silver-plated copper coins marketed as pure silver coins. Copper has a specific gravity of 8.94, which is very close to silver's specific gravity of 9.32. So, even experienced buyers cannot tell a solid silver coin from a silver-plated copper coin just by hefting it to approximate its specific gravity. They must determine the coin's exact specific gravity as one method of ensuring its authenticity. Mineral identification is also aided by knowledge of specific gravity. If you heft same-sized pieces of the minerals galena (lead sulfide, an ore of lead) and quartz, you can easily tell that one has a much higher specific gravity than the other. But the difference in specific gravities of different minerals is not always so obvious. In this activity you will learn how to measure the volume and mass of mineral samples, calculate their specific gravities, and use the results to identify them.

Before you begin, read the following background information and be sure you have a pencil, eraser, and Worksheet 3.3 (p. 102). **Then** complete the activity and Worksheet 3.3.

How to Determine Volume. Recall that **volume** is the amount of space that an object takes up. Most mineral samples have odd shapes, so their volumes cannot be calculated from linear measurements. Their volumes must be determined by measuring the volume of water they displace. This is done in the laboratory with a *graduated cylinder* (FIGURE 3.17), an instrument used to measure volumes of fluid (fluid volume). Most graduated cylinders are graduated in metric units called milliliters (mL or ml), which are thousandths of a liter. *You should also note that 1 mL (1 ml) of fluid volume is exactly the same as 1 cm^3 of linear volume.*

Procedures for determining the volume of a mineral sample are provided in FIGURE 3.17. Note that when you pour water into a glass graduated cylinder, the surface of the liquid is usually a curved *meniscus*, and the volume is read at the bottom of its concave surface. In most plastic graduated cylinders, however, there is no meniscus. The water level is flat and easy to read.

If you slide a mineral sample into a graduated cylinder full of water (so no water splashes out), then it takes up space previously occupied by water at the bottom of the graduated cylinder. This displaced water has nowhere to go except higher into the graduated cylinder. Therefore, the volume of the mineral sample is exactly the same as the volume of fluid (water) that it displaces.



PROCEDURES

A. Place water in the bottom of a graduated cylinder. Add enough water to be able to totally immerse the mineral sample. It is also helpful to use a dropper bottle or wash bottle and bring the volume of water (before adding the mineral sample) up to an exact graduation mark like the 5.0 mL mark above. Record this starting volume of water.

B. Carefully slide the mineral sample down into the same graduated cylinder, and record the ending volume of the water (7.8 mL in the above example).

C. Subtract the starting volume of water from the ending volume of water to obtain the displaced volume of water. In the above example: 7.8 mL − 5.0 mL = 2.8 mL (2.8 mL is the same as 2.8 cm^3). This volume of displaced water is the volume of the mineral sample.

FIGURE 3.17 How to determine volume of a mineral sample.

How to Determine Mass. Earth materials do not just take up space (volume). They also have a mass of atoms that can be weighed. You will use a gram balance to measure the **mass** of materials (by determining their weight under the pull of Earth's gravity). The gram (g) is the basic unit of mass in the metric system, but instruments used to measure grams vary from triple-beam balances to spring scales to digital balances (page viii). Consult with your laboratory instructor or other students to be sure that you understand how to read the gram balance provided in your laboratory.

How to Calculate Density and Specific Gravity. Every material has a *mass* that can be weighed and a *volume* of space that it occupies. However, the relationship between a material's mass and volume tends to vary from one kind of material to another. For example, a bucket of rocks has much greater mass than an equal-sized bucket of air. Therefore a useful way to describe an object is to determine its mass per unit of volume, called **density**. *Per* refers to division, as in miles *per* hour (distance divided by time). So density is the measure of an object's mass divided by its volume (density = mass ÷ volume). Scientists and mathematicians use the Greek character rho (ρ) to represent density. Also, the gram (g) is the basic metric unit of mass, and the cubic centimeter is the basic unit of metric volume (cm^3), so density (ρ) is usually expressed in grams per cubic centimeter (g/cm^3). For example:

$$\frac{\text{Mineral sample weighs 44.0 grams}}{\text{Mineral sample takes up 11.0 ml of volume}}$$

$$= \frac{44.0\ g}{11.0\ cm^3} = 4.00\ g/cm^3 = \rho$$

Specific gravity (SG) is the ratio of the density of a substance divided by the density of water. Since water has a density of 1 g/cm^3 and the units cancel out, specific gravity is the same number as density but without any units. In the example above, the specific gravity of the mineral sample would be 4.00 (i.e., SG = 4.00). The mineral quartz has a density of 2.65 g/cm^3 so its specific gravity is 2.65 (i.e., SG = 2.65).

Calculating Density and Specific Gravity—The Math You Need

You can learn more about calculating density and specific gravity at this site featuring The Math You Need, When You Need It math tutorials for students in introductory geoscience courses: **http://serc.carleton.edu/mathyouneed/density/index.html**

ACTIVITY

3.4 Mineral Identification and Uses

THINK About It **How and why do people study minerals? How do you personally depend on minerals and elements extracted from them?**

OBJECTIVE Identify common minerals on the basis of their properties and assess how you depend on them.

PROCEDURES

1. **Before you begin**, read the introduction and mineral identification procedures below. Your instructor will provide laboratory equipment, but this is **what you will need** to bring to lab:

   ___ Activity 3.4 Worksheets (pp. 105–108) and pencil

2. **To complete the activity, follow your instructor's directions** about where to obtain a set of mineral analysis tools and mineral samples and any additional procedures for completing Worksheet 3.4 (which you will also need for Activity 3.5).
3. **When you have completed your worksheets,** reflect on how you depend on each of the minerals that you identified. What did you learn about how you depend on minerals? Be prepared to discuss this question and your mineral identifications. Save your Activity 3.4 worksheets to complete Activity 3.5.

Introduction

You are expected to learn how to identify common minerals on the basis of their properties and assess how you depend on them. 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 comprising them. Only after minerals and rocks have been identified can their origin, classification, and alteration be adequately understood. Mineral identification is based on your ability to describe mineral properties using identification charts (FIGURES 3.18–3.20) and a Mineral Database (FIGURE 3.21). The database also lists the chemical composition and some common uses for each mineral. Some minerals, like halite (table salt) and gemstones are used in their natural state. Others are valuable as *ores*—materials from which specific chemical *elements* (usually metals) can be extracted at a profit.

Mineral Identification Procedures

Obtain a set of mineral samples and analysis tools according to your instructor's instructions. For each sample, fill in the Activity 3.3 tear-out worksheet using the procedures provided below.

1. Record the **sample number or letter**.
2. Determine and record the mineral's **luster** as metallic (M) or nonmetallic (NM)
   - **A.** Metallic (M): mineral is opaque, looks like metal or sort of like metal)
   - **B.** Nonmetallic (NM): e.g., vitreous (glassy, glossy reflection), waxy, pearly, earthy/dull, greasy
3. Determine and record the mineral's **hardness** (FIGS. 3.8, 3.9): give a hardness range, if possible.
4. Determine and record the mineral's **cleavage** (if present, FIGURES. 3.10–3.16) and **fracture** (if present, FIGURE 3.10). For cleavage, determine number of cleavage directions or name, if possible (FIGURE 3.12).
5. Determine and record the mineral's **color** (fresh surface) and **streak** (using a streak plate).

   Minerals harder than 6.5 will scratch the streak plate, so no streak can be determined for them.
6. Determine and record **other notable properties** like these:
   - **A.** What is the mineral's **tenacity**: brittle, elastic, malleable, or sectile (can be carved with a knife)?
   - **B.** Does the mineral sample display **magnetic attraction** (strongly or weakly)?
   - **C.** Does the mineral sample display a **reaction with acid** (dilute HCl)?
   - **D.** If crystals are visible, then what is their **crystal form?**
   - **E.** Does the mineral sample have **striations** on cleavage surfaces or crystal faces or **exsolution lamellae** (FIGURE 3.15)?
   - **F.** Estimate **specific gravity** (SG) as low, intermediate, or high.
   - **G.** Does the mineral sample have any unique diagnostic properties like **smell** when scratched or during acid test?
7. Use mineral identification figures to identify the **name of the mineral.**
   - **A.** If the mineral is opaque and metallic or submetallic, follow steps 1–5 in FIGURE 3.18.
   - **B.** If the mineral is light colored and nonmetallic, then follow steps 1–4 in FIGURE 3.19.
   - **C.** If the mineral is dark colored and nonmetallic, then follow steps 1–4 in FIGURE 3.20.

8. Use the Mineral Database (FIGURE 3.21) and FIGURE 3.22 to determine and record the mineral's **chemical composition** and help you determine **how you personally depend on the mineral** (including commodities refined from it). For more information about specific minerals or elements, you can refer to the U.S. Geological Survey's Mineral Commodity Summaries (**http://minerals.usgs.gov/minerals/pubs/mcs/**).

ACTIVITY 3.5 The Mineral Dependency Crisis

THINK About It How do you personally depend on minerals and elements extracted from them? How sustainable is your dependency on minerals and elements extracted from them?

OBJECTIVE Evaluate your personal and U.S. dependency on minerals.

PROCEDURES

1. **Before you begin**, read the background information below and on page 99. Your instructor will provide laboratory equipment, but this is **what you will need** to bring to lab:
   ___ Activity 3.5 Worksheet (p. 109) and pencil
   ___ Activity 3.4 Worksheets that you already completed
2. **Then refer to FIGURE 3.22, and follow your instructor's directions** about how to complete the Activity 3.5 worksheet.

Mineral Dependency

Did you know that some of the minerals used to make your cell phone and fluorescent light bulbs are quite rare nonrenewable resources? Many high-tech products depend on such nonrenewable mineral resources, yet many are either not mined within the United States or are mined here only in small quantities. The locations where they can be economically extracted in the United States have already been mined or are too small to be developed. Of particular concern are minerals mined as ores for *rare earth elements*, a group of 17 elements used in products like fluorescent light bulbs, flat screen televisions, cell phones, computers, solar panels, wind turbines, hybrid cars, cameras, DVDs, rechargeable batteries, magnets, medical equipment, night-vision goggles, missile systems, and medical equipment. China currently produces nearly all of the world's supply of rare earth elements, and the United States produces almost none. This has created what is widely known as the "rare earth crisis," and a shortage of rare earth elements used to make fluorescent light bulbs has become widely known as the "phosphor crisis." Yet the United States also relies on foreign supplies of many other minerals and elements extracted from them. Has the United States entered an unsustainable level of mineral dependency?

U.S. Net Import Reliance on Non-fuel Mineral Resources

Commodities are natural materials that people buy and sell, because they are required to sustain our wants and needs. Three classes are: agricultural products, energy resources, and non-fuel mineral resources. The **non-fuel mineral resources** include *rocks, minerals* used in their unrefined state or as ore from which specific elements can be profitably refined, and chemical *elements* extracted from ores. The U.S. Geological Survey (USGS) has determined that the United States was the world's largest user of non-fuel mineral resources in 2012 (about 12,000 pounds, or 11.3 metric tons, per person each year). To sustain its needs, the U.S. imported some of the minerals (and elements already extracted from them) that it needed. FIGURE 3.22 shows the 2012 U.S. net import reliance (expressed as a percent) on some selected minerals and elements refined from them. The United States exports some of the same non-fuel mineral resources that it imports, so net import reliance is the total of U.S. production and imports, minus the percentage of exports. A net import reliance of 80% means that 80% of the resource is imported. FIGURE 3.22 does not include all of the rare earth elements. Also not shown are minerals and elements for which the U.S. is less than 5% import reliant (or a net exporter).

USGS Mineral Resources Data System (MRDS)

Recall that commodities are natural materials that people buy and sell, because they are required to sustain our wants and needs. Three classes are: agricultural products, energy resources, and non-fuel mineral resources. The U.S. Geological Survey (USGS) divides the non-fuel mineral resources into two groups. **Nonmetallic mineral resources** are mostly rocks made of unrefined minerals (such as rock salt) and rocks (gravel, granite, marble). **Metallic mineral resources** are *ores* (rocks or minerals from which chemicals, usually metals, can be extracted at a profit) and chemical *elements* that have already been extracted from ore minerals. The **USGS Mineral Resources Data System (MRDS)** is a global database of both kinds of mineral resources and where they have been found and/or processed.

METALLIC AND SUBMETALLIC (M) MINERAL IDENTIFICATION

STEP 1: What is the mineral's hardness?	STEP 2: Does the mineral have cleavage?	STEP 3: What is the mineral's streak?	STEP 4: Match the mineral's physical properties to other characteristic properties below.	STEP 5: Mineral name. Find out more about it in the mineral database (Fig.3.21).
HARD (H > 5.5) Scratches glass Not scratched by masonry nail or knife blade	Cleavage absent, poor, or not visible	Dark gray to black	Color silvery gold; Tarnishes brown; H 6–6.5; Brittle; conchoidal to uneven fracture; Crystals: cubes (may be striated), pyritohedrons, or octahedrons; Distinguished from chalcopyrite, which is soft	Pyrite
			Silvery dark gray to black; Tarnishes gray or rusty yellow-brown; Strongly attracted to a magnet and may be magnetized; H 6–6.5; Crystals: octahedrons	Magnetite
HARD or SOFT		Yellow-brown	Color submetallic silvery brown; Tarnishes to dull and earthy yellow-brown to brown rust colors; H 1–5.5; More commonly occurs in its nonmetallic yellow to brown forms (H 1–5)	Limonite
		Brown	Color silvery black to black; Tarnishes gray to black; H 5.5–6; May be weakly attracted to a magnet; Crystals: octahedrons	Chromite
		Red to red-brown	Color steel gray, reddish-silver, to glittery bright silver (var. specular); Both metallic varieties have the characteristic red-brown streak; May be attracted to a magnet; H 5–6; Also occurs in nonmetallic, dull to earthy, red to red-brown forms	Hematite
SOFT (H ≤ 5.5) Does not scratch glass Scratched by masonry nail or knife blade	Cleavage good to excellent	Dark gray to black	Color bright silvery gray; Tarnishes dull gray; Brittle; breaks into cubes and shapes made of cubes; H 2.5; Crystals: cubes or octahedrons; Feels heavy for its size because of high specific gravity	Galena
		White to pale yellow-brown	Color silvery yellow-brown, silvery red, or black with submetallic to resinous luster; Tarnishes brown or black; H 3.5–4.0; smells like rotten eggs when scratched, powdered, or in acid test	Sphalerite
	Cleavage absent, poor, or not visible	Dark gray to black	Color bright silvery gold; Tarnishes bronze brown brassy gold, or iridescent blue-green and red; H 3.5–4.0; Brittle; uneven fracture; Crystals: tetrahedrons	Chalcopyrite
			Color characteristically brownish-bronze; Tarnishes bright iridescent purple, blue, and/or red, giving it its nickname "peacock ore"; May be weakly attracted to a magnet; H 3; Usually massive, rare as cubes or dodecahedrons	Bornite
			Color opaque brassy to brown-bronze; Tarnishes dull brown, may have faint iridescent colors; Fracture uneven to conchoidal; No cleavage; Attracted to a magnet; H 3.5–4.5; Usually massive or masses of tiny crystals; Resembles chalcopyrite, which is softer and not attracted to a magnet	Pyrrhotite
			Color dark silvery gray to black; Can be scratched with your fingernail; Easily rubs off on your fingers and clothes, making them gray; H 1–2	Graphite
		Yellow-brown	Metallic or silky submetallic luster, Color dark brown, gray, or black; H 5–5.5; Forms layers of radiating microscopic crystals and botryoidal masses	Goethite
		Copper	Color copper; Tarnishes dull brown or green; H 2.5–3.0; Malleable and sectile; Hackly fracture; Usually forms dendritic masses or nuggets	Copper (native copper)
		Gold	Color yellow gold; Does not tarnish; Malleable and sectile; H 2.5–3.0; Forms odd-shaped masses, nuggets, or dendritic forms	Gold (native gold)
		Silvery white	Color silvery white to gray; Tarnishes gray to black; H 2.5–3.0; Malleable and sectile; Forms dendritic masses, nuggets, or curled wires	Silver (native silver)

FIGURE 3.18 Identification chart for opaque minerals with metallic or submetallic luster (M) on freshly broken surfaces.

DARK TO MEDIUM-COLORED NONMETALLIC (NM) MINERAL IDENTIFICATION

STEP 1: What is the mineral's hardness?	STEP 2: What is the mineral's cleavage?	STEP 3: Compare the mineral's physical properties to other distinctive properties below.	STEP 4: Find mineral name(s) and check the mineral database for additional properties (Figure 3.21).
HARD (H > 5.5) Scratches glass Not scratched by masonry nail or knife blade	Cleavage excellent or good	Translucent to opaque dark gray; blue-gray, or black; May have silvery iridescence; 2 cleavages at nearly 90° and with striations; H 6	Plagioclase feldspar
		Translucent to opaque brown, gray, green, or red; 2 cleavages at nearly right angles; Exsolution lamellae; H 6	Potassium feldspar (K-spar)
		Green to black; Vitreous luster; H 5.5–6.0; 2 cleavages at about 124° and 56° plus uneven fracture; Usually forms long blades and masses of needle-like crystals	Actinolite (amphibole)
		Dark gray to black; Vitreous luster; H 5.5–6.0; 2 cleavages at about 124° and 56° plus uneven fracture; Forms long crystals that break into blade-like fragments	Hornblende (amphibole)
		Dark green to black; Dull to vitreous luster; H 5.5–6.0; two cleavages at nearly right angles (93° and 87°) plus uneven fracture; Forms short crystals with squarish cross sections; Breaks into blocky fragments	Augite (pyroxene)
	Cleavage absent, poor, or not visible	Transparent or translucent gray, brown, or purple; Greasy luster; Massive or hexagonal prisms and pyramids; H 7	Quartz Smoky quartz (black/brown var.), Amethyst (purple var.)
		Gray, black, or colored (dark red, blue, brown) hexagonal prisms with flat striated ends; H 9	Corundum Emery (black impure var.), Ruby (red var.) Sapphire (blue var.)
		Opaque red-brown or brown; Luster waxy; Cryptocrystalline; H 7	Jasper (variety of quartz)
		Transparent to translucent dark red to black; Equant (dodecahedron) crystal form or massive; H 7	Garnet
		Opaque gray; Luster waxy; Cryptocrystalline; H 7	Chert (gray variety of quartz)
		Opaque black; Luster waxy; Cryptocrystalline; H 7	Flint (black variety of quartz)
		Black or dark green; Long striated prisms; H 7–7.5	Tourmaline
		Olive green, Transparent or translucent; No cleavage; Usually has many cracks and conchoidal to uneven fracture; Single crystals or masses of tiny crystals resembling green granulated sugar or aquarium gravel; The crystals have vitreous (glassy) luster	Olivine
		Opaque dark gray to black; Tarnishes gray to rusty yellow-brown; Cleavage absent; Strongly attracted to a magnet; May be magnetized; H 6–6.5	Magnetite
		Opaque green; Poor cleavage; H 6–7	Epidote
		Opaque brown prisms and cross-shaped twins; H 7	Staurolite
SOFT (H ≤ 5.5) Does not scratch glass Scratched by masonry nail or knife blade	Cleavage excellent or good	Yellow-brown, brown, or black; vitreous to resinous luster (may also be submetallic); Dodecahedral cleavage; H 3.5–4.0; Rotten egg smell when scratched or powdered	Sphalerite
		Purple cubes or octahedrons; Octahedral cleavage; H 4	Fluorite
		Black short opaque prisms; Splits easily along 1 excellent cleavage into thin sheets; H 2.5–3	Biotite (black mica)
		Green short opaque prisms; Splits easily along 1 excellent cleavage into thin sheets; H 2–3	Chlorite
	Cleavage absent, poor, or not visible	Opaque rusty brown or yellow-brown; Massive and amorphous; Yellow-brown streak; H 1–5.5	Limonite
		Rusty brown to red-brown, may have shades of tan or white; Earthy and opaque; Contains pea-sized spheres that are laminated internally; H 1–5; Pale brown streak	Bauxite
		Deep blue; Crusts, small crystals, or massive; Light blue streak; H 3.5–4	Azurite
		Opaque green or gray-green; Dull or silky masses or asbestos; White streak; H 2–5	Serpentine
		Opaque green in laminated crusts or massive; Streak pale green; Effervesces in dilute HCl; H 3.5–4	Malachite
		Translucent or opaque dark green; Can be scratched with your fingernail; Feels greasy or soapy; H 1	Talc
		Transparent or translucent green, brown, blue, or purple; Brittle hexagonal prisms; Conchoidal fracture; H 5	Apatite
		Opaque earthy brick red to dull red-gray, or gray; H 1.5–5; Red-brown streak; Magnet may attract the gray forms	Hematite

FIGURE 3.19 Identification chart for dark to medium-colored minerals with nonmetallic (NM) luster on freshly broken surfaces.

LIGHT-COLORED NONMETALLIC (NM) MINERAL IDENTIFICATION

STEP 1: What is the mineral's hardness?	STEP 2: What is the mineral's cleavage?	STEP 3: Compare the mineral's physical properties to other distinctive properties below.	STEP 4: Find mineral name(s) and check the mineral database for additional properties (Figure 3.21).
HARD (H > 5.5) Scratches glass Not scratched by masonry nail or knife blade	Cleavage excellent or good	White or pale gray; 2 good cleavages at nearly 90° plus uneven fracture; May have striations; H 6	Plagioclase feldspar
		Orange, pink, pale brown, green, or white; H 6; 2 good cleavages at 90° plus uneven fracture; exsolution lamellae	Potassium feldspar
		Pale brown, white, or gray; Long slender prisms; 1 excellent cleavage plus fracture surfaces; H 6–7	Sillimanite
		Blue, very pale green, white, or gray; Crystals are blades; H 4–7	Kyanite
	Cleavage absent, poor, or not visible	Gray, white, or colored (dark red, blue, brown) hexagonal prisms with flat striated ends; H 9	Corundum vars. ruby (red), sapphire (blue)
		Colorless, white, gray, or other colors; Greasy luster; Massive or hexagonal prisms and pyramids; Transparent or translucent; H 7	Quartz: vars. rose (pink), rock crystal (colorless), milky (white), citrine (amber)
		Opaque gray or white; Luster waxy; H 7	Chert (variety of quartz)
		Colorless, white, yellow, light brown, or pastel colors; Translucent or opaque; Laminated or massive; Cryptocrystalline; Luster waxy; H 7	Chalcedony (variety of quartz)
		Pale green to yellow; Transparent or translucent; H 7; No cleavage; Usually has many cracks and conchoidal to uneven fracture; Single crystals or masses of tiny crystals resembling green or yellow granulated sugar or aquarium gravel; Crystals vitreous (glassy)	Olivine
SOFT (H ≤ 5.5) Does not scratch glass Scratched by masonry nail or knife blade	Cleavage excellent or good	Colorless, white, yellow, green, pink, or brown; 3 excellent cleavages; Breaks into rhombohedrons; Effervesces in dilute HCl; H 3	Calcite
		Colorless, white, gray, creme, or pink; 3 excellent cleavages; Breaks into rhombohedrons; Effervesces in dilute HCl only if powdered; H 3.5–4	Dolomite
		Colorless or white with tints of brown, yellow, blue, black; Short tabular crystals and roses; Very heavy; H 3–3.5	Barite
		Transparent, colorless to white; H 2, easily scratched with your fingernail; White streak; Blade-like crystals or massive	Gypsum var. selenite
		Colorless, white, gray, or pale green, yellow, or red; Spheres of radiating needles; Luster silky; H 5–5.5	Natrolite (zeolite)
		Colorless, white, yellow, blue, brown, or red; Cubic crystals; Breaks into cubes; Salty taste; H 2.5	Halite
		Colorless, purple, blue, gray, green, yellow; Cubes with octahedral cleavage; H 4	Fluorite
		Colorless, yellow, brown, or red-brown; Short opaque prisms; Splits along 1 excellent cleavage into thin flexible transparent sheets; H 2–2.5	Muscovite (white mica)
	Cleavage absent, poor, or not visible	White, gray or yellow; Earthy to pearly; massive form; H 2, easily scratched with your fingernail; White streak	Gypsum var. alabaster
		White to gray; Fibrous form with silky or satiny luster; H 2, easily scratched with your fingernail	Gypsum var. satin spar
		Yellow crystals or earthy masses; Luster greasy; H 1.5–2.5; Smells like rotten eggs when powdered	Sulfur (Native sulfur)
		Opaque pale blue to blue-green; Conchoidal fracture; H 2-4; Massive or amorphous earthy crusts; Very light blue streak	Chrysocolla
		Opaque green, yellow, or gray; Dull or silky masses or asbestos; White streak; H 2–5	Serpentine
		Opaque white, gray, green, or brown; Can be scratched with fingernail; Greasy or soapy feel; H 1	Talc
		Opaque earthy white to very light brown masses of "white clay"; H 1–2; Powdery to greasy feel	Kaolinite
		Mostly pale brown to tan or white; Earthy and opaque; Contains pea-sized spheres that are laminated internally; H 1–5; Pale brown to white streak	Bauxite
		Colorless to white, orange, yellow, blue, gray, green, or red; May have internal play of colors; H 5.0–5.5; Amorphous; Often has many cracks; Conchoidal fracture	Opal
		Colorless or pale green, brown, blue, white, or purple; Brittle hexagonal prisms; Conchoidal fracture; H 5	Apatite

FIGURE 3.20 Identification chart for light-colored minerals with nonmetallic (NM) luster on freshly broken surfaces.

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster and Crystal System	Hardness	Streak	Distinctive Properties	Some Uses
ACTINOLITE (amphibole)	Nonmetallic (NM) Monoclinic	5.5–6	White	Color dark green or pale green; Forms needles, prisms, and asbestose fibers; Good cleavage at 56° and 124°; SG = 3.1	Green gem varieties are the gemstone "nephrite jade"; asbestos products
AMPHIBOLE: See HORNEBLENDE and ACTINOLITE					
APATITE $Ca_5F(PO_4)_3$ calcium fluorophosphate	Nonmetallic (NM) Hexagonal	5	White	Color pale or dark green, brown, blue, white, or purple; Sometimes colorless; Transparent or opaque; Brittle; Conchoidal fracture; Forms hexagonal prisms; SG = 3.1–3.4	Used mostly to make fertilizer, pesticides; Transparent varieties sold as gemstones
ASBESTOS: fibrous varieties of AMPHIBOLE and SERPENTINE					
AUGITE (pyroxene) calcium ferromagnesian silicate	Nonmetallic (NM) Monoclinic	5.5–6	White to pale gray	Color dark green to brown or black; Forms short, 8-sided prisms; Two good cleavages that intersect at 87° and 93° (nearly right angles); SG = 3.2–3.5	Ore of lithium, used to make lithium batteries, ovenware glazes, high temperature grease, and to treat depression
AZURITE $Cu_3(CO_3)_2(OH)_2$ copper carbonate hydroxide	Nonmetallic (NM) Monoclinic	3.5–4	Light blue	Color a distinctive deep blue; Forms crusts of small crystals, opaque earthy masses, or short and long prisms; Brittle; Effervesces in dilute HCl; SG = 3.7–3.8	Ore of copper used to make pipes, electrical wire, coins, ammunition, bronze, brass; added to vitamin pills for healthy hair and skin; Gemstone
BARITE $BaSO_4$ barium sulfate	Nonmetallic (NM) Orthorhombic	3–3.5	White	Colorless to white, with tints of brown, yellow, blue, or red; Forms short tabular crystals and rose-shaped masses (Barite roses); Brittle; Cleavage good to excellent; Very heavy, SG = 4.3–4.6	Ore of barium, used to harden rubber, make fluorescent lamp electrodes, and in fluids used to drill oil/gas wells
BAUXITE Mixture of aluminum hydroxides	Nonmetallic (NM) No visible crystals	1–3	White	Brown earthy rock with shades of gray, white, and yellow; Amorphous; Often contains rounded pea-sized structures with laminations; SG = 2.0–3.0	Ore of aluminum used to make cans, foil, airplanes, solar panels; Ore of gallium used to make LED bulbs and liquid crystal displays in cell phones, computers, flat screen televisions
BIOTITE MICA ferromagnesian potassium, hydrous aluminum silicate $K(Mg,Fe)_3\,(Al,Si_3O_{10})(OH,F)_2$	Nonmetallic (NM) Monoclinic	2.5–3	Gray-brown to white	Color black, green-black, or brown-black; Cleavage excellent; Forms very short prisms that split easily into very thin, flexible sheets; SG = 2.7–3.1	Used for fire-resistant tiles, rubber, paint
BORNITE Cu_5FeS_4 copper-iron sulfide	Metallic (M) Isometric	3	Dark gray to black	Color brownish bronze; Tarnishes bright purple, blue, and/or red; May be weakly attracted to a magnet; H 3; Cleavage absent or poor; Forms dense brittle masses; Rarely forms crystals	Ore of copper, used to make pipes, electrical wire, coins, ammunition, bronze, brass; added to vitamin pills for healthy hair and skin
CALCITE $CaCO_3$ calcium carbonate	Nonmetallic (NM) Hexagonal	3	White	Usually colorless, white, or yellow, but may be green, brown, or pink; Opaque or transparent; Excellent cleavage in 3 directions not at 90°; Forms prisms, rhombohedrons, or scalenohedrons that break into rhombohedrons; Effervesces in dilute HCl; SG = 2.7	Used to make antacid tablets, fertilizer, cement; Ore of calcium
CHALCEDONY SiO_2 cryptocrystalline quartz	Nonmetallic (NM) No visible crystals	7	White*	Colorless, white, yellow, light brown, or other pastel colors in laminations; Often translucent; Conchoidal fracture; Luster waxy; Cryptocrystalline; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones (agate, chrysoprase)

*Streak cannot be determined with a streak plate for minerals harder than 6.5. They scratch the streak plate.

FIGURE 3.21 Mineral Database. This is an alphabetical list of minerals and their properties and uses.

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster and Crystal System	Hardness	Streak	Distinctive Properties	Some Uses
CHALCOPYRITE $CuFeS_2$ copper-iron sulfide	Metallic (M) Tetragonal	3.5–4	Dark gray	Color bright silvery gold; Tarnishes bronze brown, brassy gold, or iridescent blue-green and red; Brittle; No cleavage; Forms dense masses or elongate tetrahedrons; SG = 4.1–4.3	Ore of copper, used to make pipes, electrical wire, coins, ammunition, bronze, brass; added to vitamin pills for healthy hair and skin
CHERT SiO_2 cryptocrystalline quartz	Nonmetallic (NM) No visible crystals	7	White*	Opaque gray or white; Luster waxy; Conchoidal fracture; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones
CHLORITE ferromagnesian aluminum silicate $(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	Nonmetallic (NM) Monoclinic	2–2.5	White	Color dark green; Cleavage excellent; Forms short prisms that split easily into thin flexible sheets; Luster bright or dull; SG = 2–3	Used as a "filler" (to take up space and reduce cost) in plastics for car parts, appliances; Massive pieces carved into art sculptures
CHROMITE $FeCr_2O_4$ iron-chromium oxide	Metallic (M) Isometric	5.5–6	Dark brown	Color silvery black to black; Tarnishes gray to black; No cleavage; May be weakly attracted to a magnet; Forms dense masses or granular masses of small crystals (octahedrons)	Ore of chromium for chrome, stainless steel, mirrors, yellow and green paint pigments and ceramic glazes, and pills for healthy metabolism and cholesterol levels
CHRYSOCOLLA $CuSiO_3 \cdot 2H_2O$ hydrated copper silicate	Nonmetallic (NM) Orthorhombic	2–4	Very light blue	Color pale blue to blue-green; Opaque; Forms cryptocrystalline crusts or may be massive; Conchoidal fracture; Luster shiny or earthy; SG = 2.0–4.0	Ore of copper, used to make pipes, electrical wire, coins, ammunition, bronze, brass; added to vitamin pills for healthy hair and skin; Gemstone
COPPER (NATIVE COPPER) Cu copper	Metallic (M) Isometric	2.5–3	Copper	Color copper; Tarnishes brown or green; Malleable; No cleavage; Forms odd-shaped masses, nuggets, or dendritic forms; SG = 8.8–9.0	Ore of copper, used to make pipes, electrical wire, coins, ammunition, bronze, brass; added to vitamin pills for healthy hair and skin
CORUNDUM Al_2O_3 aluminum oxide	Nonmetallic (NM) Hexagonal	9	White*	Gray, white, black, or colored (red, blue, brown, yellow) hexagonal prisms with flat striated ends; Opaque to transparent; Cleavage absent; SG = 3.9–4.1 H 9	Used for abrasive powders to polish lenses; gemstones (red ruby, blue sapphire); emery cloth
DOLOMITE $CaMg(CO_3)_2$ magnesian calcium carbonate	Nonmetallic (NM) Hexagonal	3.5–4	White	Color white, gray, creme, or pink; Usually opaque; Cleavage excellent in 3 directions; Breaks into rhombohedrons; Resembles calcite, but will effervesce in dilute HCl only if powdered; SG = 2.8–2.9	Ore of magnesium used to make paper; lightweight frames for jet engines, rockets, cell phones, laptops; pills for good brain, muscle, and skeletal health
EPIDOTE complex silicate	Nonmetallic (NM) Monoclinic	6–7	White*	Color pale or dark green to yellow-green; Massive or forms striated prisms; Cleavage poor, SG = 3.3–3.5	Used as a green gemstone
FELDSPAR: See PLAGIOCLASE (Na-Ca Feldspars) and POTASSIUM FELDSPAR (K-Spar)					
FLINT SiO_2 cryptocrystalline quartz	Nonmetallic (NM) No visible crystals	7	White*	Color black to very dark gray; Opaque to translucent; Conchoidal fracture; Crypto-crystalline; SG = 2.5–2.8	Used as an abrasive; Used to make glass; Black gemstone
FLUORITE CaF_2 calcium fluoride	Nonmetallic (NM) Isometric	4	White	Colorless, purple, blue, gray, green, or yellow; Cleavage excellent; Crystals usually cubes; Transparent or opaque; Brittle; SG = 3.0–3.3	Ore of fluorine used in fluoride toothpaste, refrigerant gases, rocket fuel

*Streak cannot be determined with a streak plate for minerals harder than 6.5. They scratch the streak plate.

FIGURE 3.21 (continued)

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster and Crystal System	Hardness	Streak	Distinctive Properties	Some Uses
GALENA PbS lead sulfide	Metallic (M) Isometric	2.5	Gray to dark gray	Color bright silvery gray; Tarnishes dull gray; Forms cubes and octahedrons; Brittle; Cleavage good in three directions, so breaks into cubes; SG = 7.4–7.6	Ore of lead for television glass, auto batteries, solder, ammunition; May be an ore of bismuth (an impurity) used as a lead substitute in pipe solder and fishing sinkers; May be an ore of silver (an impurity) used in jewelry, electrical circuit boards
GARNET complex silicate	Nonmetallic (NM) Isometric	7	White*	Color usually red, black, or brown, sometimes yellow, green, pink; Forms dodecahedrons; Cleavage absent but may have parting; Brittle; Translucent to opaque; SG = 3.5–4.3	Used as an abrasive; Red gemstone
GOETHITE FeO(OH) iron oxide hydroxide	Metallic (M) Orthorhombic	5–5.5	Yellow-brown	Color dark brown to black; Tarnishes yellow-brown; Forms layers of radiating microscopic crystals; SG = 3.3–4.3	Ore of iron for iron and steel used in machines, buildings, bridges, nails, tools, file cabinets; Added to pills and foods to aid hemoglobin production in red blood cells
GOLD (NATIVE GOLD) Au pure gold	Metallic (M) Isometric	2.5–3.0	Gold-yellow	Color gold to yellow-gold; Does not tarnish; Ductile, malleable and sectile; Hackly fracture; SG = 19.3; No cleavage; Forms odd-shaped masses, nuggets, and dendritic forms	Ductile and malleable metal used for jewelry; Electrical circuitry in computers, cell phones, car air bags; Heat shields for satellites
GRAPHITE C carbon	Metallic (M) Hexagonal	1	Dark gray	Color dark silvery gray to black; Forms flakes, short hexagonal prisms, and earthy masses; Greasy feel; Very soft; Cleavage excellent in 1 direction; SG = 2.0–2.3	Used for pencils, anodes (negative ends) of most batteries, synthetic motor oil, carbon steel, fishing rods, golf clubs
GYPSUM $CaSO_4 \cdot 2H_2O$ hydrated calcium sulfate	Nonmetallic (NM) Monoclinic	2	White	Colorless, white, or gray; Forms tabular crystals, prisms, blades, or needles (satin spar variety); Transparent to translucent; Very soft; Cleavage good; SG = 2.3	Plaster-of-paris, wallboard, drywall, art sculpture medium (alabaster)
HALITE NaCl sodium chloride	Nonmetallic (NM) Isometric	2.5	White	Colorless, white, yellow, blue, brown, or red; Transparent to translucent; Brittle; Forms cubes; Cleavage excellent in 3 directions, so breaks into cubes; Salty taste; SG = 2.1–2.6	Table salt, road salt; Used in water softeners and as a preservative; Sodium ore
HEMATITE Fe_2O_3 iron oxide	Metallic (M) or Nonmetallic (NM) Hexagonal	1–6	Red to red-brown	Color silvery gray, reddish silver, black, or brick red; Tarnishes red; Opaque; Soft (earthy) and hard (metallic) varieties have same streak; Forms thin tabular crystals or massive; May be attracted to a magnet; SG = 4.9–5.3	Red ochre pigment in paint and cosmetics. Ore of iron for iron and steel used in machines, buildings, bridges, nails, tools, file cabinets; Added to pills and foods to aid hemoglobin production in red blood cells
HORNBLENDE (amphibole) calcium ferromagnesian aluminum silicate	Nonmetallic (NM) Monoclinic	5.5–6.0	White to pale gray	Color dark gray to black; Forms prisms with good cleavage at 56° and 124°; Brittle; Splintery or asbestos forms; SG = 3.0–3.3	Fibrous varieties used for fire-resistant clothing, tiles, brake linings
JASPER SiO_2 cryptocrystalline quartz	Nonmetallic (NM) No visible crystals	7	White*	Color red-brown, or yellow; Opaque; Waxy luster; Conchoidal fracture; Cryptocrystalline; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones
KAOLINITE $Al_4(Si_4O_{10})(OH)_8$ aluminum silicate hydroxide	Nonmetallic (NM) Triclinic	1–2	White	Color white to very light brown; Commonly forms earthy, microcrystalline masses; Cleavage excellent but absent in hand samples; SG = 2.6	Used for pottery, clays, polishing compounds, pencil leads, paper
K-SPAR: See POTASSIUM FELDSPAR					
KYANITE $Al_2(SiO_4)O$ aluminum silicate oxide	Nonmetallic (NM) Triclinic	4–7	White*	Color blue, pale green, white, or gray; Translucent to transparent; Forms blades; SG = 3.6–3.7	High temperature ceramics, spark plugs

*Streak cannot be determined with a streak plate for minerals harder than 6.5. They scratch the streak plate.

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster and Crystal System	Hardness	Streak	Distinctive Properties	Some Uses
LIMONITE $Fe_2O_3 \cdot nH_2O$ hydrated iron oxide and/or $FeO(OH) \cdot nH_2O$ hydrated iron oxide hydroxide	Metallic (M) or Nonmetallic (NM) Amorphous	1–5.5	Yellow-brown	Color yellow-brown to dark brown; Tarnishes yellow to brown; Amorphous masses; Luster dull or earthy; Hard or soft; SG = 3.3–4.3	Yellow ochre pigment in paint and cosmetics. Ore of iron for iron and steel used in machines, buildings, bridges, nails, tools, file cabinets; Added to pills and foods to aid hemoglobin production in red blood cells
MAGNETITE Fe_3O_4 iron oxide	Metallic (M) or Nonmetallic (NM) Isometric	6–6.5	Dark gray	Color silvery gray to black; Opaque; Forms octahedrons; Tarnishes gray; No cleavage; Attracted to a magnet and can be magnetized; SG = 5.0–5.2	Ore of iron for iron and steel used in machines, buildings, bridges, nails, tools, file cabinets; Added to pills and foods to aid hemoglobin production in red blood cells
MALACHITE $Cu_2CO_3(OH)_2$ copper carbonate hydroxide	Nonmetallic (NM) Monoclinic	3.5–4	Green	Color green, pale green, or gray-green; Usually in crusts, laminated masses, or microcrystals; Effervesces in dilute HCl; SG = 3.6–4.0	Ore of copper, used to make pipes, electrical wire, coins, ammunition, bronze, brass; added to vitamin pills for healthy hair and skin; Gemstone
MICA: See BIOTITE and MUSCOVITE					
MUSCOVITE MICA potassium hydrous aluminum silicate $KAl_2(Al,Si_3O_{10})(OH,F)_2$	Nonmetallic (NM) Monoclinic	2–2.5	White	Colorless, yellow, brown, or red-brown; Forms short opaque prisms; Cleavage excellent in 1 direction, can be split into thin flexible transparent sheets; SG = 2.7–3.0	Computer chip substrates, electrical insulation, roof shingles, Cosmetics with a satiny sheen
NATIVE COPPER: See COPPER					
NATIVE GOLD: See GOLD					
NATIVE SILVER: See SILVER					
NATIVE SULFUR: See SULFUR					
NATROLITE (ZEOLITE) $Na_2(Al_2Si_3O_{10}) \cdot 2H_2O$ hydrous sodium aluminum silicate	Nonmetallic (NM) Orthorhombic	5–5.5	White	Colorless, white, gray, or pale green, yellow, or red; Forms masses of radiating needles; Silky luster; SG = 2.2–2.4	Used in water softeners
OLIVINE $(Fe,Mg)_2SiO_4$ ferromagnesian silicate	Nonmetallic (NM) Orthorhombic	7	White*	Color pale or dark olive-green to yellow, or brown; Forms short crystals that may resemble sand grains; Conchoidal fracture; Cleavage absent; Brittle; SG = 3.3–3.4	Green gemstone (peridot); Ore of magnesium used to make paper; lightweight frames for jet engines, cell phones, laptops; pills for good brain, muscle, and skeletal health
OPAL $SiO_2 \cdot nH_2O$ hydrated silicon dioxide	Nonmetallic (NM) Amorphous	5–5.5	White	Colorless to white, orange, yellow, brown, blue, gray, green, or red; may have play of colors (opalescence); Amorphous; Cleavage absent; Conchoidal fracture; SG = 1.9–2.3	Gemstone
PLAGIOCLASE FELDSPAR $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$ calcium-sodium aluminum silicate	Nonmetallic (NM) Triclinic	6	White	Colorless, white, gray, or black; May have iridescent play of color from within; Translucent; Forms striated tabular crystals or blades; Cleavage good in two directions at nearly 90°; SG = 2.6–2.8	Used to make ceramics, glass, enamel, soap, false teeth, scouring powders
POTASSIUM FELDSPAR $KAlSi_3O_8$ potassium aluminum silicate	Nonmetallic (NM) Monoclinic	6	White	Color orange, brown, white, green, or pink; Forms translucent prisms with subparallel exsolution lamellae; Cleavage excellent in two directions at nearly 90°; SG = 2.5–2.6	Used to make ceramics, glass, enamel, soap, false teeth, scouring powders
PYRITE ("fool's gold") FeS_2 iron sulfide	Metallic (M) Isometric	6–6.5	Dark gray	Color silvery gold; Tarnishes brown; H 6–6.5; Cleavage absent to poor; Brittle; Forms opaque masses, cubes (often striated), or pyritohedrons; SG = 4.9–5.2	Ore of sulfur for matches, gunpowder, fertilizer, rubber hardening (car tires), fungicide, insecticide, paper pulp processing
PYRRHOTITE FeS iron sulfide	Metallic (M) Monoclinic	3.5–4.5	Dark gray to black	Color brassy to brown-bronze; Tarnishes dull brown, sometimes with faint iridescent colors; Fracture uneven to conchoidal; No cleavage; attracted to a magnet; SG = 4.6	Ore of iron and sulfur; Impure forms contain nickel and are used as nickel ore; the nickel is used to make stainless steel

*Streak cannot be determined with a streak plate for minerals harder than 6.5. They scratch the streak plate.

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster and Crystal System	Hardness	Streak	Distinctive Properties	Some Uses
PYROXENE: See AUGITE					
QUARTZ SiO_2 silicon dioxide	Nonmetallic (NM) Hexagonal	7	White*	Usually colorless, white, or gray but uncommon varieties occur in all colors; Transparent to translucent; Luster greasy; No cleavage; Forms hexagonal prism and pyramids; SG = 2.6–2.7 Some quartz varieties are: • var. flint (opaque black or dark gray) • var. smoky (transparent gray) • var. citrine (transparent yellow-brown) • var. amethyst (purple) • var. chert (opaque gray) • var. milky (white) • var. jasper (opaque red or yellow) • var. rock crystal (colorless) • var. rose (pink) • var. chalcedony (translucent, waxy luster)	Used as an abrasive; Used to make glass, gemstones
SERPENTINE $Mg_6Si_4O_{10}(OH)_8$ magnesium silicate hydroxide	Nonmetallic (NM) Monoclinic	2–5	White	Color pale or dark green, yellow, gray; Forms dull or silky masses and asbestos forms; No cleavage; SG = 2.2–2.6	Fibrous varieties used for fire-resistant clothing, tiles, brake linings
SILLIMANITE $Al_2(SiO_4)O$ aluminum silicate	Nonmetallic (NM) Orthorhombic	6–7	White	Color pale brown, white, or gray; One good cleavage plus fracture surfaces; Forms slender prisms and needles; SG = 3.2	High-temperature ceramics
SILVER (NATIVE SILVER) Ag pure silver	Metallic (M) Isometric	2.5–3.0	White to silvery white	Color silvery white to gray; Tarnishes dark gray to black; Ductile, malleable and sectile; Hackly fracture; No cleavage; Forms nuggets, curled wires, and dendritic forms; SG = 10.5	Ductile and malleable metal used for jewelry and silverware; Electrical circuit boards for computers and cell phones; Photographic film
SPHALERITE ZnS zinc sulfide	Metallic (M) or Nonmetallic (NM) Isometric	3.5–4	White to pale yellow-brown	Color silvery yellow-brown, dark red, or black; Tarnishes brown or black; Dodecahedral cleavage excellent to good; Smells like rotten eggs when scratched/powdered; Forms misshapen tetrahedrons or dodecahedrons; SG = 3.9–4.1	Ore of zinc for brass, galvanized steel and roofing nails, skin-healing creams, pills for healthy immune system and protein production: Ore of Indium (an impurity) used to make solar cells
STAUROLITE iron magnesium zinc aluminum silicate	Nonmetallic (NM) Monoclinic	7	White to gray*	Color brown to gray-brown; Tarnishes dull brown; Forms prisms that interpenetrate to form natural crosses; Cleavage poor; SG = 3.7–3.8	Gemstone crosses called "fairy crosses"
SULFUR (NATIVE SULFUR) S sulfur	Nonmetallic (NM) Orthorhombic	1.5–2.5	Pale yellow	Color bright yellow; Forms transparent to translucent crystals or earthy masses; Cleavage poor; Luster greasy to earthy; Brittle; SG = 2.1	Used for matches, gunpowder, fertilizer, rubber hardening (car tires), fungicide, insecticide, paper pulp processing
TALC $Mg_3Si_4O_{10}(OH)_2$ hydrous magnesian silicate	Nonmetallic (NM) Monoclinic	1	White	Color white, gray, pale green, or brown; Forms cryptocrystalline masses that show no cleavage; Luster silky to greasy; Feels greasy or soapy (talcum powder); Very soft; SG = 2.7–2.8	Used as a "filler" (to take up space and reduce cost) in plastics for car parts, appliances; Massive pieces carved into art sculptures
TOURMALINE complex silicate	Nonmetallic (NM) Hexagonal	7–7.5	White*	Color usually opaque black or green, but may be transparent or translucent green, red, yellow, pink or blue; Forms long striated prisms with triangular cross sections; Cleavage absent; SG = 3.0–3.2	Crystals used in radio transmitters; gemstone
ZEOLITE: A group of calcium or sodium hydrous aluminum silicates. See NATROLITE.					

*Streak cannot be determined with a streak plate for minerals harder than 6.5. They scratch the streak plate.

2012 U.S. NET IMPORT RELIANCE ON SELECTED NON-FUEL MINERAL COMMODITIES			
COMMODITY (Element, Ore, or Raw Mineral)	**ORE MINERAL or RAW MINERAL**	**Percent Import Reliance**	**WHAT IS THIS COMMODITY USED FOR?**
Fluorine ore (F): fluorspar	**Fluorite**	100	Fluorine is used in fluoride toothpaste, fluorocarbon refrigerant gases and fire extinguishers, and fluoropolymer plastics that coat non-stick fry pans and insulate wiring in cell phones, laptops, and airplanes.
Graphite (C)	**Graphite**	100	Used to make carbon steel, pencils, carbon fiber reinforced plastics in car bodies, and negative ends of most batteries (including those in all cell phones, power tools, computers, and hybrid/electric vehicles).
Indium metal (In)	**Sphalerite** with In as an impurity	100	Indium is used to make solar cells, and liquid-crystal displays (LCDs) in cell phones, computers, and flat-screen television sets.
Mica (sheet)	**Muscovite**	100	Muscovite is used in heating elements of hair dryers and toasters, joint compound, and cosmetics with a satiny or glittery sheen.
Quartz crystal (industrial)	**Quartz** var. rock crystal	100	Crystals of cultured pure quartz are used to make quartz watches and the frequency controls and timers in every computer and cell phone.
Niobium metal (Nb, "columbium")	**Columbite** (in "coltan")	100	Niobium is used to make high-strength non-corrosive steel alloys (for jet engines, power plants) and arc welding rods, plus electrical insulation coatings in cell phones, computers, and electronic games.
Tantalum metal (Ta)	**Tantalite** (in "coltan")	100	Tantalum is used to make "tantalum capacitors" that buffer the flow of electricity between a battery and electronic parts in the circuits of cell phones, laptops, iPods, and most other electrical devices.
Gallium metal (Ga)	**Bauxite** is Ga ore	99	Gallium is used to make light-emitting diode (LED) bulbs and liquid-crystal displays (LCDs) in things like cell phones, computers, and flat-screen television sets.
Vanadium metal (V)	**Magnetite** with V as an impurity	96	Vanadium is used for cutting tools; mixed with iron to make lightweight shock-resistant steel for car axles and gears, springs, and cutting tools.
Bismuth metal (Bi)	**Galena** with Bi as an impurity	92	Bismuth is used as a nontoxic replacement for lead (in ceramic glazes, fishing sinkers, food processing equipment, plumbing, and shot for hunting) and in antidiarrheal medications.
Barium metal ore (Ba)	**Barite**	80	Barium (Ba) is widely used to make capacitors (that store energy) and memory cells in cell phones and other portable electronic devices.
Zinc metal (Zn)	**Sphalerite** is an ore of Zn	72	Zinc is used to make alloys like brass, skin-healing creams, and galvanized (rust-proof) steel and roofing nails; added to vitamin pills for a healthy immune system and to aid protein production.
Chromium metal (Cr)	**Chromite** is an ore of Cr	70	Chromium is used to make stainless steel, yellow and green ceramic glazes and paints, and military camouflage paints; added to vitamin pills for healthy metabolism and lower cholesterol levels.
Garnet (industrial)	**Garnet**	65	Industrial garnet is used as an abrasive in things like sandpaper and sandblasting.
Silver metal (Ag)	**Native silver; Galena** with Ag as an impurity	57	Silver is used to make jewelry and silverware, photographic film, and solder on electrical circuit boards of computers and cell phones.
Nickel metal (Ni)	**Pyrrhotite** contains Ni as an impurity	49	Nickel is used to make rechargeable batteries (Ni-Cd) for portable electronic devices, screw-end caps of light bulbs, and stainless steel.
Magnesium metal (Mg)	**Dolomite** and **Olivine** are Mg ores	46	Magnesium is used to make strong, lightweight frames for jet engines and rockets, lightweight cell phone and laptop cases, and incendiary flares and bombs; added to vitamin pills to aid good brain and muscle function and strengthen bones.
Tungsten metal (W)	**Wolframite** is W ore	42	Tungsten is a dense metal that makes cell phones and pagers vibrate (by attaching it to an electric motor spinning off center); also used for light bulb filaments, golf clubs, and tungsten carbide cutting tools.
Copper metal (Cu)	**Azurite, Bornite, Chalcopyrite, Chrysocolla,** and **Malachite** are Cu ores	35	Copper is used to make copper pipes; electrical wire for homes, businesses, electric motors, and circuit boards in cell phones and other electrical devices. Hybrid cars contain about 100 pounds (45 kg) of copper. Added to vitamin pills for healthy hair and skin.
Aluminum (Al)	**Bauxite is Al ore**	20	Aluminum is a lightweight silvery metal used to make drink cans, foil, airplanes, and solar panels.
Salt	**Halite**	19	Used as table salt, road salt (to melt snow), in water softeners, and as a food preservative.
Sulfur (S)	**Native Sulfur; Pyrite** is a S ore	19	Used to make matches, gunpowder, fertilizer, fungicide, insecticide, and harden rubber (car tires).
Gypsum	**Gypsum**	12	Used to make Plaster-of-Paris, drywall and for art (alabaster).
Iron metal (Fe), **Steel**	**Geothite, Limonite, Magnetite,** and **Hematite** are Fe ores	11	Iron and steel are used to construct machines, buildings, bridges, nails, bolts, tools, file cabinets; iron is added to vitamin pills to aid hemoglobin production in red blood cells for oxygen transport.
Cement	**Calcite**	7	Calcite is processed into cement, which is used to make concrete.

FIGURE 3.22 Selected Net Non-Fuel Mineral Resource Imports by the United States in 2012. This list includes only some of the mineral resources reported in *USGS Mineral Commodity Summaries 2013*. Net import reliance is the total of U.S. production and imports, minus the percentage of exports. (Adapted from USGS Mineral Commodity Summaries, 2013)

What Are Conflict Minerals?

Niobium (Nb) and tantalum (Ta) are two rare metallic mineral resources (metal elements). Niobium (formerly called columbium) is mixed with iron to make high-strength non-corrosive steel alloys (for rockets, jet engines, chemical pipelines, nuclear power plants) and superconducting magnets for medical MRI scanners. Tantalum is used to make alloys with high heat tolerance for electronic microchips (for small electrical devices like cell phones) and non-irritating steel for surgical steel tools. Niobium is refined from the mineral columbite, and tantalum is refined from the mineral tantalite. The two minerals commonly occur together as an ore called "coltan." Unfortunately, a primary source of coltan is the Democratic Republic of Congo (DRC) in Africa, where rebel groups use forced labor to mine the coltan and engage in extreme violence against women and children. The United States regards all coltan from DRC as a "conflict mineral." It is illegal to import any coltan, niobium, or tantalum into the United States if it originated in the DRC or another conflict-mineral site.

ACTIVITY 3.6 Urban Ore

THINK About It **How sustainable is your dependency on minerals and elements extracted from them?**

OBJECTIVE Evaluate the prospect of recycling products and mining discarded products to extract their metals.

PROCEDURES

1. **Before you begin,** read the background information ahead. You must also obtain access to a computer that has Internet access. This is **what you will need** to bring to lab:
   ___ Activity 3.6 Worksheet (p. 110) and pencil
   ___ calculator
2. **Then follow your instructor's directions** about how to complete the worksheet.

How Ores and Precious Metals Are Weighed

Did you know that it is common practice in the United States to weigh gold and its ore using different systems of measurement? Within the United States, mining companies use an avoirdupois system to weigh bulk amounts of rock like gold *ore*—material (usually rocks or minerals) from which chemicals can be extracted at a profit. If they sell the gold ore to another country, then its weight is quoted using the metric system (page xiii at the front of the manual). However, once gold is extracted from its ore, its weight is quoted everywhere in the world using the troy system.

Grams Are Metric; Ounces Are Not

A gram is a metric unit of weight (mass) equal to one thousandth of a kilogram—roughly the mass of a paper clip. Any metric scale or balance can be used to measure the weight (mass) of an object in the metric unit called a gram. However, there are no metric ounces. Ounces are used in the avoirdupois and troy systems of measurement. An avoirdupois ounce is 28.349523125 grams, and a troy ounce is 31.1034768 grams. Also, note that fluid ounces are units of volume, not weight.

What Is Avoirdupois?

Avoirdupois (avdp) is pronounced in English as "aver-due-pois," with the "pois" as in poison. It refers to a system of weights (masses) that is widely used in the United States, and parts of Canada and Great Britain, to weigh everything except precious metals, gems, and pharmaceuticals (drugs). It is based on a 28.35-gram *ounce* (oz), 16-avdp-ounce *pound* (lb), and 2000-pound *short ton*. The concept of a pound originated in the Roman Empire, developed into a 16-ounce pound in Europe by the year 1300, and was the system of weights adopted by the 13 British Colonies that became the United States of America. However, the United States developed the 2000-pound "short ton" that is still used today (instead of the British 2240-pound "long ton").

What Are Troy Weights?

Troy (t) refers to an old British system of weights (masses) that is now used globally to quote the weights of precious metals (gold and silver) and gems. It is based on a 31.1-gram *troy ounce* (ozt) and a 12-troy-ounce *troy pound* (lbt). Because some gems and jewelry pieces are small, jewelers often express their weight in troy "pennyweight" (abbreviated "DWT"). One pennyweight is equal to 1/20th of a troy ounce (0.05 ozt) or 1.555 grams.

Unit Conversion—The Math You Need

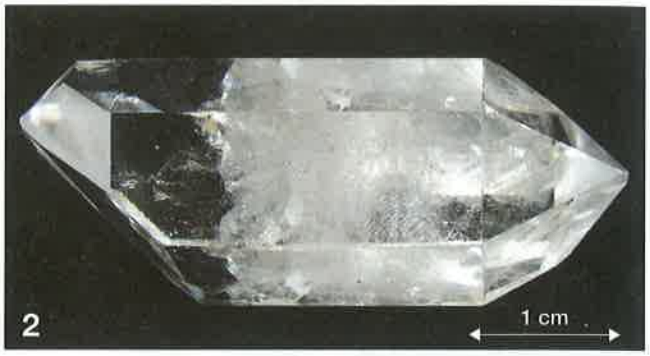
You can learn more about unit conversion (including problems on converting weights) at this site featuring The Math You Need, When You Need It math tutorials for students in introductory geoscience courses: **http://serc.carleton.edu/mathyouneed/units/index.html**

ACTIVITY 3.1 Mineral and Rock Inquiry

Name: ______________________________ **Course/Section:** ____________________ **Date:** __________

A. All of the samples below are rocks from Earth's crust. Record how many crystals you see in each sample (Write 1, 2, 3, or many). Then make a numbered list of how many different kinds of minerals are in the sample and describe each one in your own words. Complete parts **B** and **C**.

How many **crystals** do you see in this sample? _____
List the number of different **minerals** in the sample and give a description of each one.



How many **crystals** do you see in this sample? _____
List the number of different **minerals** in the sample and give a description of each one:

How many **crystals** do you see in this sample? _____
List the number of different **minerals** in the sample and give a description of each one:

How many **crystals** do you see in this sample? _____
List the number of different **minerals** in the sample and give a description of each one:

B. Which of these samples seems to have crystals of a valuable chemical element? _______ What element? ________

C. **REFLECT & DISCUSS** Based on your observations in this activity—what is a rock, and how are rocks related to minerals and crystals?

ACTIVITY 3.2 Mineral Properties

Name: ______________________ **Course/Section:** ______________________ **Date:** __________

A. Indicate whether the luster of each of the following materials looks metallic (M) or nonmetallic (NM):

1. a mirror: ________ **2.** butter: ________ **3.** ice: ________ **4.** a rusty nail: ________

B. What is the streak color (i.e., color in powdered form) of each of the following substances?

1. salt: ____________ **2.** wheat: ____________ **3.** pencil lead: ____________

C. What is the crystal form (**FIGURE 3.4**) of the:

1. quartz in **FIGURE 3.1B**? ____________ **2.** native copper in **FIGURE 3.6**? ____________

D. Look up quartz in the Mineral Database (**FIGURE 3.21**, page 93) to find a list of the varieties (var.) of quartz. Then identify each quartz variety below, and write its name beneath the image.


var. ____________


var. ____________


var. ____________


var. ____________

E. A mineral can be scratched by a masonry nail or knife blade but not by a wire (iron) nail (**FIGURE 3.9**).

1. Is this mineral hard or soft? ____________

2. What is the hardness number of this mineral on Mohs Scale? ________

3. What mineral on Mohs Scale has such a hardness? ____________

F. A mineral can scratch calcite, and it can be scratched by a wire (iron) nail.

1. What is the hardness number of this mineral on Mohs Scale? ________

2. Which mineral on Mohs Scale has this hardness? ____________

G. The brassy, opaque, metallic mineral in **FIGURE 3.7A** is the same as the mineral in **FIGURE 3.8**. What is this mineral's hardness, and how can you tell?

H. Analyze the mineral samples and figure caption in **FIGURE 3.16**.

1. What is this mineral's hardness (give a number or range of numbers)? ____________

2. Very carefully cut out the cleavage goniometer from GeoTools Sheet 1 at the back of this manual. Be sure to cut the angles as exactly as possible. **Sketch the characteristic shape** that this mineral breaks into. Using the cleavage goniometer, measure the angles between flat flat cleavage surfaces of this mineral in **FIGURE 3.16**, and record the angles here:

What is the name of this kind of cleavage?

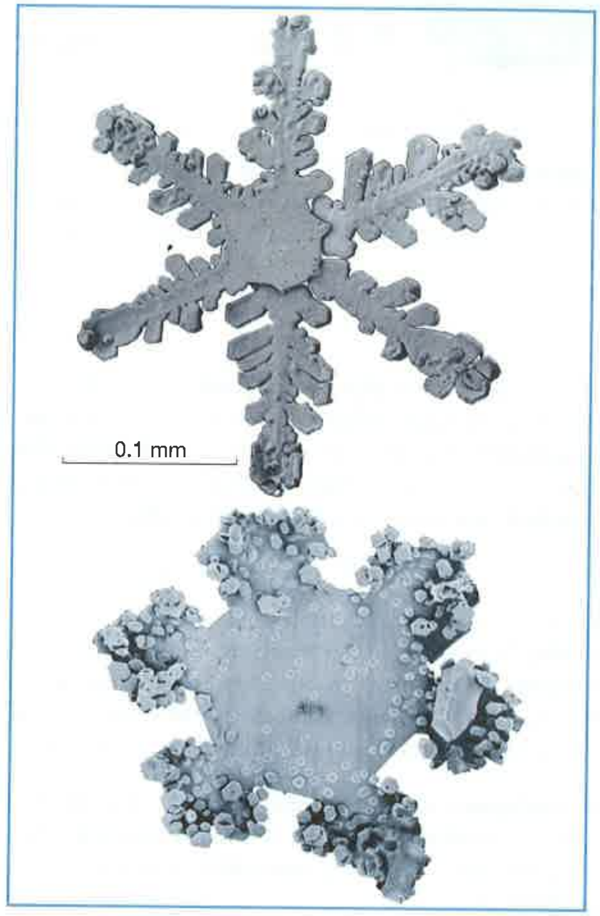
I. A mineral sample weighs 27 grams and takes up 10.4 cubic centimeters of space. What is the SG (specific gravity) of this mineral? Show your work.

J. Analyze these two photomicrographs of ice crystals (snowflakes) by William Bentley.

1. Based on **FIGURE 3.4**, what is the crystal form of the top crystal?

2. Notice that the crystals are symmetrical, but not exactly. Imperfections are common in crystals, but their underlying crystal form can still be detected. To what crystal system in **FIGURE 3.5** do ice crystals belong? How can you tell?

3. **REFLECT & DISCUSS** The habit of snowflakes (crystals of water ice) includes a variety of different crystal forms. Why don't all snowflakes have the same crystal form?



K. Analyze each crystalline household material pictured below and identify which crystal system it belongs to. (Use a hand lens or microscope to observe actual samples of the materials if they are available.)

1. Sucrose (table sugar) belongs to the ______________________ crystal system. How can you tell?

2. Epsomite (epsom salt) belongs to the ______________________ crystal system. How can you tell?

3. Halite (table salt) belongs to the ______________________ crystal system. How can you tell?

4. **REFLECT & DISCUSS** Which of these crystalline household materials (sucrose, epsomite, or halite) cannot be a mineral? Why not?

ACTIVITY 3.3 Determining Specific Gravity (SG)

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Imagine that you want to buy a box of breakfast cereal and get the most cereal for your money. You have narrowed your search to two brands of cereal that are sold in boxes of the exact same size and price. The boxes are made of opaque cardboard and have no labeling of weight. Without opening them, how can you tell which box contains the most cereal?

B. Like the cereal boxes above, equal-sized samples of different minerals often have different weights. If you hold a mineral sample in one hand and an equal-sized sample of a different mineral in the other hand, then it is possible to act like a human balance and detect that one may be heavier than the other. This is called **hefting**, and it is used to estimate the relative densities of two objects. Heft the three mineral samples provided to you, then write sample numbers/letters on the lines below to indicate the sample densities from least dense to most dense.

(Least dense) ____________ ____________ ____________ (Most dense)

C. In more exact terms, **density** is a measure of an object's mass (weighed in grams, g) divided by its volume (how much space it takes up in cubic centimeters, cm^3). Scientists use the Greek character rho (ρ) to represent density, which is always expressed in g/cm^3. What is the density of a box of cereal that is 20 cm by 25 cm by 5 cm and weighs 0.453 kg? Show your work.

D. Mineralogists compare the relative densities of minerals according to their **specific gravity (SG)**: the ratio of the density of a mineral divided by the density of water. Since water has a density of 1 g/cm^3, and the units cancel out, specific gravity is the same number as density but without any units. For example, the density of quartz is 2.6 g/cm^3, so the specific gravity of quartz is 2.6.

Return to the three mineral samples that you hefted above, and do the following:

1. First (while they are still dry), determine and record the mass (weight) of each sample in grams.
2. Use the water displacement method to measure and record the volume of each sample (**FIGURE 3.15**). Recall that one fluid milliliter (mL or ml on the graduated cylinder) equals one cubic centimeter.
3. Calculate the specific gravity of each sample.
4. Identify each sample based on the list of specific gravities of some common minerals.

Sample	Mass in Grams (g)	Volume in Cubic cm (cm^3)	Specific Gravity (SG)	Mineral Name

SG OF SOME MINERALS	
2.1	Sulfur
2.6–2.7	Quartz
3.0–3.3	Fluorite
3.5–4.3	Garnet
4.4–4.6	Barite
4.9–5.2	Pyrite
7.4–7.6	Galena
8.8–9.0	Native copper
10.5	Native silver
19.3	Native gold

D. REFLECT & DISCUSS Were your data and calculations accurate enough to be useful in identifying the samples? If not, how could they be made more accurate?

Name: ______________ Course/Section: ______________ Date: ______________

ACTIVITY 3.4 Mineral Analysis, Identification, and Uses

MINERAL DATA CHART

Sample Letter or Number	Luster*	Hardness	Color / Streak	Cleavage / Fracture	Other notable properties; tenacity, magnetic attraction, reaction with acid, specific gravity, smell, etc	Name (Fig. 3.18, 3.19, or 3.20) and chemical composition (Fig. 3.21)	How do you depend on this mineral or elements from it? (Fig. 3.21)

*M = metallic or submetallic, NM = nonmetallic

MINERAL DATA CHART

Sample Letter or Number	Luster*	Hardness	Color / Streak	Cleavage / Fracture	Other notable properties; tenacity, magnetic attraction, reaction with acid, specific gravity, smell, etc	Name (Fig. 3.18, 3.19, or 3.20) and chemical composition (Fig. 3.21)	How do you depend on this mineral or elements from it? (Fig. 3.21)

*M = metallic or submetallic, NM = nonmetallic

Name: ______________________ **Course/Section:** ______________ **Date:** __________

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

MINERAL DATA CHART

Sample Letter or Number	Luster*	Hardness	Color / Streak	Cleavage / Fracture	Other notable properties: tenacity, magnetic attraction, reaction with acid, specific gravity, smell, etc	Name (Fig. 3.18, 3.19, or 3.20) and chemical composition (Fig. 3.21)	How do you depend on this mineral or elements from it? (Fig. 3.21)

*M = metallic or submetallic, NM = nonmetallic

Name: ______________________ **Course/Section:** ______________________ **Date:** ______________

MINERAL DATA CHART

Sample Letter or Number	Luster*	Hardness	Color / Streak	Cleavage / Fracture	Other notable properties: tenacity, magnetic attraction, reaction with acid, specific gravity, smell, etc	Name (Fig. 3.18, 3.19, or 3.20) and chemical composition (Fig. 3.21)	How do you depend on this mineral or elements from it? (Fig. 3.21)

*M = metallic or submetallic, NM = nonmetallic

ACTIVITY 3.5 The Mineral Dependency Crisis

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Refer to the list of selected net non-fuel mineral resource Imports by the United States in 2012 (**FIGURE 3.22**).

1. Based on **FIGURE 3.22**, complete the table below.

Element used to make cell phones	**Mineral ore(s)** from which it is extracted	How is the element used to make cell phones?

2. Would the United States be able to manufacture cell phones if a world crisis prevented it from importing minerals and elements? _____yes _____ no What evidence from **FIGURE 3.22** supports your answer?

B. Refer to **FIGURE 3.22** and your uses of minerals recorded in your completed Worksheet 3.4. How would your lifestyle change if the U.S. could no longer import the minerals and elements that it imported 100% of in 2012?

C. **REFLECT & DISCUSS** Do you think that it will be possible in the future for the United States to sustain its 2012 levels of net import reliance for the selected commodities and minerals in **FIGURE 3.22**? Explain your answer.

ACTIVITY 3.6 Urban Ore

Name: ______________________ **Course/Section:** ______________ **Date:** ________

A. Recall that "ore" is a material (usually rocks or minerals) from which chemicals can be extracted at a profit.

1. More than half of the gold mined in the U.S. is from mines in northern Nevada. These mines produced an average of 3.2 grams of gold per 2000-pound short ton of ore in 2012.

a. Search the Internet for "New York spot gold price" in U.S. dollars (USD) per ounce, and enter it here. Note that ounces of gold are always quoted in troy ounces (ozt), but some people incorrectly report it as "oz."

NY spot gold price: ______________

b. There are 31.1 grams (g) in one troy ounce (ozt). How many troy ounces of gold are extracted from one short ton of average Nevada ore? Show your work.

c. What is the gold worth (in USD) from one ton of the Nevada ore? Show your work.

d. It costs about $640 to extract 1 troy ounce of Nevada gold from the mine. So how much does it cost to mine and extract the gold from one short ton of the Nevada ore? Show your work.

e. Based on your answers in **c** and **d** above, what is the current average profit per ton of gold ore from northern Nevada?

B. The average iPhone 5 contains 0.0012 grams of gold and weighs 3.951 ounces (avdp).

1. There are 16.00 ounces in one avoirdupois pound and 2000 pounds in one short ton (avoirdupois ton). How many iPhone 5 cell phones are there in one short ton? Show your work.

2. Based on your work above, and the fact that there are about 0.0012 grams of gold in one iPhone 5, how many grams of gold are there in one short ton of iPhone 5 cell phones? Show your work.

3. There are 31.1 grams in one troy ounce. How many troy ounces of gold are there in 1 short ton of iPhone 5s? Show your work.

4. Based on the New York spot gold price in USD per troy ounce) that you determined above (part **A1a**), what is the current value of the gold in one short ton of iPhone 5 cell phones?

C. **REFLECT & DISCUSS** What materials besides cell phones could the U.S. recycle or mine as "urban ore" for metals noted in **FIGURE 3.22**, and what impact would this have on the environment and the ability of the U.S. to sustain its need for metals and mineral ores?