Rodrigo Luna

EXERCISE 22

PHYSICAL PROPERTIES OF MINERALS I: HABIT, TWINNING, CLEAVAGE, FRACTURE, LUSTER, COLOR, AND STREAK

PURPOSE OF EXERCISE

To gain familiarity with several diagnostic physical properties used in hand specimen identification of minerals and rocks. Evaluations of such properties form the basis of mineral identification assignments in exercises 24 through 30.

BACKGROUND INFORMATION: In exercises 2 through 4 you were introduced to various aspects of the external crystal form, or the *morphology*, of minerals. In these three exercises many of the common crystal forms, their names, and Miller indices were discussed. If at this stage you have not yet systematically covered these crystallographic subjects, your should refer at least to Fig. 3.1 and Table 3.1 for a quick introduction to the geometry of common crystal forms and the names applied to such forms.

Habit

Our first impression of a mineral, or crystal, is of its *habit*, or *crystal habit*. A crystal habit is defined as the common and characteristic form, or combination of forms, assumed by a mineral, including its general shape and irregularities of growth. Even when a specimen lacks a regular external form, its regular internal (atomic) structure may be reflected in the smooth, plane fracture surfaces known as cleavage. In exercises 2 and 3 you have seen highly idealized drawings of "perfect" crystal forms. Examples of such highly symmetrical crystals are generally seen only in the exhibit cases of museums, or in locked cabinets in the laboratory. Such crystals are uncommon and tend to be very expensive, because of their rarity. If real crystals (as opposed to wooden blocks) are available for study in the laboratory, many of them will probably be somewhat *malformed* (see Fig. 22.1) and as such their true symmetry is not apparent. On such malformed crystals, the size of the equivalent faces may vary, and therefore the shape of the crystal as a whole appears distorted. However, the interfacial angles between the faces of a malformed crystal and those of an equivalent perfect crystal remain the same. Three common terms that express the quality of the development of external crystal forms are

euhedral – (from the Greek roots *eu*, meaning good, and *hedra*, meaning plane)–describing a mineral that is completely bounded by crystal faces and whose growth during crystallization was not restrained or interfered with by adjacent crystals or mineral grains.

subhedral – (from the Latin root *sub*, meaning less than)–describing a crystal or mineral grain that is partly bounded by crystal faces and partly by surfaces formed against preexisting grains.

anhedral – (from the Greek root *an*, meaning without)–for minerals that lack crystal faces and that may show rounded or irregular surfaces produced by the crowding of adjacent minerals during crystallization.

All the crystal drawings in exercises 2 and 3 are therefore of *euhedral* crystals, whereas the minerals that are intergrown, for example, in a granite, will tend to be *subhedral* and *anhedral*.

If mineral specimens display well-developed crystal forms, the form names (see Fig. 3.1 and Table 3.1) are used to describe their outward appearance. Examples are

prismatic – for a crystal with one dimension markedly longer than the other two.

rhombohedral – with the external form of that of a rhombohedron, for example, $\{10\bar{1}1\}$.

cubic – with the external form of a cube, $\{100\}$.

octahedral – with the external form of an octahedron, $\{111\}$.

pinacoidal – with the pronounced development of one or more two-sided forms, the pinacoid.

However, most mineral specimens will tend to be *aggregates* of many smaller grains, ranging in form from euhedral through subhedral to anhedral. These crystalline aggregates are traditionally defined by descriptive terms, such as the following (see also Fig. 22.2).

massive – applied to a mineral specimen totally lacking crystal faces.

cleavable – applied to a specimen exhibiting one or several well-developed cleavage directions.

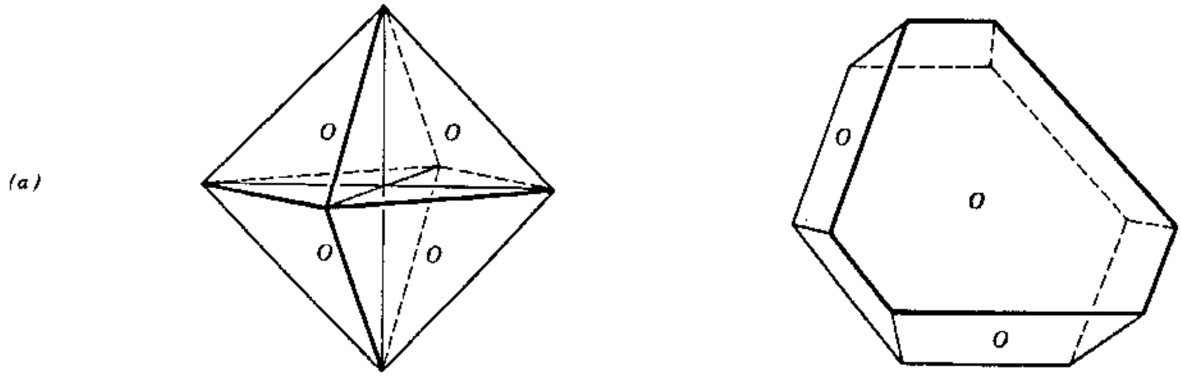
granular – made up of mineral grains that are of approximately equal size. The term is mainly applied to minerals whose grains range in size from about 2 to 10 mm. If the individual grains are larger, the aggregate is described as *coarse-granular;* if smaller, it is *fine-granular.*

compact – applied to a specimen so fine-grained that the state of aggregation is not obvious to the eye.

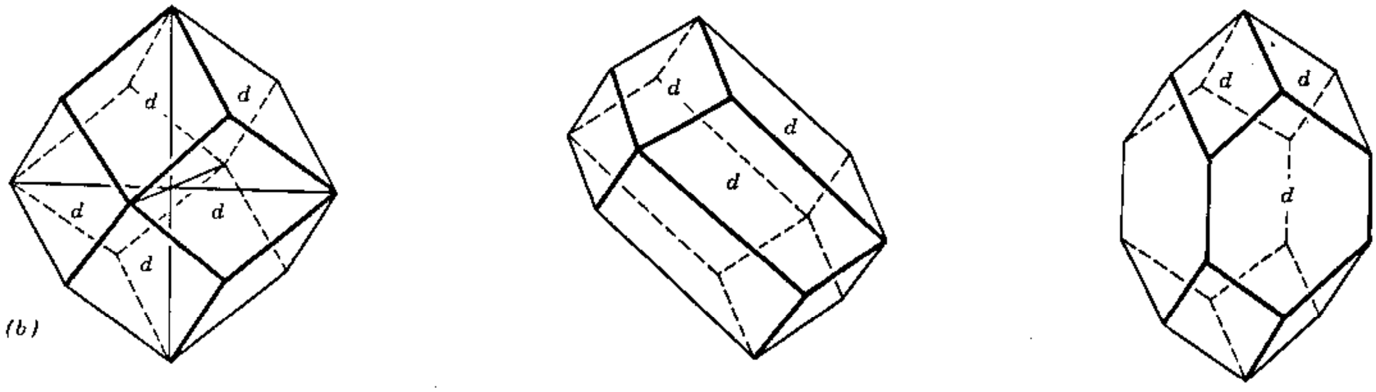
lamellar – made up of layers like the leaves in a book.

foliated – made up of thin leaves or plates that can be

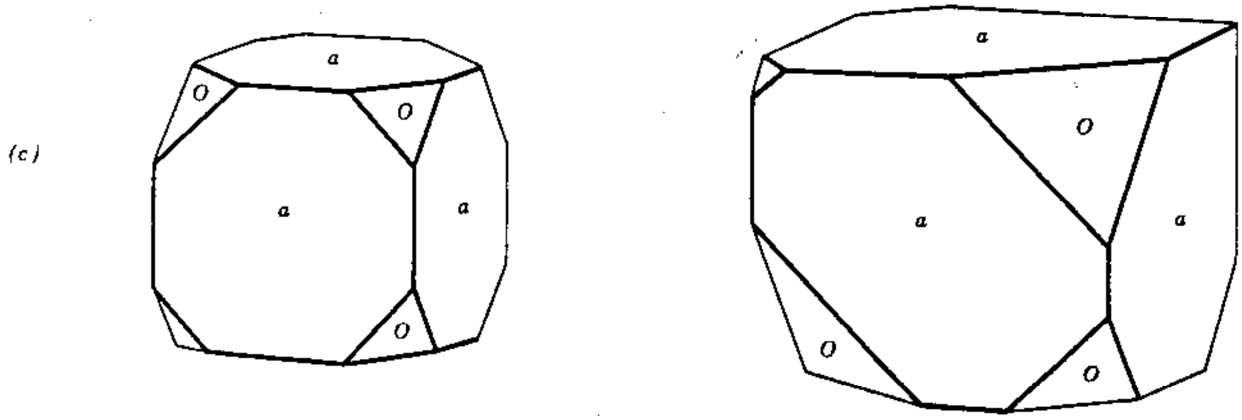
FIGURE 22.1 (*a*) Octahedral and malformed octahedron. (*b*) Dodecahedron and malformed dodecahedrons. (*c*) Cube and octahedron and a malformed combination of cube and octahedron. (From C. S. Hurlbut, Jr., 1949, *Minerals and How to Study Them*, Wiley, New York, pp. 46, 47.)



Octahedron and malformed octahedron

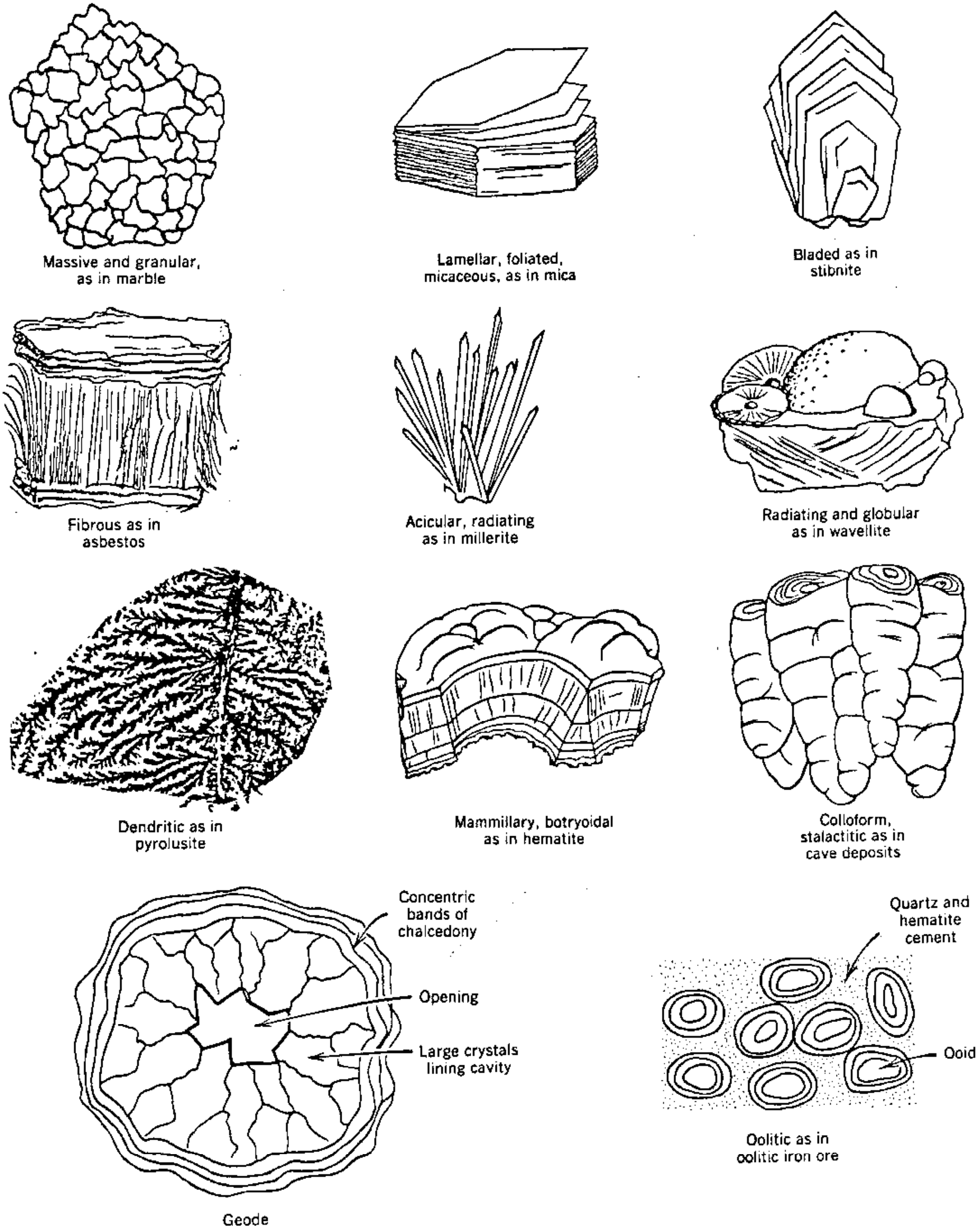


Dodecahedron and malformed dodecahedrons



Cube and octahedron and a malformed combination of cube and octahedron

FIGURE 22.2 Some common mineral habits and occurrences. (Several of these illustrations are modified after J. Sinkankas, 1964, *Mineralogy*, Van Nostrand Reinhold, New York, p. 94.)



Massive and granular, as in marble

Lamellar, foliated, micaceous, as in mica

Bladed as in stibnite

Fibrous as in asbestos

Acicular, radiating as in millerite

Radiating and globular as in wavellite

Dendritic as in pyrolusite

Mammillary, botryoidal as in hematite

Colloform, stalactitic as in cave deposits

Geode

Oolitic as in oolitic iron ore

separated from each other, as in graphite.

micaceous – applied to a mineral whose separation into thin plates occurs with great ease, as in mica.

columnar – with a crystal habit made up of a subparallel arrangement of columnar individuals, as in some occurrences of calcite.

bladed – with individual crystals (or grains) that are flattened blades or flattened elongate crystals.

fibrous – having a tendency to crystallize in needlelike grains or fibers, as in some amphiboles and in asbestos. In asbestos the fibers are *separable*, that is, they are easy to pull apart.

acicular (from the Latin root *acicula*, meaning needle) – describing a mineral with a needlelike habit.

radiating (or *radiated*) – describing a mineral in which acicular crystals radiate from a central point.

dendritic (from the Greek root *dendron*, meaning tree) – applied to a mineral exhibiting a branching pattern.

banded – describing a mineral aggregate in which a single species may show thin and roughly parallel banding (as in banded malachite) or in which two or more minerals form a finely banded intergrowth (as in quartz and hematite bands in banded iron-formation).

concentric – with bands or layers arranged in parallel positions about one or more centers (as in malachite).

mammillary (from the Latin word *mamma* meaning breast) – with an external form made up of rather large, rounded prominences. Commonly shown by massive hematite or goethite.

botryoidal (from the Greek root *botrys* meaning bunch or cluster of grapes) – having the form of a bunch of grapes. The rounded prominences are generally smaller than those described as mammillary. Botryoidal forms are common in smithsonite, chalcedony, and prehnite.

globular – having a surface made of little spheres or globules (as commonly in prehnite).

reniform (from the Latin *renis*, meaning kidney) – with a rounded, kidney-shaped outer surface as in some massive hematite specimens.

colloform (from the Greek root *collo*, meaning cementing or welding) – Since there is often no clear distinction between the four previous descriptive terms (mammillary, botryoidal, globular, and reniform), the term colloform includes them all.

stalactitic from the Greek *stalaktos* meaning dripping) – made up of small stalactites, which are conical or cylindrical in form as is common on the ceilings of caves.

concretionary – clustering about a center, as in calcium carbonate concretions in clay. Some concretions are roughly spherical, whereas others assume a great variety of shapes.

geode – a rock cavity lined with mineral matter but not wholly filled. Geodes may be banded as in agate, through successive depositions of material, and the inner surface is commonly covered with projecting crystals.

oolitic (from the Greek *oön*, meaning egg) – made up of oolites, which are small, round, or ovate (meaning egg-shaped) accretionary bodies, resembling the roe of fish. This texture is common in some iron-rich specimens, made of hematite, known as oolitic iron ore.

pisolitic (from the Greek *pisos*, meaning pea; therefore, pea-sized) – having a texture similar to that of an oolitic aggregate but somewhat coarser in grain size. Bauxite, the major source of aluminum ore, is commonly pisolitic.

Twinning and Striations

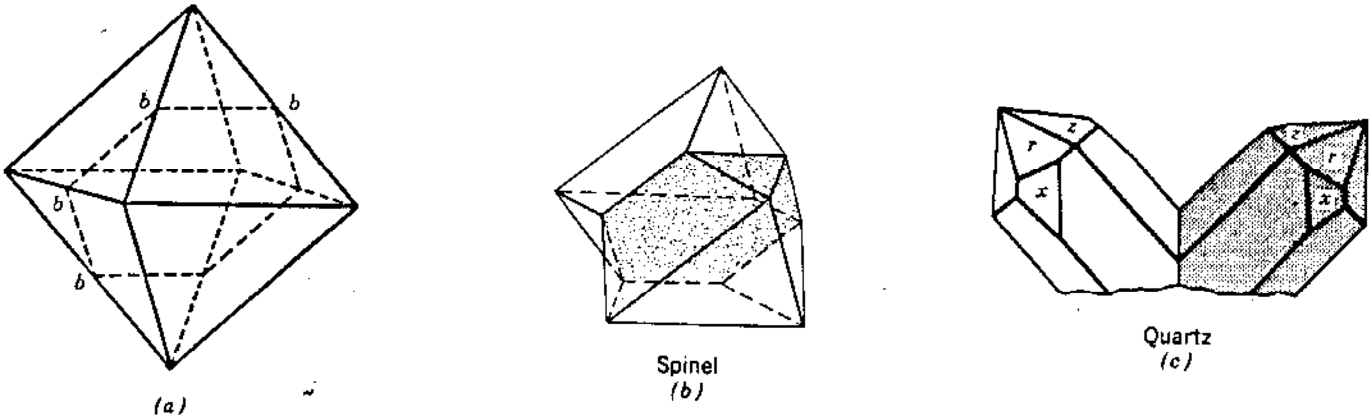
Twinning is very common in crystals, and the size of the twinned units can range from an almost atomic scale (with twin lamellae or twin domains on the order of 10s to 100s of angstroms in size) to such a large scale that the individuals are easily seen by the naked eye. Generally the twins that are easiest to recognize in hand specimen are *contact* twins or *penetration twins*. Although the twinned relationship in such symmetric intergrowths is easily recognized, the twin law that underlies the twinned relationship may not be so obvious. Examples of common contact and penetration twins are shown in Fig. 22.3.

A twin relationship that is more subtle in its appearance is *polysynthetic twinning*. In a polysynthetic twin the successive composition planes of the twin are parallel to each other. When a large number of individuals in a polysynthetic twin are closely spaced, crystal faces or cleavage surfaces cutting across the composition planes show striations owing to the reversed positions of adjacent individuals. A highly diagnostic polysynthetic twin is albite twinning in the plagioclase feldspar series. The twin plane is {010}, and the individual twin lamellae that can be seen by the naked eye are commonly quite thin, ranging from 0.1 to several millimeters in thickness. This twin is evidenced by parallel lines or striations seen on cleavage directions that cut across the {010} pinacoid. The striations resulting from this polysynthetic twinning are shown in Figs. 22.4*a* and *b*. Polysynthetic twinning in a magnetite crystal is shown in Fig. 22.4*c*.

By no means are all striations, as seen on crystal faces, the result of polysynthetic twinning, however. Figures 22.4*d* and *e* show striations that result from the intergrowths of two forms. Pyrite cubes (Fig. 22.4*d*) typically show striations that are the result of successive combinations of other faces or of another form (pyritohedral) in narrow lines with the cube. The magnetite crystal in Fig. 22.4*e* shows striations on dodecahedral faces caused by the stepwise growth of octahedral faces.

FIGURE 22.3 (*a*) Octahedron with possible twin plane *b–b* $(1\bar{1}1)$. This is one of four octahedral directions in the form {111}. (*b*) Octahedral twinning {111} as shown by spinel. (*c*) Right- and left-handed quartz crystals twinned along $(11\bar{2}2)$, the Japanese twin law. (*d*) Two interpenetrating cubes of fluorite twinned on [111] as the twin axis. (*e*) Two pyritohedral crystals (of pyrite) forming an iron cross, with twin axis [001]. (*f*) Orthoclase exhibiting the Carlsbad twin law in which two interpenetrating crystals are twinned by a 180° rotation about the *c* axis, [001] direction. The schematic cross section, parallel to (010), reveals the presence of the 2-fold twin axis along [001]. (From *Manual of Mineralogy*, 20th ed., Fig. 2.111, p. 99.)

Contact Twins

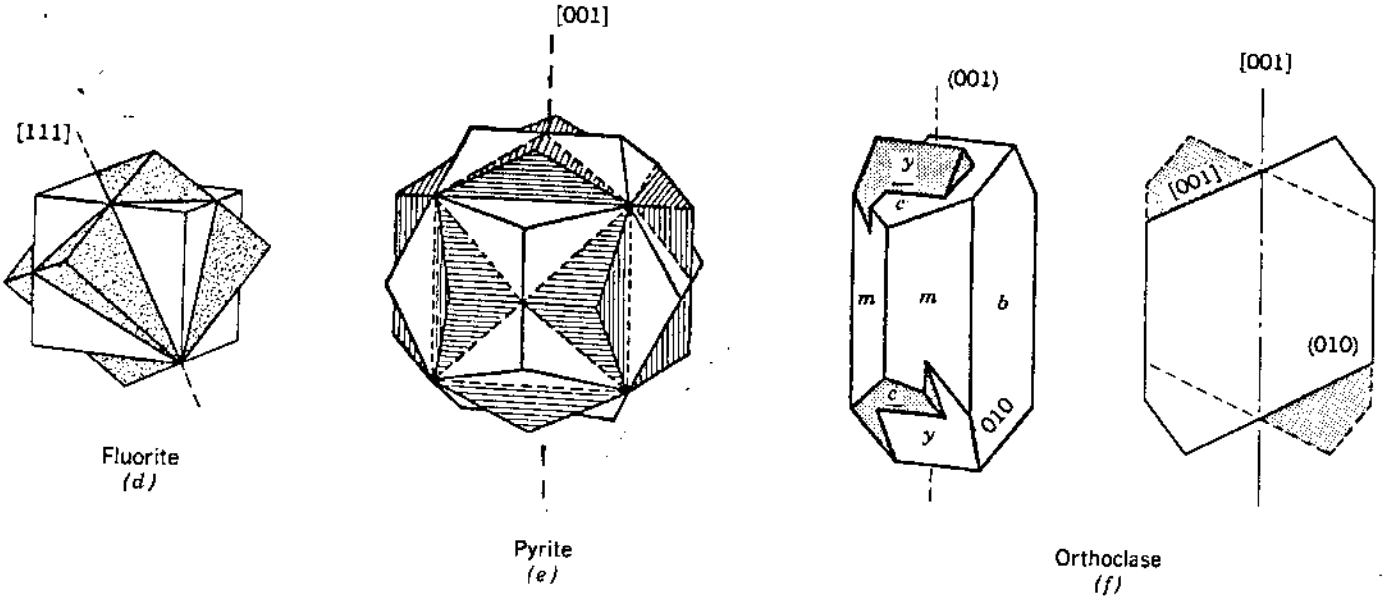


(*a*)

Spinel
(*b*)

Quartz
(*c*)

Penetration Twins



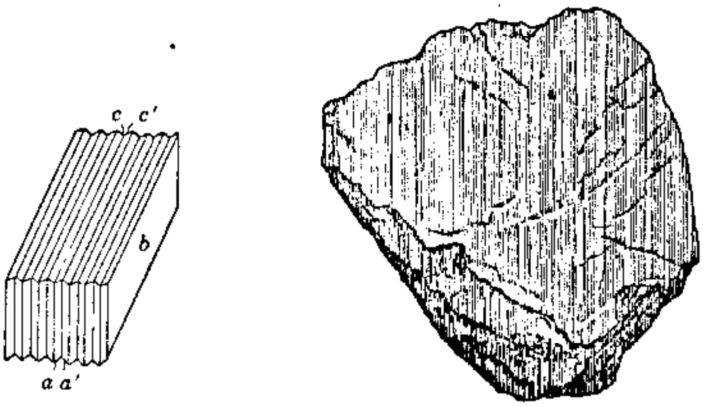
Fluorite
(*d*)

Pyrite
(*e*)

Orthoclase
(*f*)

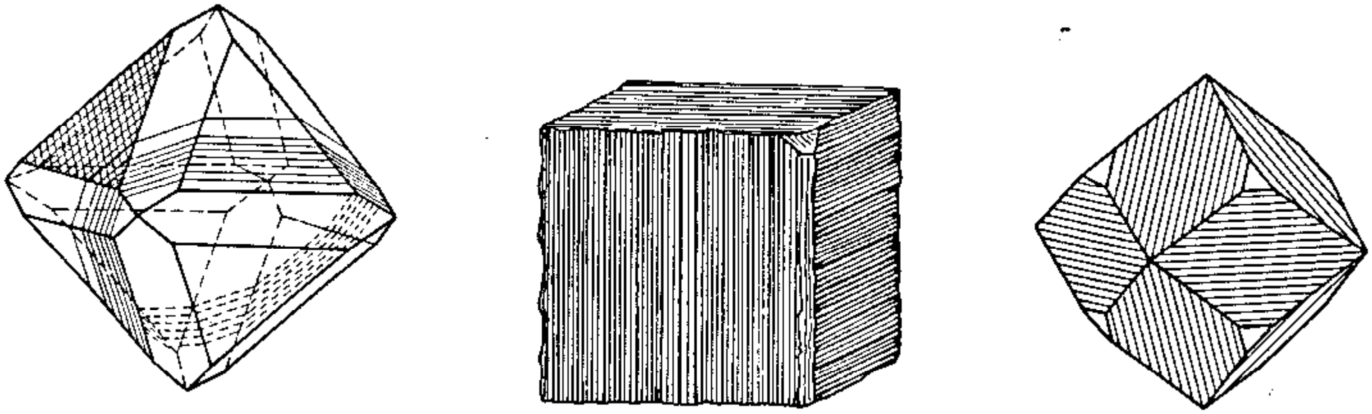
FIGURE 22.4 Polysynthetic twinning and striations. (*a*) Albite polysynthetically twinned on {010}. (*b*) The appearance of albite twinning as striations or parallel groovings across a cleavage or crystal face that crosses {010}. (*c*) Octahedral crystal of magnetite with twinning lamellae appearing as striations on an octahedral face. (*d*) Striations on a cube of pyrite. (*e*) Striations on dodecahedral faces of magnetite caused by the presence of octahedral faces (*o*). (Parts *c, d* and *e* from C. S. Hurlbut, Jr., 1949, *Minerals and How to Study Them*, Wiley, New York, p. 50.)

POLYSYNTHETIC TWINS



(*a*) (*b*)

STRIATIONS



(*c*) (*d*) (*e*)

Cleavage, Parting, and Fracture

Cleavage, parting, and fracture are the responses of a mineral to hammering or crushing. *Cleavage* is the natural and easy fracture that yields more or less smooth, plane surfaces in some crystallographic directions. *Parting* is commonly less obvious than well-developed cleavage and is a breaking parallel to rational crystallographic planes. It is restricted to specimens that are subjected to pressures or have been twinned. *Fracture* is the breaking of a mineral in response to a hammerblow along an irregular surface. Cleavage, parting, and fracture all mark directions in crystal structures where the forces binding the atoms (or ions) are relatively weak (see Fig. 22.5). *Cleavage* may be strongly developed in some minerals, or it may be fairly obscure in some other minerals. The range of cleavage development is expressed as *perfect cleavage*, as, for example, the cubic cleavage of galena; *good cleavage*, as, for example, the prismatic cleavage in pyroxenes; and *poor cleavage*, as in beryl or apatite. A mineral such as quartz shows no cleavage. When we determine cleavage in a mineral, it is important to note (1) the number of cleavage directions in a single mineral specimen, (2) the angles between these directions, and (3) the quality and ease of cleavage. Because cleavage planes are parallel to possible rational crystal faces, the planes are commonly identified by Miller indices. For example, cubic cleavage is noted as $\{100\}$, octahedral cleavage as $\{111\}$, dodecahedral cleavage as $\{011\}$, rhombohedral cleavage as $\{10\bar{1}1\}$, prismatic cleavage as $\{110\}$, and basal cleavage as $\{001\}$. (See Fig. 22.5 for illustrations of these cleavage directions.)

Directions of *parting* can similarly be expressed by Miller index notation. Basal parting in pyroxene is parallel to $\{100\}$, and rhombohedral parting in corundum is parallel to $\{10\bar{1}1\}$.

Because *fracture* surfaces are not parallel to any specific crystallographic directions, they can be described only in qualitative terms such as

conchoidal – showing smooth, curved fracture surfaces resembling the interior surface of a shell. Conchoidal fracture is diagnostic of amorphous materials such as glass (see Fig. 22.5*i*), but it is also shown by quartz.

fibrous and ***splintering***.

hackly – showing fractures with sharp edges.

uneven or ***irregular***.

Luster

The term *luster* refers to the general appearance of a mineral surface in reflected light. The two distinct types of luster are *metallic* and *nonmetallic*, but there is no sharp division between them. Although the difference between these types of luster is not easy to describe, the eye discerns it easily and, after some experience, seldom makes a mistake. *Metallic* is the luster of a metallic surface such as chrome, steel, copper, and gold. These materials are quite opaque to light; no light passes through even at very thin edges. Galena, pyrite, and chalcopyrite are common minerals with metallic luster. *Nonmetallic* luster is generally shown by light-colored minerals that transmit light, if not through thick portions at least through their edges. The following terms are used to describe further the luster of nonmetallic minerals.

vitreous – with the luster of a piece of broken glass. This is commonly seen in quartz and many nonmetallic minerals.

resinous or waxy – with the luster of a piece of resin. This is common in samples of sphalerite.

pearly – with the luster of mother of pearl. An iridescent pearllike luster. This is characteristic of mineral surfaces that are parallel to well-developed cleavage planes. The cleavage surface of talc and the basal plane cleavage of apophyllite show pearly luster.

greasy – appears as though covered with a thin layer of oil. This luster results from light scattered by a microscopically rough surface. Some milky quartz and nepheline specimens may show this.

silky, or ***silklike*** – describing the luster of a skein of silk or a piece of satin. This is characteristic of some minerals in fibrous aggregates. Examples are fibrous gypsum, known as satin spar, and chrysotile asbestos.

adamantine (from the Greek word *adamas*, meaning diamond) – with the luster of the diamond. This is the brilliant luster shown by some minerals that also have a high refractive index and as such refract light strongly as does diamond. Examples are the carbonate of lead, cerussite, and the sulfate of lead, anglesite.

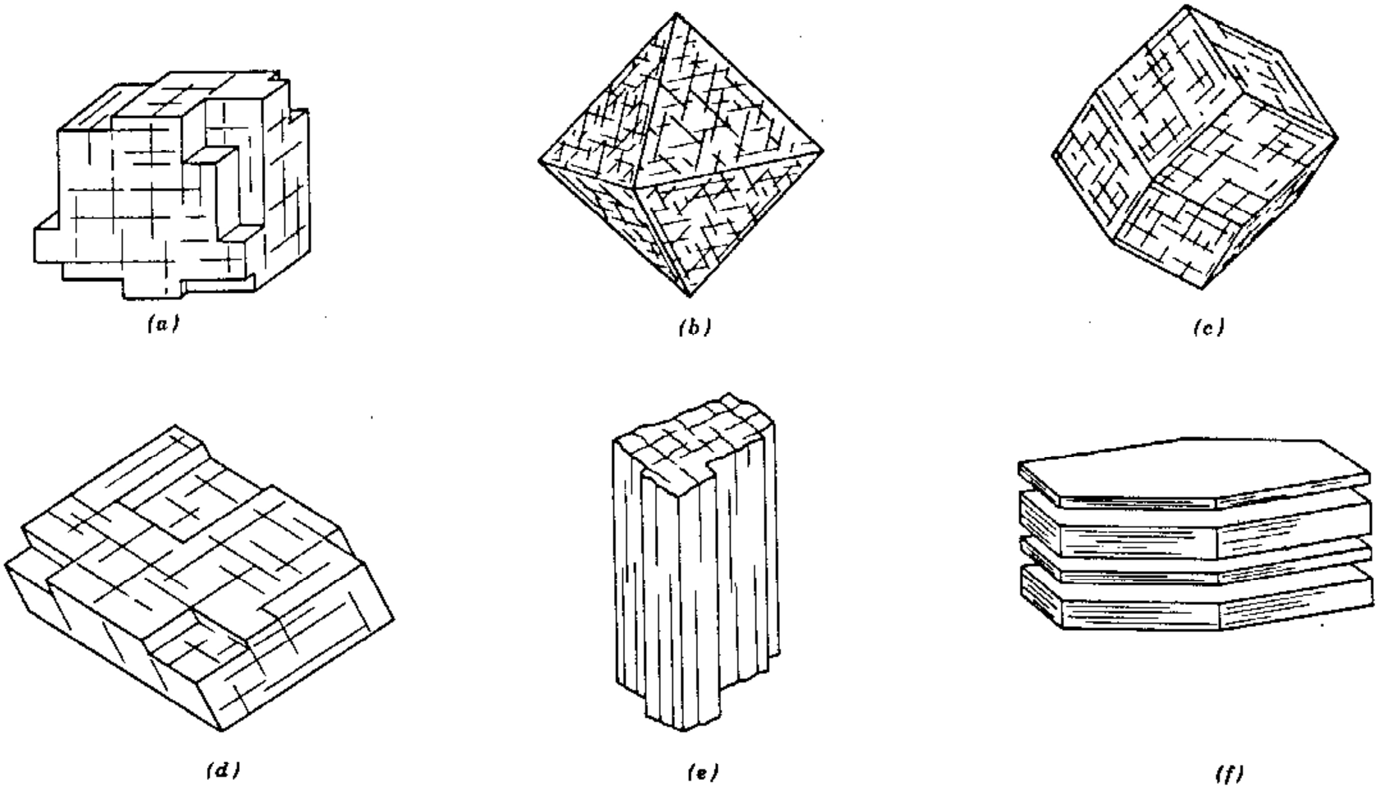
Color

The variation in the color of minerals is very great, and the terms used in describing the color are so familiar that they explain themselves.

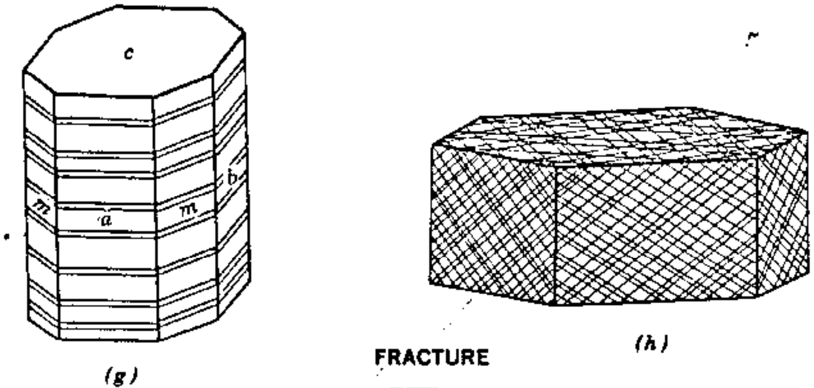
Because color varies not only from one mineral to another, but also within the same mineral (or mineral group), the mineralogy student must learn in which minerals it is a constant property and can therefore be relied upon as a distinguishing criterion. Most minerals with a metallic luster vary little in color, but most nonmetallic minerals vary widely in color. Although the color of a freshly broken surface of metallic minerals is often highly diagnostic, these same minerals may become tarnished with time. Such a tarnish may dull some minerals such as galena, which has a bright, bluish lead-gray color on a fresh surface, but may become dull upon long exposure to air. Bornite, which on a freshly broken surface has a brownish-bronze color, may be so highly tarnished on an older surface that it shows variegated purples and blues; hence, it is called *peacock ore*. In other

FIGURE 22.5 Cleavage: (*a*) cubic, (*b*) octahedral, (*c*) dodecahedral, (*d*) rhombohedral, (*e*) prismatic and pinacoidal, (*f*) pinacoidal (basal). (From *Manual of Mineralogy*, 20th ed.,Fig. 5.3, p. 201.) (*g*) Basal parting in pyroxene, and (*h*) rhombohedral parting in corundum with twinning striations, which are potential parting planes. (From *Manual of Mineralogy*, 20th ed., Fig. 5.4 p. 202), (*i*) conchoidal fracture in obsidian (volcanic glass). (From *Manual of Mineralogy*, 20th ed., Fig. 5.5, p. 202).

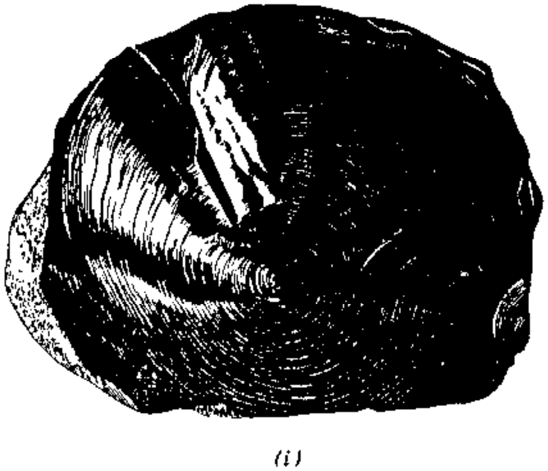
CLEAVAGE



PARTING



FRACTURE



words, in the identification of minerals with a metallic luster, it is important to have a freshly broken surface to which a more tarnished surface can be compared.

Of all the minerals with nonmetallic luster, a few have such a *constant color* that their coloration can be used as a truly diagnostic property. Examples are malachite, which is green; azurite, which is blue; rhodonite, which is red; and turquoise, which gives its name to the turquoise color, a greenish blue to blue-green. Most nonmetallic minerals have a relatively narrow *range in colors,* although some show an unusually large range. Members of the plagioclase feldspar series range from almost pure white in albite, through light gray to darker gray toward the anorthite end-member. Most common garnets show various shades of red to red-brown to brown. Members of the monoclinic pyroxene group range from almost white in pure diopside, to light green in diopside with a little iron in substitution for magnesium in the structure, through dark green in hedenbergite, to almost black in many augites. Members of the orthopyroxene series (enstatite to ferrosilite) range from light beige to darker brown. On the other hand, tourmaline may show many colors (red, blue, green, brown, and black) as well as distinct color zonation from colorless through pink to green within a single crystal . Similarly, gem minerals such as corundum, beryl, quartz, and numerous others occur in many colors; the gemstones cut from them are given varietal names. In short, in most nonmetallic minerals color is a helpful property, but not commonly a truly diagnostic (and therefore unique) property.

Streak

It is commonly very useful, especially in metallic minerals, to test the color of the fine powder or the color of the streak. To determine the color of the streak of a mineral, you will use a piece of unglazed white porcelain called a *streak plate.* Minerals with a hardness higher than that of the streak plate will not powder by rubbing them against it. The hardness of a streak plate is about 7 (see exercise 23). This test will show that black hematite with a silvery luster has a red streak. Most minerals with a nonmetallic luster will have a whitish streak, even though the minerals themselves are colored.

Other Properties Depending On Light

Minerals are commonly described in terms of the amount of light they can transmit. Such properties are grouped under the term *diaphaneity,* meaning the light-transmitting qualities of a mineral, from the Greek word *diaphanes,* meaning transparent. Examples follow.

transparent – describing a mineral that is capable of transmitting light, and through which an object may be seen. Quartz and calcite are commonly transparent. Most gem materials are highly transparent and commonly priced on the basis of the quality of their transparency.

translucent – said of a mineral that is capable of transmitting light diffusely, but is not transparent. Although a translucent mineral allows light to be transmitted, it will not show a sharp outline of an object seen through it. Some varieties of gypsum are commonly translucent.

opaque – describing a mineral that is impervious to visible light, even on the outer edges of the mineral. Most metallic minerals are opaque.

As a mineral is turned in a light source, the light may be reflected (or defracted) in such a way that a series of unusual light patterns are produced. The following properties may be observed.

Play of colors – the result of the production of a series of colors as the angle of the incident light is changed. Precious (gem) opals may show such striking color displays.

Opalescence – the pearly reflection of a range of colors from the interior of a mineral. It may be well developed in common opal and in varieties of Na-rich plagioclase known as *moonstone.*

Iridescence (also referred to as *schiller,* or *labradorescence*) – a show of rainbow colors in shifting patterns, the result of light scattered by extremely thin and closely spaced (microscopic) cleavage planes, twin or exsolution lamellae within the mineral. The plagioclase feldspar, *labradorite,* may show colors ranging from blue to green to yellow with the changing angle of light.

Chatoyancy – a movable wavy or silky sheen concentrated in a narrow band of light that changes position as the mineral is turned. It results from the reflection of light from minute parallel fibers, cavities, or needlelike inclusions within the mineral. The effect is best seen on cabochon-cut gemstones, which may display a thin band of light at right angles to the length of inclusions or fibers inside the cut stone. Examples are *cat's eye,* a gem variety of chrysoberyl, and *tiger's eye,* fibrous crocidolite (blue or oxidized to brown) replaced by quartz.

Asterism – the optical phenomenon of a rayed or star-shaped figure of light displayed by some minerals when viewed in reflected light. It is generally the result of minute, needlelike inclusions arranged in three crystallographic directions at 120° to each other. This is beautifully shown by cabochon-cut gemstones such as star sapphires and star rubies.

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Zoltai, T., and Stout, J. H., 1984, *Mineralogy,* Macmillan, New York, pp. 9–19, 159–167.

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MATERIALS

Various collections of mineral specimens that display a range of habits, aspects of twinning, types of cleavage, metallic and nonmetallic luster, and a range of colors. Such specialized collections, if not already available in the laboratory, can be bought from mineral supply houses such as Ward's Natural Science Establishment, Inc., Rochester, New York. For the determination of streak an unglazed white porcelain plate is needed. A hand lens, with about 10x magnification, is very helpful for the detailed observation of various physical properties. A binocular microscope with a good light source is also very useful. Note that some of the physical properties introduced in this exercise form the basis for determinative tables in several textbooks (e.g., Appendix 1 in *Manual of Mineralogy*, 20th ed., and Chapter 16 in *Mineralogy*, by Berry, Mason, and Dietrich).

ASSIGNMENT

1. *Habit.* If a specific mineral collection with a range of mineral habits is available, observe and carefully handle each of the specimens and familiarize yourself with the various descriptive terms. Read through the listing of such terms, as just given, and at the same time look over the illustrations in Fig. 22.2. If a specific habit collection is not available, look through any mineral exhibits that are available in the laboratory, in the hallways of your building, or in museum collections, and locate in these collections the various habits as described earlier.
2. *Crystal form.* If you have already worked your way through exercises 1 through 3, or 1 through 8, you will have little difficulty in recognizing the forms displayed by well-developed crystals. Good crystal collections are usually housed in locked cabinets, and you will probably have little chance to handle good-sized, well-developed crystals. If, however, you have been asked to do the present assignment without prior knowledge of various aspects of crystallography, you will find it helpful to consult at least Fig. 3.1 and Table 3.1 for a brief introduction to the most common geometrical shapes and form names of crystals. You can further acquaint yourself with crystal form descriptions by consulting any of the references quoted in exercise 3.
3. *Twinning.* The most important type of twinning that you should learn to recognize is that displayed by members of the plagioclase feldspar series. This mineral group commonly shows well-developed polysynthetic twinning, as illustrated in Fig. 22.4*b*. The presence of this twinning, commonly seen as closely spaced striations on a cleavage face, is highly diagnostic of the plagioclase feldspars. Several specimens ranging from albite to anorthite should be handled and observed. A hand lens or binocular microscope will be very helpful in recognizing this type of twinning.
4. *Cleavage and fracture.* A collection showing minerals with a range of cleavage types and perfection is very helpful. The collection should include minerals such as galena, calcite, fluorite, halite, tremolite (or some other amphibole), diopside (or some other pyroxene), muscovite (or some other mica), microcline, and quartz. For each of the mineral specimens in such a collection, note the number of cleavage directions and the quality of the cleavage (as described, under background information). If more than one cleavage direction is present, estimate the angles between them; this is especially diagnostic in amphiboles, pyroxenes, and feldspars. *Conchoidal fracture* is generally very well illustrated by volcanic glass specimens.
5. *Luster.* A collection of minerals illustrating various types of luster is very instructive. In such a collection observe the obvious distinction between *metallic* and *nonmetallic* luster, and among the nonmetallic minerals familiarize yourself with the various descriptive terms given under background information.
6. *Color, streak, and some other properties dependent on light.* Here again a collection specifically directed to various colors and color ranges is helpful for introductory study. The concept of *streak* is best introduced by scratching black, metallic hematite on an unglazed porcelain plate and observing the color of the streak. *Iridescence* is commonly well developed in specimens of the plagioclase feldspar known as labradorite. Properties such as chatoyance, and asterism are best seen in exhibits of some gem materials.

Rodrigo Luna.

EXERCISE 23

PHYSICAL AND SOME CHEMICAL PROPERTIES OF MINERALS II: HARDNESS, TENACITY, SPECIFIC GRAVITY, MAGNETISM, FUORESCENCE, SOLUBILITY IN HYDROCHLORIC ACID, AND RADIOACTIVITY

PURPOSE OF EXERCISE

To gain familiarity with some additional diagnostic properties used in hand specimen identification of minerals and rocks. Evaluations of such properties are the basis for mineral identification assignments in exercises 24 through 30.

BACKGROUND INFORMATION: In exercise 22 you were introduced to several physical properties that are relatively easy to observe in hand specimens without specific testing tools (except for the streak plate needed to obtain a streak). In this exercise you will be introduced to additional physical properties all of which require various kinds of testing tools or apparatus.

Hardness (H)

Hardness is the resistance of a mineral to scratching. It is a property by which minerals may be described, relative to a standard scale of ten minerals known at the *Mohs scale.* The ten minerals making up the *Mohs scale of hardness* are listed in Table 23.1. The degree of hardness is determined by observing the comparative ease or difficulty with which one mineral is scratched by another,.or by a pocket knife or a steel file. Figure 23.1 shows the relationship of the Mohs *relative* hardness scale to *absolute* measurements of hardness.

For measuring the hardness of a mineral, several common objects that can be used for scratching are very helpful, such as a fingernail, a copper coin, a steel pocket knife, a glass plate or window glass, the steel of a file, and a streak plate. The approximate hardness of these materials is listed next to the minerals of the Mohs scale in Table 23.1.

In the practical determination of the relative hardness of a mineral, it is necessary to decide which of the minerals, or other materials (as listed in Table 23.1) it can or cannot scratch. In making hardness tests, keep the following in mind: sometimes when one mineral is softer than another, portions of the softer mineral may leave a mark on the harder material, which may be mistaken for a scratch. Such a mark can be rubbed off, whereas a real scratch is permanent. The surface of some minerals may have been altered to material that is softer than the original mineral. Therefore, a *fresh surface* of the specimen must be used in hardness testing. In addition, the physical and aggregate nature of a mineral may prevent a correct determination of its hardness. For example, if the mineral is finely granular or splintery, it may be broken down and apparently scratched by a mineral softer than itself. It is therefore advisable when making a hardness test to confirm it by reversing the procedure. That is, do not try just to scratch mineral *A* with mineral *B*, but also try to scratch sample *B* with sample *A*.

Because there is a general link between hardness and chemical composition, the following generalizations can be made.

1. Most hydrous minerals are relatively soft ($H < 5$).
2. Halides, carbonates, sulfates, and phosphates are also relatively soft ($H < 5\frac{1}{2}$).
3. Most sulfides are relatively soft ($H < 5$) with pyrite being an exception ($H < 6$ to $6\frac{1}{2}$).
4. Most anhydrous oxides and silicates are hard ($H > 5\frac{1}{2}$).

Because hardness is a highly diagnostic property in mineral identification, most determinative tables use relative hardness as a sorting parameter (see, for example, Appendix 1 in *Manual of Mineralogy,* 20th ed., and Chapter 16 in *Mineralogy,* by Berry, Mason and Dietrich).

Tenacity

Under tenacity are grouped several other mineral properties that depend on the cohesive force between atoms (and ions) in mineral structures. The following terms are used to describe a mineral's tenacity.

malleable – capable of being flattened under the blows of a hammer into thin sheets without breaking or crumbling in fragments. Malleability is conspicuous in gold, silver, and copper. Indeed, most of the native elements show various degrees of malleability.

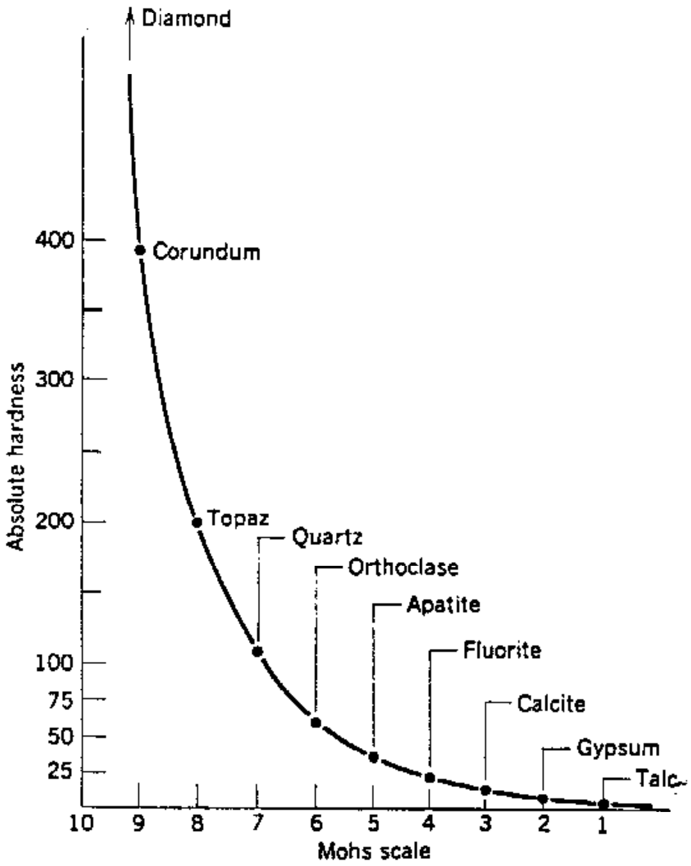
sectile – capable of being severed by the smooth cut of a knife. Copper, silver, and gold are sectile, whereas chalcocite and gypsum are both imperfectly sectile.

ductile – capable of being drawn into the form of a wire. Gold, silver, and copper are ductile.

flexible – bending easily and staying bent after the pressure is removed. Talc is flexible.

brittle – showing little to no resistance to breakage, and as such separating into fragments under the blow of a hammer or with the cut of a knife. Most silicate minerals are brittle.

FIGURE 23.1 Comparison of the Mohs relative hardness scale to absolute measurements of hardness. (From *Manual of Mineralogy*, 20th ed., p. 203.)



elastic – capable of being bent or pulled out of shape but, returning to the original form when relieved. Mica is elastic.

Specific Gravity (G)

Specific gravity is a number that expresses the ratio between the weight of a substance and the weight of an equal volume of water at 4°C. Thus a mineral with a specific gravity (G) of 2 weighs twice as much as the same volume of water.

The specific gravity of a mineral depends on (1) the atomic weights of all the elements of which it is composed and (2) the manner in which the atoms (and ions) are packed together. In mineral series whose species have essentially identical structures (known as *isostructural*), those with elements of higher atomic weight have higher specific gravities. If two minerals (as in the two polymorphs of carbon, namely graphite and diamond) have the same chemical composition, the differences in specific gravity reflect the difference in internal packing of the atoms or ions (diamond with G = 3.51 has a much more densely packed structure than graphite with G = 2.23).

Most people, from everyday experience, have acquired a sense of relative weight even about nonmetallic and metallic minerals. For example, borax (G = 1.7) seems light for a nonmetallic mineral, whereas barite (G = 4.5) appears heavy. This means that people have developed an idea of an *average specific gravity* for a nonmetallic mineral, or a sense of what a nonmetallic mineral of a given size should weigh. The average specific gravity is considered to be somewhere between 2.65 and 2.75,

TABLE 23.1 Mohs Hardness Scale and Additional Observations

Mineral	*Mohs Hardness*	*Other Materials*	*Observations on the Minerals*
Talc	1		Very easily scratched by the fingernail; has a greasy feel
Gypsum	2	~2.2 fingernail	Can be scratched by the fingernail
Calcite	3	~3.2 copper penny	Very easily scratched with a knife and just scratched by a copper coin
Fluorite	4		Easily scratched with a knife but not as easily as calcite
Apatite	5	~5.1 pocket knife ~5.5 glass plate	Scratched with a knife with difficulty
Orthoclase	6	~6.5 steel file	Cannot be scratched with a knife, but scratches glass with difficulty
Quartz	7	~7.0 streak plate	Scratches glass easily
Topaz	8		Scratches glass very easily
Corundum	9		Cuts glass
Diamond	10		Used as a glass cutter

which is reflected by the range of specific gravities of quartz (G = 2.65), feldspar (G = 2.60 to 2.75), and calcite (G = 2.72). People have the same sense about metallic minerals: graphite (G = 2.23) seems light, whereas silver (G = 10.5) appears heavy. The average specific gravity for metallic minerals is about 5.0, that of pyrite. Thus, with some practice, a person can, by merely lifting specimens, distinguish minerals that have comparatively small differences in specific gravity.

A simple spring balance allows us to determine specific gravity with ease and with much greater accuracy than is possible by assessing the average heft of a mineral by hand. Such a balance, known as the *Jolly balance* (see Fig. 23.2), provides numerical values for a small mineral specimen (or fragment) in air as well as in water. When the mineral is weighed immersed in water, it is buoyed up and weighs less than it does in air; this weight loss is equal to the weight of water it displaces. Hence, if we find first the weight of a mineral fragment on a pan of the balance in air, and subsequently its weight while immersed in water (it being suspended on a pan by a thin wire thread), and subtract the two weights, the difference is the weight of the equal volume of water. For example, the weight of a small quartz fragment is 4.265 grams in air; in water it is 1.609 grams. The loss of weight, or weight of an equal volume of water exactly equal to it, is therefore 2.656 grams; hence the specific gravity is

$$\frac{4.265}{4.265 - 2.656} = \frac{4.265}{1.609} = 2.65$$

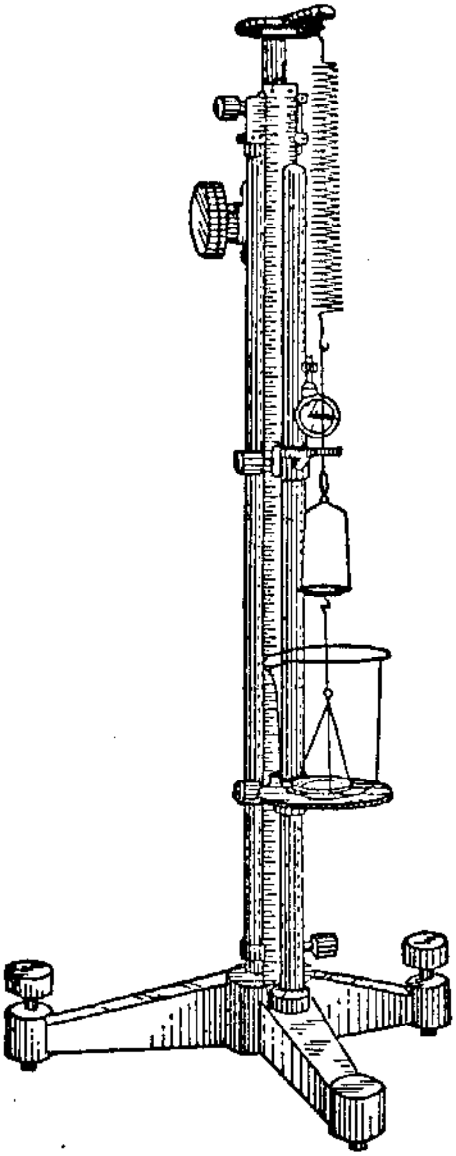
which is indeed that of quartz.

In other words, the specific gravity of a mineral (G) can be expressed as follows,

$$G = \frac{W_a}{W_a - W_w}$$

in which W_a is the weight in air and W_w is the weight in water.

FIGURE 23.2 Jolly balance. (From *Manual of Mineralogy*, 20th ed., p. 205.)



Because specific gravity is merely a ratio, it is not necessary to determine the absolute weight of a specimen but merely values proportional to the weights in air and in water. The *Jolly balance* allows us to do this directly by measuring the stretch of a spiral spring. In using the balance, first place a fragment on the upper scale pan and note the elongation of the spring (this gives the weight in air, W_a). The fragment is subsequently transferred to the lower pan and immersed in water. The elongation of the spring is now propositional to the weight of the fragment in water (W_w). More specific instructions regarding the use of the Jolly balance are given in the assignment section.

For the accurate determination of the specific gravity of a mineral fragment, one must use a *homogeneous* and *pure* specimen. The specimen must also be compact, without cracks or cavities within which bubbles or films of air may be trapped. For routine mineralogical work, the specimen should have a volume of about one cubic centimeter. If these conditions are not met, a specific gravity determination with the Jolly balance will have little meaning.

Magnetism

The two common minerals, magnetite and pyrrhotite, are highly magnetic. That is, both are easily attracted to a small hand magnet. Both are opaque minerals that may occur as minor constituents in a wide range of mineral associations and rock types. Even if present in small quantities, or with small-sized grains, the removal of one or several grains from a specimen with a needle or a pocket knife allows for the testing of magnetism of individual grains. Magnetite is very strongly attracted to a magnet, pyrrhotite less so.

Fluorescence

Some minerals when exposed to ultraviolet light will emit visible light during irradiation; this is known as fluorescence. Some minerals fluoresce only in shortwave ultraviolet, whereas others may fluoresce only in longwave ultraviolet, and still others fluoresce under either. The color and intensity of the emitted light vary considerably with the wavelengths of ultraviolet light. Fluorescence is an unpredictable property, because some specimens of a mineral show it, whereas other apparently similar specimens, even those from the same locality, do not. Several minerals that may show fluorescence are fluorite, sheelite, clacite, scapolite, willemite, and autunite. Specimens of willemite and calcite from the Franklin district, New Jersey, may show brilliant fluorescence colors.

Solubility in HCl

The positive identification of carbonate minerals is much aided by the fact that the carbon–oxygen bond of the (CO_3) group in carbonates becomes unstable and breaks down in the presence of hydrogen ions available in acids. This is expressed by the reaction $2H^+ + CO_3 \longrightarrow H_2O + CO_2$, which is the basis for the "fizz" test with dilute hydrochloric acid. Calcite, aragonite, witherite, and strontianite as well as Cu-carbonates show bubbling or effervescence (fizz) when a drop of dilute HCl is placed on the mineral. The fizz is the result of the release of CO_2. Other carbonates such as dolomite, rhodochrosite, magnesite, and siderite will show effervescence only in hot HCl.

Radioactivity

Minerals containing uranium and thorium will continually undergo *decay reactions* in which radioactive isotopes of U and Th form various daughter elements and also release energy in the form of alpha and beta particles and gamma radiation. The radiation produced can be measured in the laboratory or in the field using a Geiger counter or a scintillation counter. A radiation counter, therefore, is helpful in the identification of U- and Th-containing minerals. Examples are uraninite, pitchblende, thorianite, and antunite.

REFERENCES

Klein, C., and Hurlbut, C. S., Jr., 1985, *Manual of Mineralogy*, 20th ed., Wiley, New York, pp. 199–219.

Zoltai, T., and Stout, J. H., 1984, *Mineralogy*, Macmillan, New York, pp. 3–17.

Berry, L. G., Mason, B., and Dietrich, R. V., *Mineralogy*, 2nd ed., Freeman, San Francisco, pp. 137–164.

MATERIALS

The minerals of Mohs' scale for testing hardness are essential to this exercise. Such a specialized collection, if not already available, can be bought from mineral supply houses, such as Ward's Natural Science Establishment, Inc., Rochester, New York. The students should be provided with glass plates for hardness testing, and they should have a pocket knife for this exercise as well for as any subsequent assignments on mineral identification. A collection of small, clean, homogeneous, and single mineral specimens for specific gravity determination with the Jolly balance is highly instructive in teaching the diagnostic aspects of specific gravity and the technique itself. Small plastic bottles with eye droppers, filled with dilute HCl (concentrated HCl diluted with distilled water in a proportion of 1 to 10) are needed for carbonate fizz tests, and horseshoe magnets are essential in the evaluation of magnetic properties. An ultraviolet light source (preferably with shortwave and longwave uv radiation) and selected fluorescent mineral specimens will quickly illustrate the usefulness of this diagnostic technique. Similarly, a Geiger counter or a scintillation counter in conjunction with some radioactive mineral specimens will illustrate the powerful diagnostic aspects of radioactivity and the need for safety precautions. A hand lens, with about 10x magnification, is very helpful for the detailed observation of the various physical properties. A binocular microscope with a good light is also very helpful. Note that some of the physical properties introduced in this exercise form the basis for determinative tables in various textbooks (e.g., Appendix 1 in *Manual of Mineralogy*, 20th ed., and Chapter 16 in *Mineralogy* by Berry, Mason, and Dietrich).

ASSIGNMENT

1. *Hardness.* Determine the relative hardness of a set of unknown minerals, and arrange them into groups of soft (H = 1 to 3), medium (H = 4 to 6), and hard (H = 7 to 9). Do this by using any of the simple tools available, such as a fingernail, copper penny, pocket knife, glass plate, and streak plate. Subsequently you may wish to arrange the same minerals in an even better-defined hardness sequence by comparing the hardness of each of the unknowns with the values of a specific hardness collection based on the Mohs scale. Generally such kits have nine minerals but lack diamond.

   One small scratch is really all that is needed for making a hardness test. Additional scratching or even gouging of softer specimens is no more diagnostic than the one small scratch; one scratch leaves a much nicer specimen for others to work with. Because hardness is a property of a single mineral grain, it is best to try to scratch a single grain instead of an aggregate of grains. When a fine-grained aggregate of quartz grains, as in a sandstone, is scratched with a pocket knife, the relatively loosely cemented grains may disaggregate, giving an erroneous impression of relatively low hardness.

2. *Specific Gravity.* As an introduction to the evaluation of the relative "heft" of minerals, weigh several (metallic and nonmetallic) mineral specimens by hand, while at the same time estimating the relative sizes of the specimens. This will help you develop a general sense of relative specific gravity.

   A much more accurate method for determining specific gravity is by the Jolly balance. The data obtained by this technique can be used for quite unambiguous identification of unknown materials; refer to Table 23.2. You should have available a few unknown, small, singe-mineral specimens for use on the balance. For measuring with the Jolly balance you also need a glass beaker filled with water and two weighing pans, one in the water, the other above it in air (and dry). Specific instructions for the use of the Jolly balance follow.

   a. With the two pans in the arrangement described, bring all scales to 0. You do this by loosening the locking screws at the left and bottom right and by turning the large knurled screw until you arrive at O.

   b. When all scales are at 0, and one pan is dry, the other in water, align the horizontal marking on the mirror very carefully with a reference point at the bottom of the spring. Now everything is at a reference position.

   c. Insert the unknown in the upper pan, being careful that your pan does not hit the water under the weight; if it gets wet, dry it. Use the large knurled knob to raise the pan until the reference point is again in line with the horizontal marking on the mirror. The number you now read on the left-hand scale is W_{air} $(=W_a)$.

   d. Insert the unknown in the lower pan, in water. Lock both locking screws. Use the large knurled knob to adjust the spring enough so that you again align the

TABLE 23.2 Minerals Arranged According to Increasing Specific Gravity

G	*Name*
1.6	Carnallite
1.7	**Borax**
1.95	**Kernite**
1.96	**Ulexite**
1.99	**Sylvite**
2.0–2.19	
2.0–2.55	**Bauxite**
2.0–2.4	**Chrysocolla**
2.05–2.09	**Sulfur**
2.05–2.15	**Chabazite**
1.9–2.2	**Opal**
2.09–2.14	Niter
2.1–2.2	**Stilbite**
2.16	**Halite**
2.18–2.20	**Heulandite**
2.2–2.39	
2.0–2.4	**Chrysocolla**
2.2–2.65	**Serpentine**
2.23	**Graphite**
2.25	**Natrolite**
2.26	Tridymite
2.27	**Analcime**
2.29	Nitratite
2.30	Cristobalite
2.30	**Sodalite**
2.32	**Gypsum**
2.33	Wavellite
2.3–2.4	**Apophyllite**
2.39	**Brucite**
2.4–2.59	
2.0–2.55	**Bauxite**
2.2–2.65	**Serpentine**
2.42	**Colemanite**
2.42	Petalite
2.4–2.45	**Lazurite**
2.45–2.50	**Leucite**
2.2–2.8	**Garnierite**
2.54–2.57	**Microcline**
2.57	**Othoclase**
2.6–2.79	
2.55–2.65	**Nepheline**
2.6–2.63	**Kaolinite**
2.62	**Albite**
2.60–2.66	Cordierite
2.65	**Oligoclase**
2.65	**Quartz**
2.69	**Andesine**
2.6–2.8	Alunite
2.6–2.8	Turquoise
2.71	**Labradorite**
2.65–2.74	**Scapolite**
2.65–2.8	**Beryl**
2.72	**Calcite**
2.6–3.3	**Chlorite**
2.62–2.76	**Plagioclase**
2.6–2.9	**Collophane**
2.74	**Bytownite**
2.7–2.8	Pectolite
2.7–2.8	**Talc**
2.76	**Anorthite**
2.8–2.99	
2.6–2.9	**Collophane**
2.8–2.9	Pyrophyllite
2.8–2.9	**Wollastonite**
2.85	**Dolomite**
2.86	Phlogopite
2.76–2.88	**Muscovite**
2.8–2.95	**Prehnite**
2.8–3.0	**Datolite**
2.8–3.0	**Lepidolite**
2.89–2.98	**Anhydrite**
2.9–3.0	Boracite
2.95	**Aragonite**
2.95	Erythrite
2.8–3.2	**Biotite**
2.95–3.0	**Cryolite**
2.97–3.00	Phenacite
3.0–3.19	
2.97–3.02	Danburite
2.85–3.2	Anthophyllite
3.0–3.1	**Amblygonite**
3.0–3.1	**Lazulite**
3.0–3.2	**Magnesite**
3.0–3.1	Margarite
3.0–3.25	**Tourmaline**
3.0–3.3	**Tremolite**
3.09	Lawsonite
3.1–3.2	Autunite
3.1–3.2	Chondrodite
3.15–3.20	**Apatite**
3.15–3.20	**Spodumene**
3.16–3.20	**Andalusite**
3.18	**Fluorite**
3.2–3.39	
3.1–3.3	Scorodite
3.2	**Hornblende**
3.23	**Sillimanite**
3.2–3.3	**Diopside**
3.2–3.4	**Augite**
3.25–3.37	Clinozoisite
3.26–3.36	Dumortierite
3.27–3.35	Axinite
3.27–4.37	**Olivine**
3.2–3.5	**Enstatite**
3.4–3.59	
3.27–4.27	Olivine
3.3–3.5	Jadeite
3.35–3.45	**Diaspore**
3.35–3.45	**Epidote**
3.35–3.45	**Vesuvianite**
3.4–3.5	**Hemimorphite**
3.45	Arfvedsonite
3.40–3.55	Acmite
3.4–3.55	**Titanite**
3.48	**Realgar**
3.42–3.56	Triphylite
3.49	**Orpiment**
3.4–3.6	**Topaz**
3.5	**Diamond**
3.45–3.60	**Rhodochrosite**

[a] The names printed in boldface type are those of the most common minerals.
SOURCE: From *Manual of Mineralogy*, 20th ed., pp. 564 and 565.

TABLE 23.2 (continued)

G	*Name*	*G*	*Name*	*G*	*Name*
3.5–4.3	Garnet	4.55	Gahnite	5.8–5.9	Bournonite
		4.52–4.62	**Stibnite**	5.85	**Pyrargyrite**
3.6–3.79					
		4.6–4.79		*6.0–6.49*	
3.27–4.37	Olivine				
3.5–4.2	Allanite	3.7–4.7	**Romanechite**	5.9–6.1	Crocoite
3.5–4.3	**Garnet**	4.6	**Chromite**	5.9–6.1	**Scheelite**
3.6–4.0	**Spinel**	4.58–4.65	**Pyrrhotite**	6.0	**Cuprite**
3.56–3.66	**Kyanite**	4.7	**Ilmenite**	6.07	**Arsenopyrite**
3.58–3.70	**Rhodonite**	4.75	**Pyrolusite**	6.0–6.2	Polybasite
3.65–3.75	**Staurolite**	4.6–4.76	Covellite	6.2–6.4	**Anglesite**
3.7	**Strontianite**	4.62–4.73	**Molybdenite**	5.3–7.3	Columbite
3.65–3.8	**Chrysoberyl**	4.68	**Zircon**	6.33	**Cobaltite**
3.75–3.77	Atacamite				
3.77	**Azurite**	*4.8–4.99*		*6.5–6.99*	
3.8–3.99		4.6–5.0	Pentlandite	6.5	**Skutterudite**
		4.6–5.1	**Tetrahedrite-Tennantite**	6.55	**Cerussite**
3.7–4.7	**Romanechite**			6.78	Bismuthinite
3.6–4.0	**Spinel**	4.89	**Marcasite**	6.5–7.1	Pyromorphite
3.6–4.0	Limonite			6.8	**Wulfenite**
3.83–3.88	**Siderite**	*5.0–5.19*		6.7–7.1	Vanadinite
3.5–4.2	Allanite			6.8–7.1	**Cassiterite**
3.5–4.3	**Garnet**	5.02	**Pyrite**		
3.9	Antlerite	4.8–5.3	**Hematite**	*7.0–7.49*	
3.9–4.03	**Malachite**	5.06–5.08	**Bornite**		
3.95–3.97	**Celestite**	5.15	**Franklinite**	7.0–7.5	**Wolframite**
		5.0–5.3	Monazite	7.3	**Acanthite**
4.0–4.19		5.18	**Magnetite**		
				7.5–7.99	
3.9–4.1	**Sphalerite**	*5.2–5.39*			
4.02	**Corundum**			7.4–7.6	**Galena**
3.9–4.2	**Willemite**	*5.4–5.59*		7.3–7.9	Iron
				7.78	**Nickeline**
4.2–4.39		5.5	Millerite		
		5.5±	**Chlorargyrite**	*>8.0*	
4.1–4.3	**Chalcopyrite**	5.55	**Proustite**		
3.7–4.7	**Romanechite**			8.0–8.2	Sylvanite
4.18–4.25	**Rutile**	*5.6–5.79*		8.10	**Cinnabar**
4.3	**Manganite**			8.9	**Copper**
4.3	**Witherite**	5.5–5.8	**Chalcocite**	9.0–9.7	Uraninite
4.37	**Goethite**	5.68	**Zincite**	9.35	Calaverite
4.35–4.40	**Smithsonite**	5.7	Arsenic	9.8	Bismuth
		5.5–6.0	Jamesonite	10.5	**Silver**
4.4–4.59		5.3–7.3	Columbite	15.0–19.3	**Gold**
				14–19	**Platinum**
4.43–4.45	**Enargite**	*5.8–5.99*			
4.5	**Barite**				

reference mark below the spring with the horizontal marking on the mirror. The right-hand scale now gives you a difference in weight directly, that is, $W_{air} - W_{water}$.

e. Using $G = W_a / W_a - W_w$, calculate the G of your unknown, and using Table 23.2, identify the unknown.

3. *Carbonate fizz test.* With a drop of dilute HCl on each, test several different carbonate minerals and evaluate their different chemical responses. This is a useful diagnostic technique in distinguishing among various species in the carbonate mineral group. So as not to deface the specimen, test a tiny fragment of the mineral on a glass plate or on a watch glass.

4. ***Magnetism.*** Using a small horseshoe magnet, evaluate the difference in magnetism of magnetite and pyrrhotite.

5. ***Fluorescence.*** Irradiate a collection of fluorescent minerals with two different wavelengths of ultraviolet light (shortwave uv and longwave uv) and note the various responses as displayed by differences in color and its intensity.

6. ***Radioactivity.*** Measure the different intensities of radioactivity (short wavelength radiation in the X-ray region) emitted from various radioactive mineral specimens using a Geiger counter or a scintillation counter.