Sulfate

Gypsum $CaSO_4 \bullet 2\ H_2O$

Diagnostic features: low hardness (H = 2, scratched by fingernail), planes of cleavage forming *rhombic plates*.

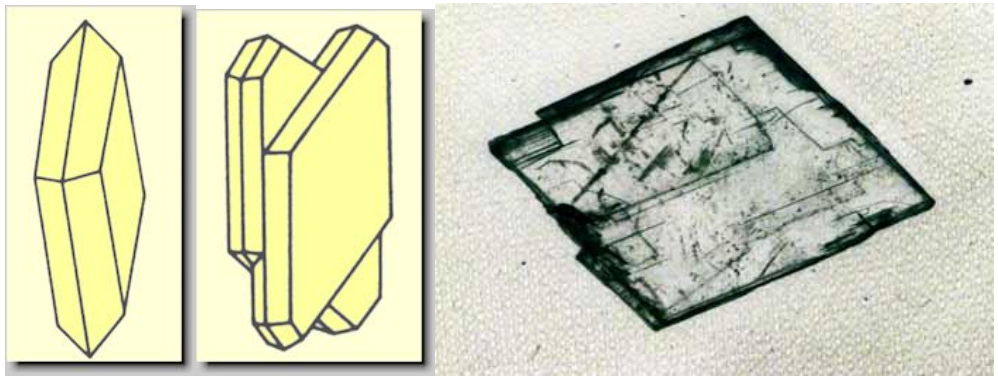
Habit: well-formed crystals are tabular, with a rhombic outline (1st picture). They sometimes grow as 'swallowtail' twins (see 2nd picture below).

Colour: white, colourless or lightly coloured by impurities (pale shades of yellow, red and brown). Vitreous luster.

Selenite is the name given to perfectly transparent gypsum. *Satin spar* is a fibrous variety with silky luster. *Alabaster* is a fine-grained massive variety used as an ornamental stone.

"Plaster of Paris", the material used as wallboard in the building industry, is obtained by heating gypsum until 3/4 of its water has been driven out.

Look-alikes: none.



Sulfate

Barite $BaSO_4$

Diagnostic features: noticeably high specific gravity (G = 6.55) for a non-metallic mineral, good cleavage.

Habit: single crystals are generally tabular, often with a rhombic cross section.

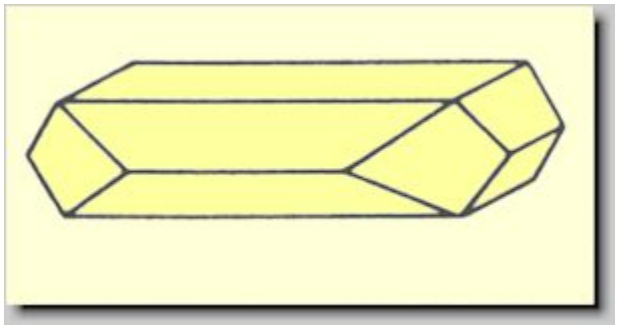
Cleavage: an excellent basal (001) cleavage and a good prismatic (210) cleavage with *rhombic cross section*. The basal cleavage is perpendicular to the rhombic cleavage so fragments break into *plates* with rhombic outlines .

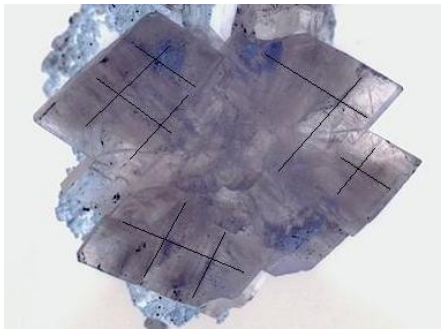
Hardness: 3 - 3.5

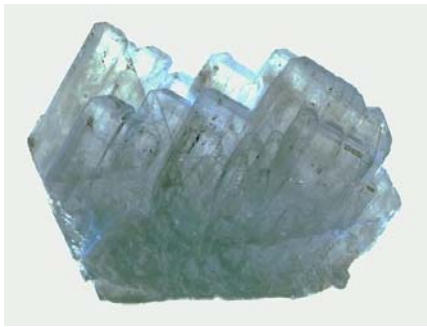
Colour: often white but can be coloured by many impurities.

Look-alikes: difficult to distinguish in hand specimens from witherite and celestine, two other less common sulfates with a similar structure and physical properties.

Barite typically forms in hydrothermal conditions, i.e. it precipitates from hot underground waters, and is often associated with fluorite and calcite (or other rhombohedral carbonates).







Native element

Silver Ag

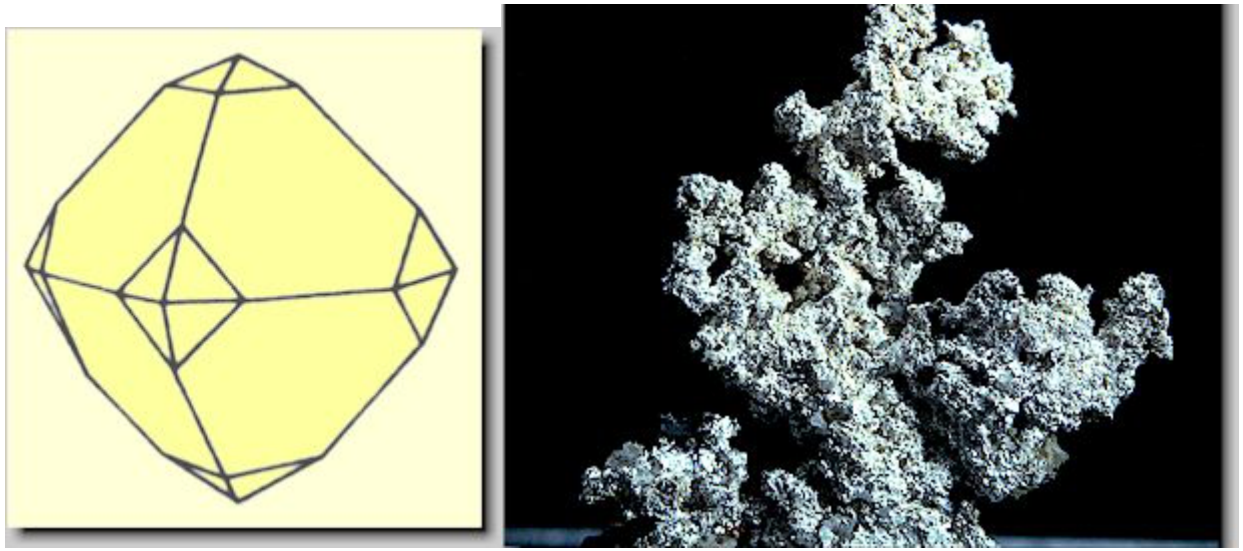
Diagnostic features: silvery, metallic luster *on fresh surfaces* (silver tarnishes quickly to brown or gray-black). High specific gravity (G = 10.5).

Cleavage: none.

Hardness: 2.5 - 3. Malleable, ductile.

Habit: crystals are usually malformed, as irregular masses, plates and scales. Sometimes found as wires or arborescent (dendritic) groups.

Look-alikes: other silver-coloured sulfides or sulfosalts (arsenopyrite, skutterudite) are brittle and have a lower specific gravity.



Native element

Copper Cu

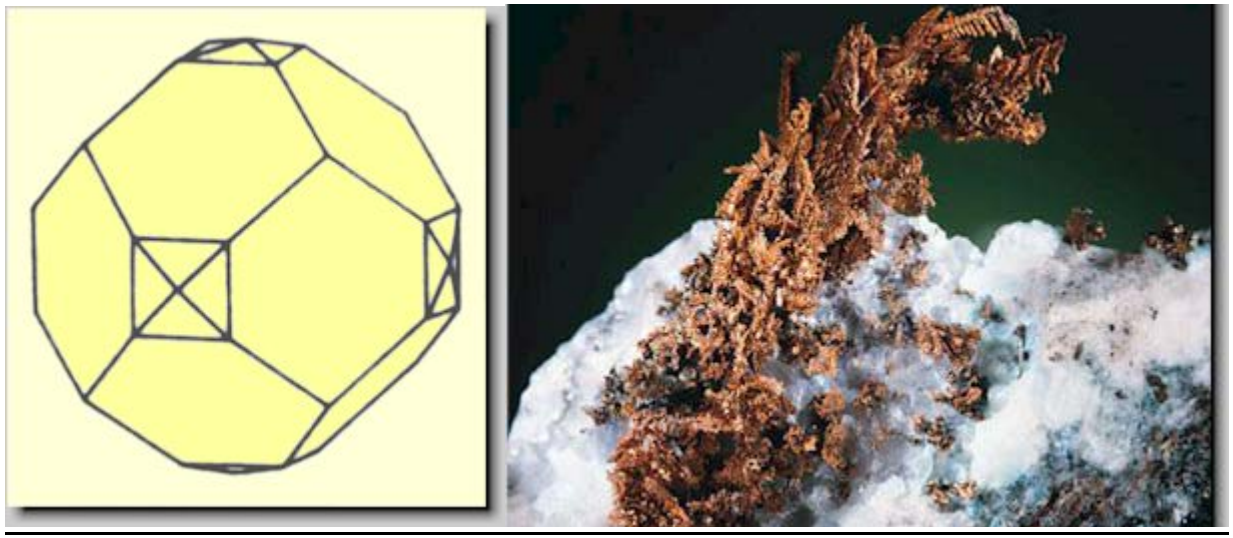
Diagnostic features: distinctive metallic luster and reddish-orange colour *on fresh surfaces*. Tarnishes to dark brown colour.

Cleavage: *none*. Malleable, with a hackly fracture.

Hardness: 2.5 - 3

Habit: crystals are usually malformed, often in branching and arborescent groups.

Look-alikes: nickeline (close in colour but harder).



Native element

Graphite C

Diagnostic features: dark gray, metallic to dull luster, greasy feel, soft enough to soil the fingers, unusually low specific gravity (G = 2.23).

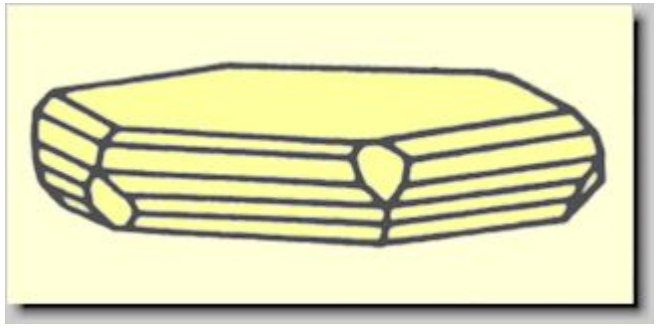
Habit: rarely well crystallized, hexagonal plates and, less commonly, spherulites.

Colour: dark gray (slightly brown in comparison to molybdenite). Streak: dark gray to black.

Hardness (1-2, easily soils the fingers).

Cleavage: perfect {0001} basal cleavage is rarely visible because the crystals are small or easily deformed.

Look-alikes: Molybdenite. Graphite's gray colour is closer to beige while molybdenite’s gray has a bluish tinge. Also, be sure to compare their streak. Molybdenite has a *greenish* black streak.



Sulfide

Molybdenite MoS_2

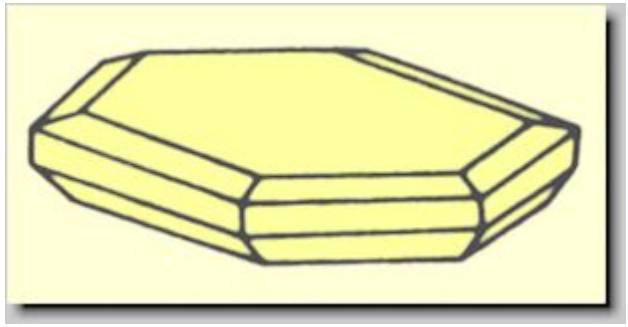
Diagnostic features: metallic luster, lead-gray colour with a *bluish tone*, soft and almost malleable (can be flaked with the fingernail).

Hardness: 1-1.5

Cleavage: {0001} perfect basal cleavage on tabular hexagonal crystals.

Habit: hexagonal plates or short prisms. Often massive, commonly foliated.

Look-alike: its *greenish gray streak*, and the *bluish tone* of its lead-gray colour distinguishes molybdenite from graphite's dark gray streak. Compare them carefully.



Sulfide

Chalcopyrite $CuFeS_2$

Diagnostic features: deep brass-yellow colour, often tarnished in places to other colours (orange, purple, bluish).

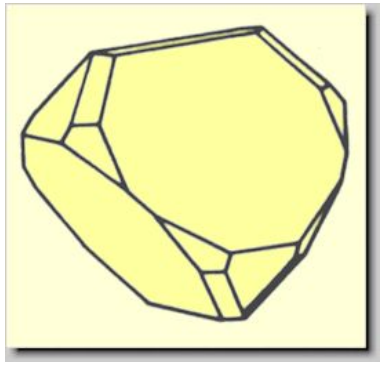
Habit: crystals are rare but when well-formed they are tetrahedra. Striations, if present, form triangles on faces.

Colour: deep brass-yellow colour, with a greenish black streak.

Hardness: 3.5-4 (easily scratched by knife but not by fingernail).

Look-alikes: distinguished from pyrite by its deeper yellow colour, iridescent tarnish and lower hardness. Its tarnish resembles bornite's but their colour on broken fresh surfaces is different. Distinguished from gold by its brittle nature, deeper yellow, and much lower density.

This copper sulfide is common, but is generally not a rich enough ore to be mined. However, hot waters from geothermal systems leach away copper from chalcopyrite, and re-deposit it as cuprite (Cu_2O) or native copper.



Sulfide

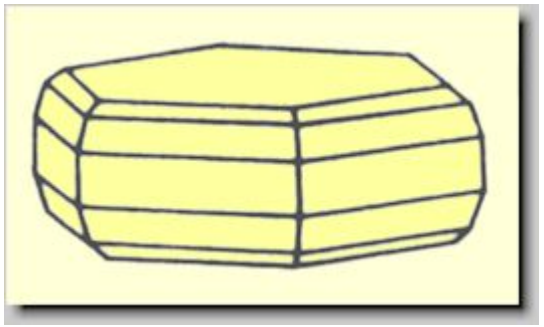
Pyrrhotite $Fe_{1-x}S$

Habit: pyrrhotite rarely forms good crystals, and is more commonly seen in massive aggregates. Under the microscope, however, it may occur as (or contain) exsolution blebs and lamellae consisting of *pentlandite* $(Fe,Ni)_9S_8$, an important ore of Ni.

Colour: brownish bronze, metallic luster, black streak.

Hardness: 4

Look alikes: pyrrhotite is close in colour and tarnish to chalcopyrite, but compare their streaks (pyrite and chalcopyrite have greenish black streaks). Pyrrhotite is also the only *common* ore mineral, with magnetite, to display magnetism. Its magnetism, though not as strong as that of magnetite, often helps to distinguish pyrrhotite from other yellow sulfides.



Sulfide

Galena PbS

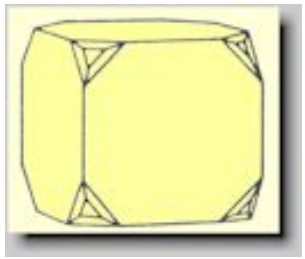
Diagnostic features: high specific gravity, gray colour, metallic luster and cubic cleavage.

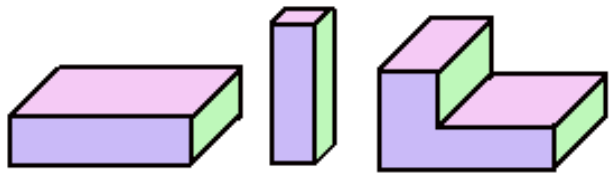
Habit: usually cubic (left, below), but may be modified by octahedra (right, below). The cubic cleavage (center, below) is often visible as broken sharp corners in coarse-grained aggregates.

Colour: the lead gray colour of the mineral matches the colour of its streak.

Hardness: 2.5 (very easy to streak)

Look-alikes: stibnite when massive, but the cubic cleavage of galena is usually diagnostic. Galena is the more common of these two sulfides.





Sulfide

Pyrite FeS_2

Diagnostic features: pale brass yellow colour, relatively high hardness, streak is greenish to brownish black.

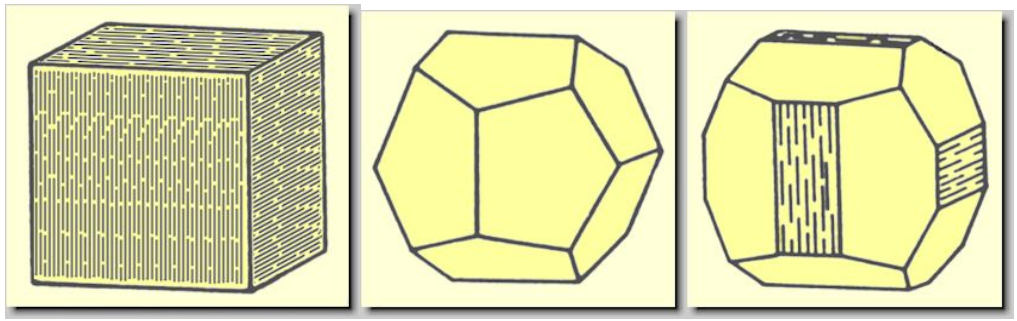
Habit: crystals are often cubic, and usually striated (one direction on each face). Pyrite can also adopt other regular forms like octahedra and dodecahedra, and some crystals combine two or three forms. Poor cleavage.

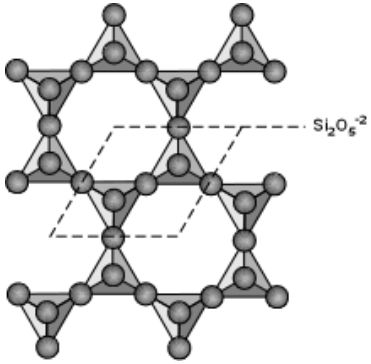
Colour: pale brass yellow (deeper if tarnished) and metallic luster.

Hardness: 6 (unusually high for a sulfide mineral).

Look-alikes: massive chalcopyrite and other yellow sulfides are easily confused with massive pyrite until your eye becomes attuned to their distinctly different colours and hardness.

This is the most common sulfide, found in sedimentary, metamorphic and igneous rocks as well as hydrothermal deposits. It is often found with other sulfides.





Phyllosilicate

Talc $Mg_3Si_4O_{10}(OH)_2$

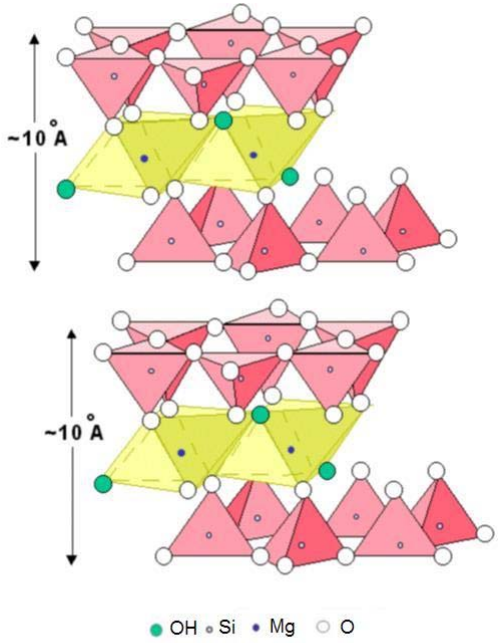
Diagnostic features: low hardness (1: softest on Moh's scale, scratched by fingernail), soapy feel and pearly luster.

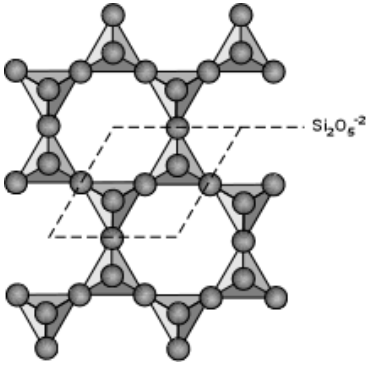
Habit: crystals are rare. Found most commonly in foliated or compact masses. When talc separates in plates, the plates are *not* elastic, i.e. that once it has been bent, the plate does not snap back.

Colour: white, gray or greenish. Its luster is non-metallic and often described as *pearly* or *silky*.

Look-alikes: Serpentine and fine grained muscovite (sericite).

Soapstone, used for carving, is a rock largely made of compact, fine-grained talc.





Phyllosilicate

Muscovite $KAl_2(AlSi_3O_{10})(OH)_2$

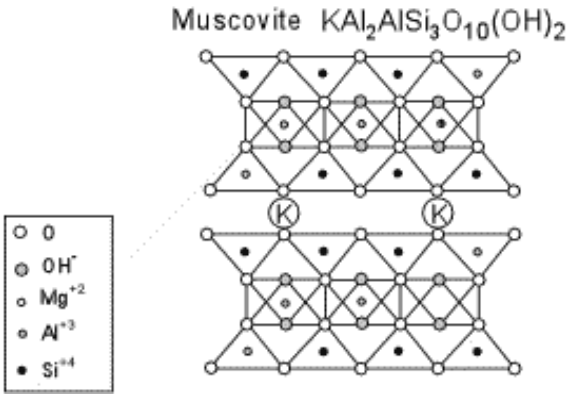
Muscovite is also called *white mica* and *potash mica.*

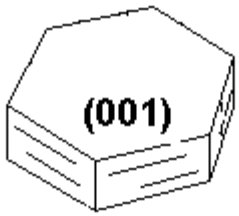
Diagnostic features: micaceous habit; perfect platy cleavage; coloured in thick blocks but colourless and transparent in thin sheets. Low hardness (2-2.5).

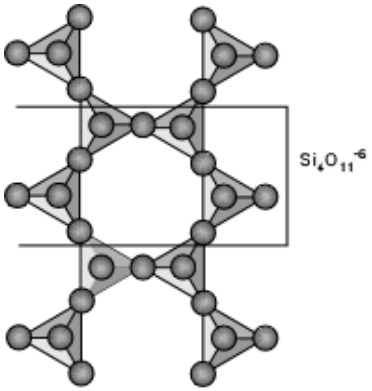
Habit: monoclinic, but euhedral crystals are rare and their cross-section is orthorhombic or hexagonal. Most commonly occurs in scales or sheets without any regular form, simply filling space between surrounding minerals. It sometimes occurs as compact masses of minute scales known as *sericite,* which is an alteration product of potassic feldspar.

Colour: transparent and colourless in thin sheets. Thicker plates are commonly smoky brown but they may also be pink, yellow or green.

Look-alikes: muscovite is far more common than phlogopite, the colorless magnesian mica.







Inosilicate

Amphiboles (double-chain silicates)

Hornblende $NaCa_2(Mg, Fe, Al)_5(Si, Al)_8O_{22}(OH)_2$

Diagnostic features: moderate hardness (5-6: barely scratched by a knife), perfect prismatic cleavage (two planes at angles of 124° and 56°) which gives a "splintery" look to its broken surfaces. Usually found as prismatic crystals, dark green to black.

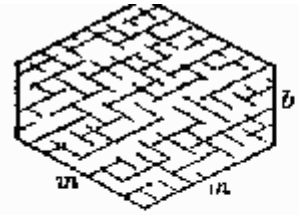
Habit: prismatic crystals with a six-sided, nearly rhombic cross section.

Colour: dark green to black. Vitreous luster.

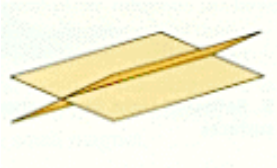
Streak: white (unless the mineral contains small inclusions of opaque oxide minerals).

Look-alikes: augite.

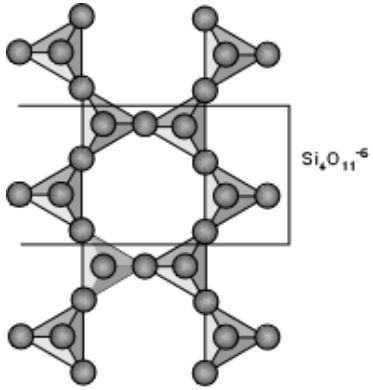
Hornblende is the most common of the amphiboles and occurs in a variety of igneous rocks.



Amphibole cross section showing cleavage



orientation of the 2 cleavage planes



Inosilicate

Amphiboles (double-chain silicates)

Tremolite $Ca_2Mg_5Si_8O_{22}(OH)_2$ - Actinolite $Ca_2Fe_5Si_8O_{22}(OH)_2$

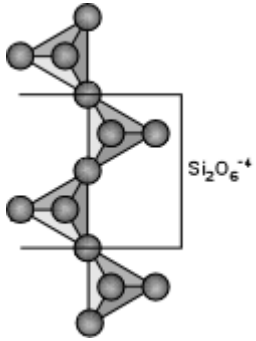
Diagnostic features: moderate hardness (5-6: barely scratched by a knife), perfect prismatic cleavage (with angles of 124° and 56°) gives a "splintery" look to broken surfaces. Found in prismatic crystals, sometimes bladed. Colour varies with iron content.

Colour: Pure tremolite is white but even a small amount of iron may give it a greenish tinge. The green colour of pure actinolite is so dark that the crystals looks black. Luster is generally vitreous but some varieties are fibrous.

Habit: Slender bladed prisms or fibrous radiating bunches.

Cleavage: Obvious parallel to their lengths; the two sets intersect at nearly 120º on basal sections

Look-alikes (Actinolite): Hornblende.
Look-alikes (Tremolite): Anthophyllite, sillimanite and wollastonite.



Inosilicate

Pyroxenes (single-chain silicates)

Augite (Ca,Na)(Fe,Mg,Al)(Al,Si)$_2$O$_6$

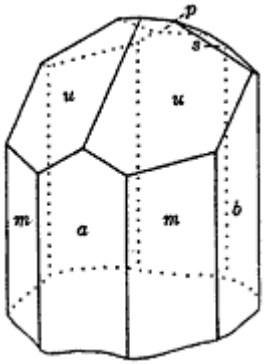
Diagnostic features: stubby prismatic habit with an octogonal cross-section, moderate hardness (5.5, about same as a steel blade) and dark colour (deep green to black). Cleavage is imperfect, at angles of 87° and 93°.

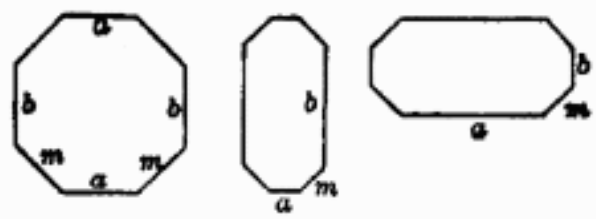
Habit: stubby prismatic crystals very similar to those of diopside. The cross section seen perpendicular to the prism is often eight-sided, because the faces ***m, a and b*** in the prism zone make angles of nearly 45° with each other.

Colour: deep green to black.

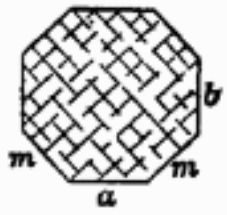
Look-alikes: Hornblende, which has a better prismatic cleavage at angles of nearly 60° and 120°.

Augite is one of the most common of the pyroxenes. It occurs mainly in igneous rocks.

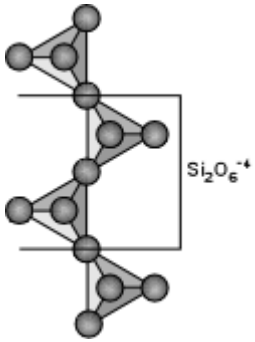




Pyroxene cross sections



Cross section showing cleavage



Inosilicate

Pyroxenes (single-chain silicates)

series: **Diopside** $CaMgSi_2O_6$ - **Hedenbergite** $CaFeSi_2O_6$

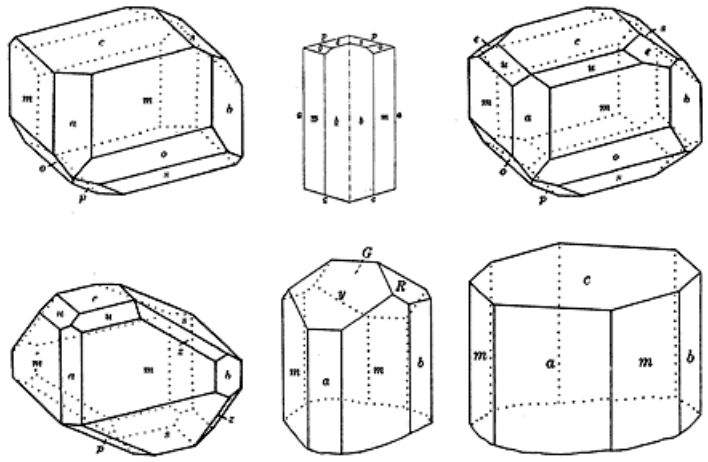
Diagnostic features: prismatic habit, octagonal section, moderate hardness (5.5, about same as knife) and colour (white to green). Imperfect cleavage, at angles of 87° and 93°. A well-developed *parting* parallel to the basal pinacoid **c** is sometimes visible.

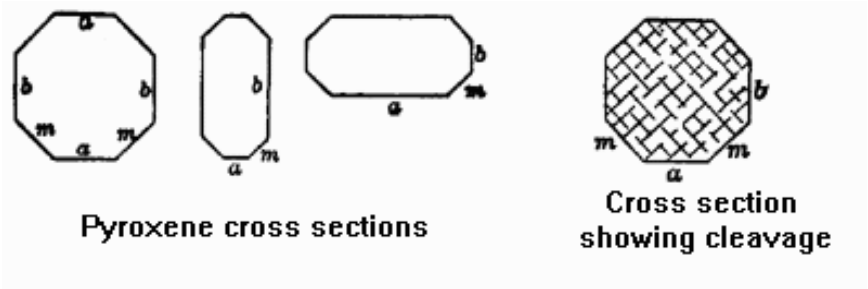
Habit: prismatic crystals are common. The cross section seen perpendicular to the prism is often eight-sided, because the faces **m, a and b** in the prism zone make angles of nearly 45° with each other.

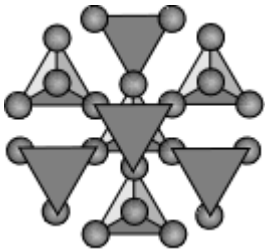
Colour: white to green, varying with the amount of Fe present.

Cleavage: prismatic, parallel to the length of the prisms, at angles of 87° and 93°.

Look-alikes: altered or smaller crystals can be mistaken for olivine (lacks good cleavage) and/or augite (usually darker).







Tectosilicate

Quartz SiO_2

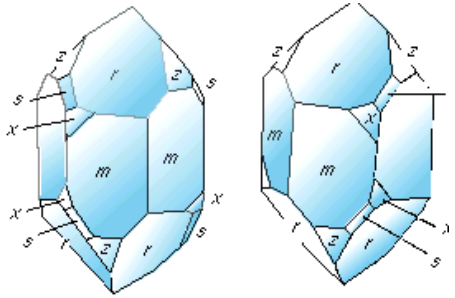
There are several polymorphs of quartz. The most common one is “low-quartz” or “alpha-quartz”.

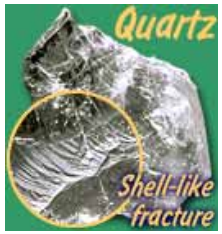
Diagnostic features: hardness (7: not scratched by knife), prismatic habit, conchoidal fracture, vitreous luster.

Habit: in euhedral (i.e. well-formed) crystals, the dominant form is generally a hexagonal prism with faces showing horizontal striations. The pointed pyramidal ends are actually two rhombohedra (labeled “r” and “z” on these drawings). Other minor faces are sometimes present. In anhedral (i.e. without faces) specimens, the lack of cleavage and hardness are characteristic.

Colour: *highly variable*, from transparent and colourless to black, with nearly every colour in between! Quartz is always very pure but minute amounts of certain impurities can give it vivid colours. Some colours can be modified by irradiation or heating because they are due to the presence of defects in the structure.

The names given to varieties of quartz having specific colours include: amethyst (purple), citrine (yellow), smoky quartz (dark brown), milky quartz (white). Quartz always leaves a white streak, regardless of its colour.





Nesosilicate

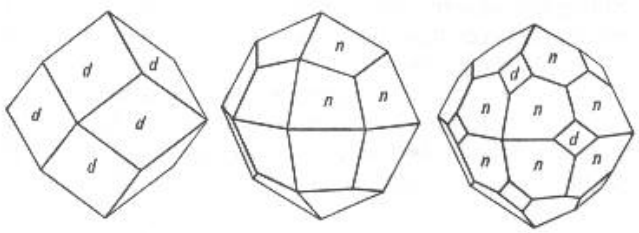
Garnet $A_3B_2Si_3O_{12}$

Diagnostic features: high hardness (6.5-7.5, harder than a knife), equant (isometric) habit, vitreous luster, no distinct cleavage.

Habit: equant, consisting of a dodecahedron, a trapezohedron or a combination of these (shown below).

Colour: highly variable with composition. Many garnets have compositions intermediate between the end-members listed below.

Pyrope, $Mg_3Al_2Si_3O_{12}$ is usually deep red.
Almandine, $Fe_3Al_2Si_3O_{12}$ is red to black.
Spessartine, $Mn_3Al_2Si_3O_{12}$ is brownish red to pink.
Grossular, $Ca_3Mg_2Si_3O_{12}$ is colourless to yellow, green or brown.
Andradite, $Ca_3Fe_2Si_3O_{12}$ is found in shades of yellow, green or brown to black.
Uvarovite $Ca_3Cr_2Si_3O_{12}$ has an emerald-green colour.



Nesosilicate

Olivine $(Mg,Fe)_2SiO_4$

series: **Forsterite** Mg_2SiO_4 - **Fayalite** Fe_2SiO_4

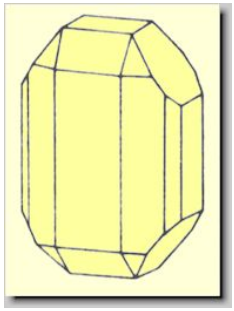
NOTE: The use of parenthesis within a chemical formula indicates elements which may be found in variable proportions within a given mineral structure. In olivine, the silicate tetrahedra are connected by either Mg^{2+} *or* Fe^{2+} *cations.*

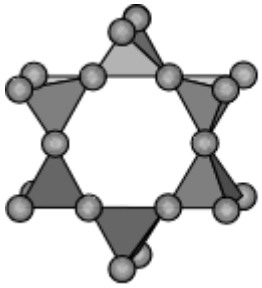
Diagnostic features: hard (6.5-7: harder than knife) but grains are easily detached from the rock; no cleavage but pronounced conchoidal fracture; colour is green but can tend towards yellow or brown. This mineral is found mostly in dark-coloured igneous rocks, like the Hawaiian basalts.

Colour: A perfectly pure forsterite would be colourless. The presence of some Fe^{2+} in most olivine is responsible for its green colour. Fe-poor varieties can be yellow, and Fe-rich varieties can be brown. The yellow-green, gem-quality variety of olivine is known as PERIDOT.

Habit: its stubby prismatic crystals usually look like small grains disseminated through the rock.

Look alikes: epidote, diopside. *Unlike epidote, green olivine is not found with quartz. It lacks the twinning and prismatic cleavage that are commonly seen in diopside.*





Cyclosilicate (ring silicate)

Beryl $Be_3Al_2Si_6O_{18}$

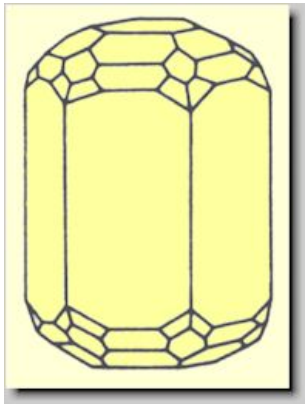
Diagnostic features: high hardness (7.5-8, harder than quartz and knife), hexagonal prismatic habit, and a poor platy cleavage.

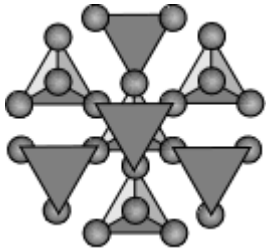
Habit: hexagonal prisms terminated by a pinacoid (less commonly by dipyramidal faces) are common. Striations are parallel to the long axis of the prism.

Colour: usually bluish green or light yellow, but it may be emerald green, pink, white or colourless.

Look-alikes: Tourmaline (usually rounded triangular cross section), apatite (softer than quartz).

Various names are given to gem-quality crystals: AQUAMARINE is the clear blue-green variety, coloured by small amounts of Fe, EMERALD is coloured deep green by chromium or vanadium, MORGANITE is pale pink to deep rose, and GOLDEN BERYL is clear yellow.





Tectosilicate

Potassic Feldspars **Orthoclase/Microcline** $KAlSi_3O_8$

Diagnostic features: moderately high hardness (6: barely harder than knife), two directions of cleavage mutually perpendicular (parallel to faces **b** and **c**), vitreous luster.

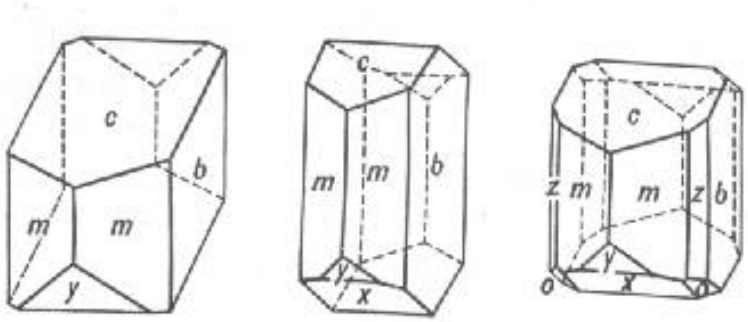
Habit: euhedral crystals have a tabular to prismatic habit.

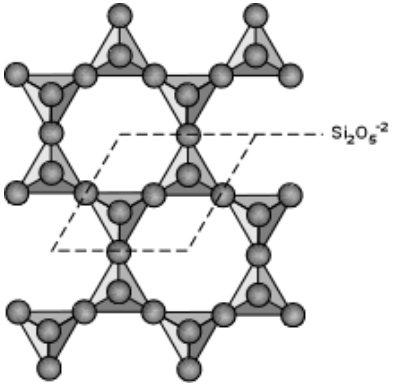
Colour: variable. Often pinkish or light orange but may also be white, pale yellow, reddish, greenish, or gray. The variety AMAZONITE has a blue-green colour related to the presence of small amounts of Pb.

Look-alikes: members of the plagioclase series (including albite).

Most feldspars contain sodium as well as potassium and are part of the "alkali feldspar" series orthoclase $KAlSi_3O_8$-albite $NaAlSi_3O_8$. Once they crystallize from magma, feldspars of intermediate composition undergo a chemical unmixing if they are allowed to cool slowly (in an intrusive rock, for example). The mineral separates into lighter and darker veins, giving rise to a characteristic texture called PERTHITE (shown in bottom right corner).

Microcline is the low-temperature version of orthoclase. The bonding angles within their structures are slightly different (cleavage directions are 89.5° apart in triclinic microcline, but exactly 90° apart in monoclinic orthoclase). Orthoclase and microcline cannot be told apart in hand specimen. Both names (and their synonym, "K-feldspar") will be accepted interchangeably on the test.





Phyllosilicate

Chlorite group

Chlorite $(Mg, Fe)_3(Si, Al)_4O_{10}(OH)_2 \cdot (Mg, Fe)_3(OH)_6$

Diagnostic features: pale green colour appears when scratched, micaceous habit and cleavage, folia are not elastic.

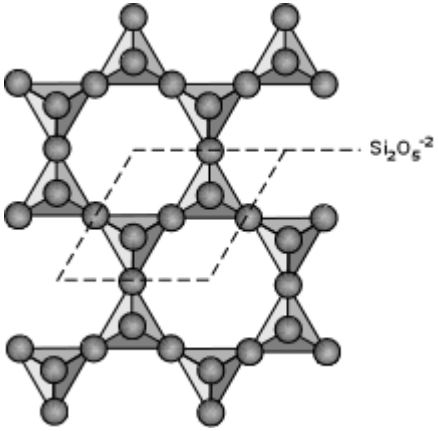
Habit: large crystals are rare. Found most commonly as small scales dispersed in metamorphic rocks, giving them a greenish colour. The perfect {001} cleavage often makes it easy to detach small platelets by scraping the rock with the knife. Chlorite is often found as a pseudomorphs of other ferromagnesian silicate minerals, and the crystals may be submicroscopic. Scratching the specimen will leave a pale green groove.

Colour: various shades of green (pale to nearly black), depending on the relative amounts of Mg and Fe.

Other properties: low hardness (2-2.5: close to fingernail). May be hard to test if small chloride crystals are dispersed among harder minerals in a rock, or if a thin layer of chlorite covers a much harder mineral.

Look-alikes: Actinolite, talc, serpentine.

Like talc and serpentine, this mineral is a common product of the alteration of other ferromagnesian minerals (e.g., olivine, augite, hornblende, actinolite and some garnets among those seen last week). The green colour of many igneous rocks is due to the alteration to chlorite of the original amphiboles (e.g. hornblende) and/or pyroxenes (e.g. augite) in these rocks. The green colour of many schists and slates (metamorphic rocks) is due to disseminated chlorite.



Phyllosilicate

Serpentine group

Chrysotile $Mg_3Si_2O_5(OH)_4$

BE CAREFUL when handling CHRYSOTILE or ANY FIBROUS MINERAL. Any fibrous mineral will release microscopic fibers if it is scratched or shaken. Breathing mineral fibers or dust irritates the lung tissues.

Diagnostic features: fibrous to asbestiform habit, greenish colour.

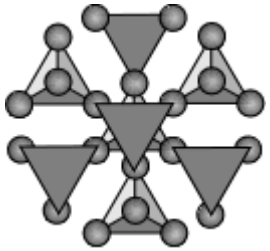
Habit: asbestiform (long, flexible fibers), usually interbedded with other massive minerals of the serpentine group.
(The fibers actually consists of layer-like crystals rolled up like miniature carpets.)

Colour: shades of green, pearly luster.

Hardness: 3-4, but hard to test on asbestiform specimens because the fibers separate so easily.

Look-alikes: other asbestiform minerals.

This is a common alteration mineral of olivine and magnesian pyroxene or amphibole. It is one of the minerals called "asbestos" (a general term for fibrous silicate minerals used in industry for fire- and earthquake-proofing materials), but probably the least harmful of them all because the fibers can dissolve in the lung fluids.



Tectosilicate

sodic end-member of the Plagioclase series

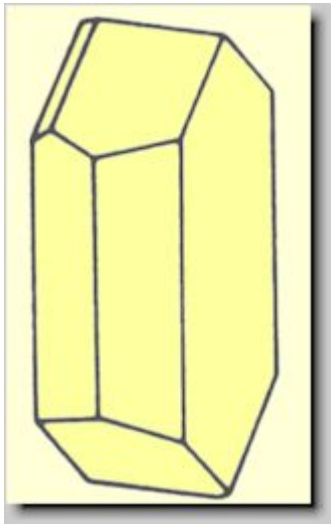
Albite $NaAlSi_3O_8$

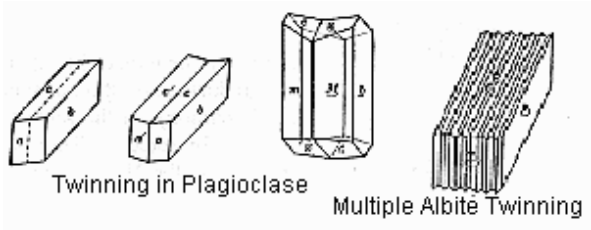
Diagnostic features: moderately high hardness (6: barely harder than knife), two directions of cleavage mutually perpendicular (parallel to faces **b** and **c**), vitreous luster, *striations due to polysynthetic twinning*.

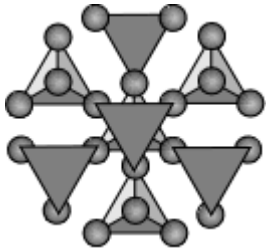
Habit: euhedral crystals have a tabular to prismatic habit. The variety *cleavelandite* displays very thin, platy, white or transparent crystals.

Colour: variable. Albite makes up the lighter-coloured veins of Na-felspar (albite, $NaAlSi_3O_8$) that often separate from the darker-coloured K-feldspar (orthoclase or microcline) during its cooling following igneous crystallization. We already saw that this texture formed by two intergrown feldspar is called PERTHITE.

Look-alikes: Orthoclase, microcline.







Tectosilicate

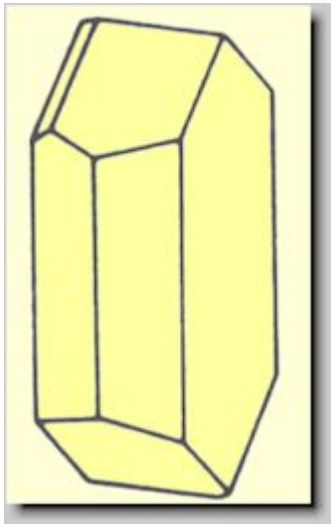
intermediate member of the Plagioclase series

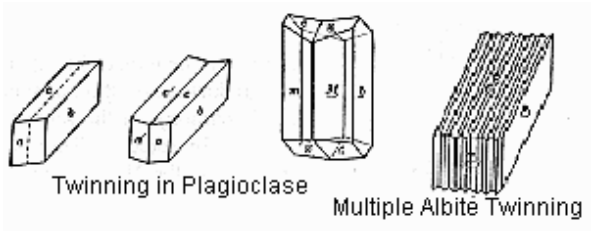
Labradorite $(Na_{\sim.5},Ca_{\sim.5})(Al_{\sim1.5},Si_{\sim2.5})O_8$

Diagnostic features: moderately high hardness (6: barely harder than knife), two directions of cleavage mutually perpendicular (parallel to faces **b** and **c**), vitreous luster, *striations due to polysynthetic twinning*, dark colour and iridescence visible on {010} (i.e. the faces **b**).

Habit: euhedral crystals have a tabular to prismatic habit similar to that of albite.

Colour: dark, due to minuscule inclusions of the mineral magnetite. The iridescence is due to the scattering of light by minuscule lamellae that form during cooling of this feldspar after crystallization. The cause is an unmixing process (exsolution) of the same type as the one forming *perthite* in microcline. Here, the unmixing gives rise to lamellae of Ca-rich feldspar (anorthite) in a Na-rich feldspar (albite), or vice-versa.





Sulfide

Sphalerite ZnS

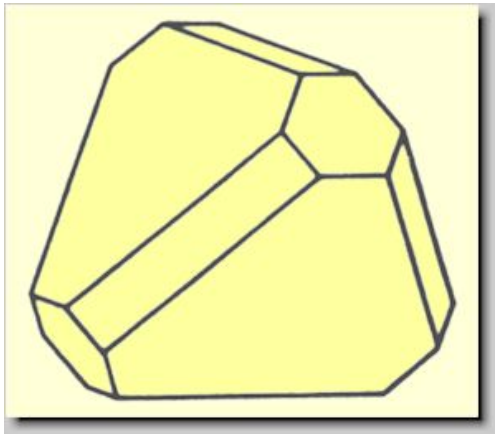
Diagnostic features: moderate hardness (H = 3.5-4), many planes of cleavage, resinous luster.

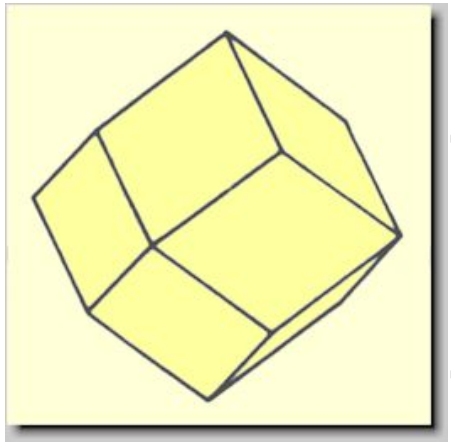
Habit: well-formed tetrahedral crystals (left, below) are rare. They cleave into dodecahedra (6 cleavage planes, below right). Even in aggregates, the many cleavage planes give a "sparkling" appearance to the specimen.

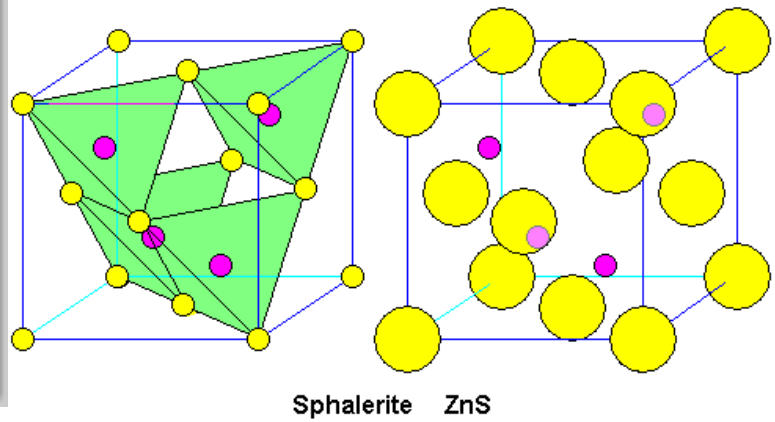
Colour: colourless when pure but generally yellow to brownish, sometimes black. The streak is colourless in pure sphalerite and its colour is yellow to brown with increasing Fe content.

Look-alikes: none, really. Hematite can be as sparkly but its streak is darker and slightly reddish.

Sphalerite is the most common zinc mineral and it forms in hydrothermal vein systems, often with galena and other sulphides. The structure of sphalerite is a derivative of diamond's but its overall symmetry is lower because two different ions are in tetrahedral coordination.







Native element

Sulfur S

Diagnostic features: yellow colour, characteristic smell.

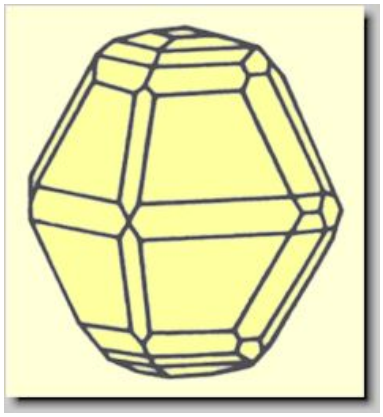
Habit: usually found as incrustations or irregular masses that are imperfectly crystallized. When well formed the crystals are orthorhombic and dipyramidal.

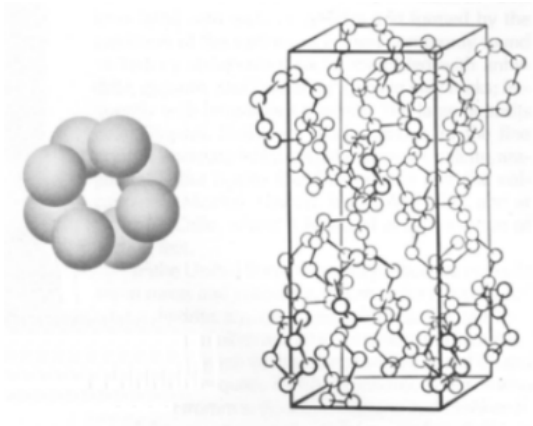
Colour: yellow (but colour can tend towards orange or greenish when impurities substitute for S).

Hardness: 1.5-2.5

Look-alikes: none.

Note : Most of the specimens in your drawers are *not* examples of natural sulfur. They are chunks of the massive microcrystalline sulfur that is extracted from most oil or natural gas before they are sold as fossil fuels. If left in oil or gas, this sulfur would react with oxygen to form a serious atmospheric pollutant.





Carbonate (rhombohedral, calcite structure)

Dolomite $CaMg(CO_3)_2$

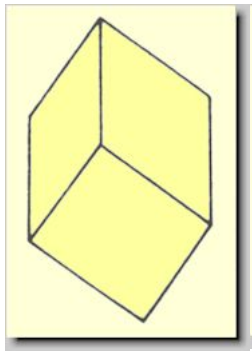
Diagnostic features: rhombohedral cleavage, little reaction with HCl at room temperature (more soluble if the mineral is powdered), often slightly rusty on weathered surface.

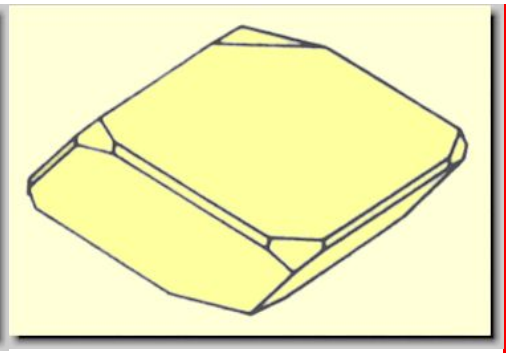
Habit: unit rhombohedra are common, sometimes with curved faces ("saddle" dolomite, shown to the right, below). Perfect rhombohedral cleavage like calcite and other rhombohedral carbonates. Polysynthetic twinning is common, giving rise to striations along the long diagonal of the rhombic faces.

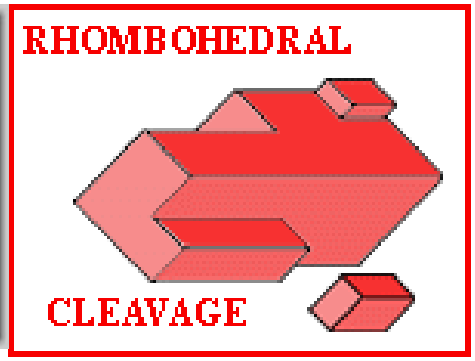
Colour: white or in shades of flesh or pink.

Hardness: 3.5-4.

Look-alikes: Siderite. *Ankerite*, $CaFe(CO_3)_2$, is the name given to Fe-rich varieties of dolomite that are intermediate in properties and compositioin between dolomite and siderite. *Ankerit* is typically yellowish to yellowish-brown, with a weak reaction to HCl similar to that of dolomite.







carbonate (rhombohedral)

Calcite $CaCO_3$

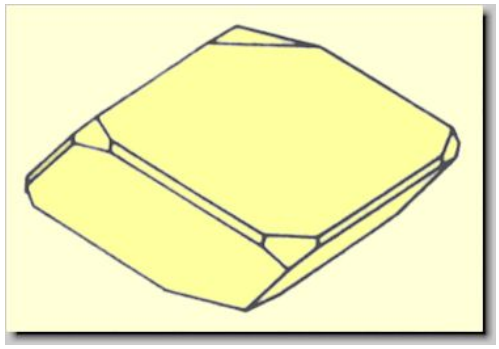
Diagnostic features: noticeable reaction (effervescence) with HCl at room temperature, rhombohedral cleavage, moderate hardness (H = 3-3.5).

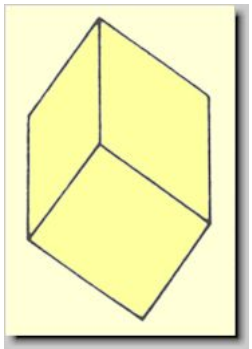
Habit: highly variable but a three-fold or six-fold symmetry is often clearly visible. Crystals can be nearly acicular or flattened plates. Most are combinations of rhombohedra and prism(s) or scalenohedra..

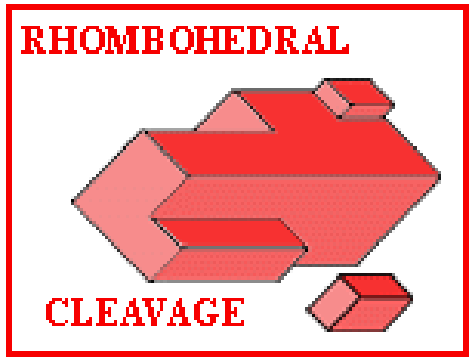
Colour: colourless when pure, but highly variable because of the presence of fluid inclusions, organic matter, inclusions of other minerals or substitution of Ca^{2+} ions by various impurities.

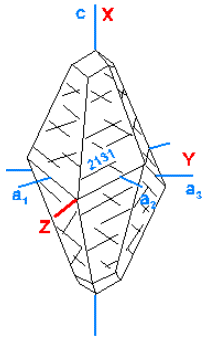
Cleavage fragments of limpid, colourless calcite crystals displays pronounced double refraction. There is no double refraction if one looks through the crystal down its *c* axis.

Calcite and aragonite are *polymorphs* of calcium carbonate.









Phosphate

Apatite $Ca_5(PO_4)_3(F, Cl, OH)$

Diagnostic features: hexagonal prismatic habit, moderate hardness (H = 5). Habit is similar to beryl but it is soft enough to be easily scratched by a knife.

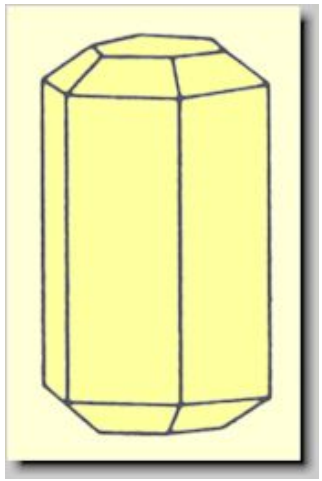
Habit: well-formed hexagonal prisms are common. Poor cleavage. Fractures perpendicular to length are common.The crystal faces are often corroded by dissolution following crystallization.

Colour: variable. Reddish-brown and green are common, sometimes in the same crystal.

Hardness: 5 (scratched by knife but not by fingernail).

Look-alikes: other hexagonal prismatic minerals such as beryl, tourmaline or corundum are much harder.

This fairly common mineral is found as accessory in igneous rocks, metamorphic rocks and hydrothermal deposits. It also makes up most of your bones and teeth. The fluorine-rich apatite (*fluorapatite*) is noticeably harder and more resistant to dissolution by acid than the other two. This is why the fluoridation of water and toothpaste is generally considered to contribute to dental health.



Halide

Halite NaCl

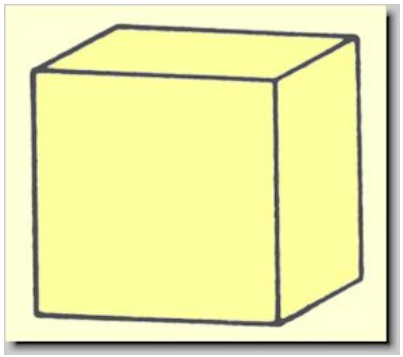
Diagnostic features: low hardness (H = 2.5, scratched by a tough fingernail), perfect cubic cleavage, salty taste.

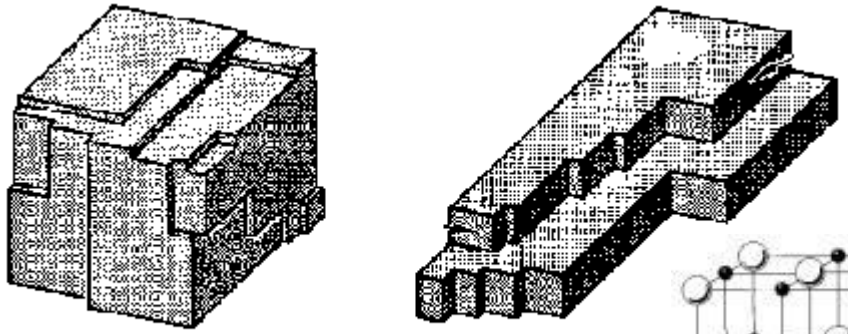
Habit: crystals are usually cubic. “Hopper-shaped” skeletal crystals grow from rapidly evaporating solutions.

Colour: colourless when pure. Often white because of inclusions (small bubbles filled with fluid that were trapped during crystal growth) or coloured by impurities or inclusions of other minerals.

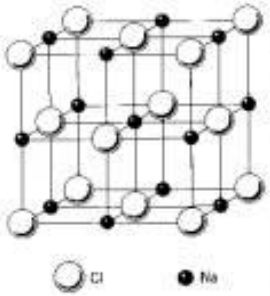
Look-alikes: Sylvite tastes more bitter.

The structure of halite, NaCl, and sylvite, KCl, are identical. Both minerals are less dense (G = 2-2.1) than most non-metallic minerals. They are part of a sequence of minerals commonly formed by evaporation of seawater: aragonite or calcite → gypsum → halite → sylvite.





cubic cleavage



structure

"hopper" cube

Oxide

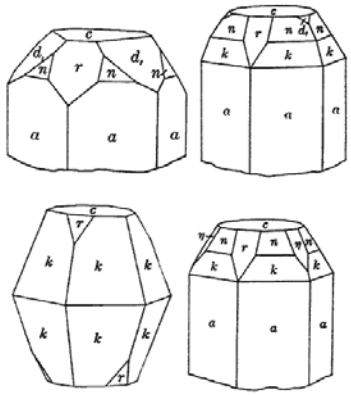
Corundum Al_2O_3

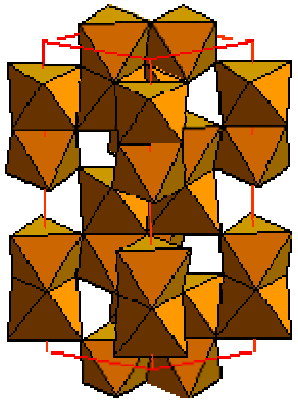
Diagnostic features: vitreous luster, often with rhombohedral parting. The parting and/or growth features often produce triangular patterns on the basal parallelohedron {0001}. Its high hardness (H = 9) is somewhat misleading because the surface of corundum easily alters to a much softer mica, and can only be observed on a freshly broken surface.

Habit: crystals are six-sided, in prismatic columns or tabular.

Colour: colourless when pure, but quite variable when impurities are present. *Sapphire* is coloured blue by electron transfers between trace amounts of Fe^{2+} and Ti^{4+}. *Ruby* is coloured red by trace amounts of Cr^{3+}.

This mineral has exactly the same structure as hematite but the strength of the Al-O bond gives it a much higher hardness. The six-sidedness of the crystals reflects the hexagonal close-packing of the oxygen ions.





Halide

Fluorite CaF_2

Diagnostic features: octahedral cleavage, moderate hardness (H = 4, easily scratched by the knife), cubic habit.

Habit: usually cubes, sometimes modified by octahedra. Often found in aggregates of interpenetrating crystals.

Colour: very variable, the mineral is coloured by a wide range of impurities substituting for the Ca^{2+} ions.

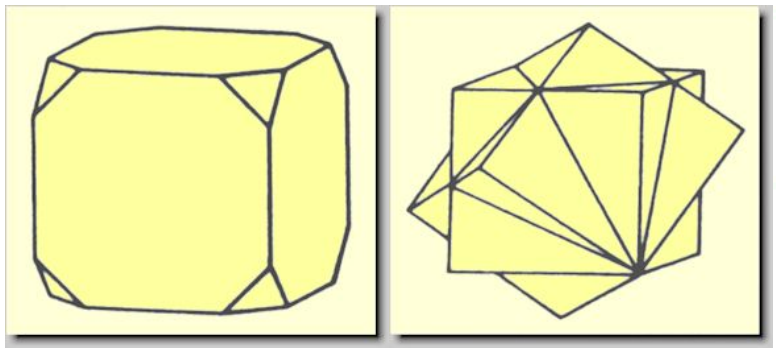
Cleavage: perfect, octahedral {111}.

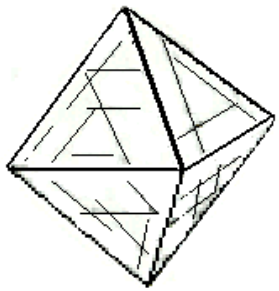
Look-alikes: None when its habit and cleavage are distinct.

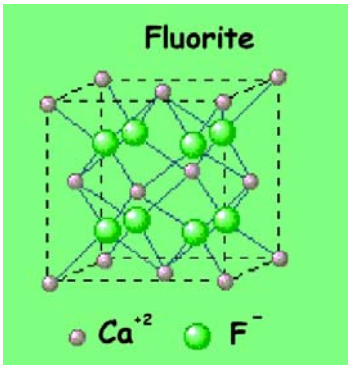
Most well crystallized fluorite is of hydrothermal origin but it also occurs widely as a disseminated phase in metamorphic and igneous rocks.

The phenomenon of *fluorescence* received its name because it was observed early in some varieties of fluorite. Not all fluorite, however, is fluorescent. The property depends on the presence of trace amounts of rare-earth elements substituting for the Ca^{2+} ions in its structure.

Avoid pouring dilute HCl on fluorite samples. Dissolving even small amounts of fluorite in an acidic solution can be quite corrosive to the skin.







Carbonate (rhombohedral, calcite structure)

Siderite $FeCO_3$

Diagnostic features: rhombohedral cleavage, brown colour, vitreous luster, moderate hardness (H = 3.5-4). Should barely react to HCl at room temperature.

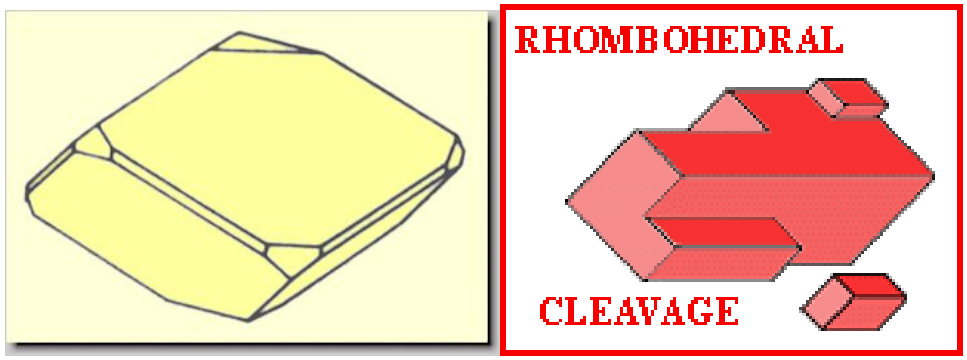
Habit: crystals are usually simple unit rhombohedra, often with curved faces. Also occurs in compact, granular masses. Perfect rhombohedral cleavage.

Colour: light to dark brown. Vitreous luster.

Hardness: 3.5-4.

Look-alikes: Dolomite, ankerite.

Siderite is associated with some coal beds and metallic ore deposits of hydrothermal origin. It has been mined as an ore of iron in Europe.



Oxide

Magnetite Fe_3O_4 (= $Fe^{2+}Fe^{3+}{}_2O_4$)

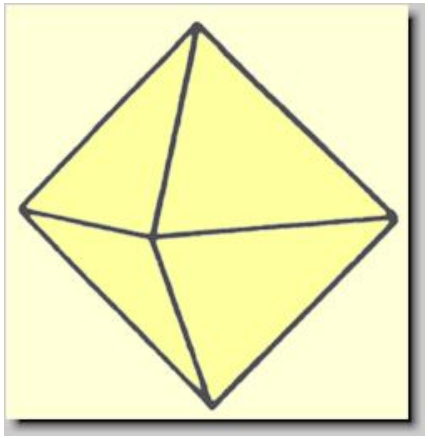
Diagnostic features: strong magnetism, black colour and black streak.

Habit: crystals are rare but are usually octahedral when visible. Magnetite usually occurs in massive aggregates.

Colour: black, with a bright metallic luster on fresh surfaces.

Hardness: 6.

Less abundant than hematite but richer in Fe (and easier to separate economically from the ***gangue minerals*** surrounding it, because of its magnetism), magnetite is an important ore mineral when it occurs in massive aggregates. It is also rather common as small scattered crystals in many magmatic, metamorphic rocks and sedimentary rocks. This is the mineral that usually preserves the "remanent magnetism" (fossil magnetic field) of rocks used to infer the past movements of continents throughout their geological history.



Oxide

Hematite Fe_2O_3

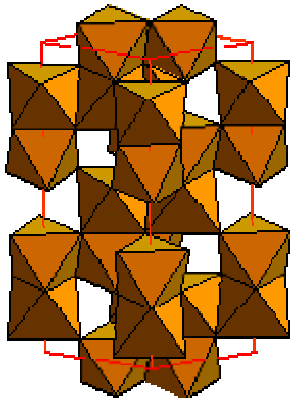
Diagnostic features: dark reddish streak. The streak is darker in pure specimens (but magnetite may also be present). The streak is much lighter (reddish brown) when the mineral is dispersed among white-streak minerals.

Habit: crystals are rare but they have a three-sided symmetry (middle photograph, below) which reflects the hexagonal close packing of the oxygen ions. Also seen in reniform aggregates (below, right). Hematite often coats other iron-bearing minerals as a weathering product.

Colour: varies from *metallic black* in larger crystals, to *ocher* (brownish red) in fine-grained aggregates. Luster also varies wildly, from metallic on large crystals to dull on fine-grained aggregates.

Hardness: 5.5 - 6.5, but hard to evaluate if small crystals are dispersed in the rock.

This mineral has exactly the same structure as corundum, but consists of Fe^{3+} O_6 octahedra. It is an important iron ore (but not the richest one). Small quantities of magnetite are often associated with hematite, giving some hematite-rich specimens a slight magnetism. Check both streak and magnetism to recognize hematite-magnetite mixtures!



Oxide

Ilmenite $FeTiO_3$

Diagnostic features: distinguished from hematite by a darker streak, black to brownish-red, and from magnetite by its lack of *strong* magnetism.

Habit: similar to hematite but rhombohedral crystals are rare and their truncation by basal planes makes them look tabular. Often in thin plates, or massive and compact. Some black sands are rich in grains of ilmenite.

Colour: iron-black. Streak: black to brownish-red.

Look-alikes: hematite, magnetite, chromite (compare their streaks).

Ilmenite may be weakly magnetic. It is a common accessory mineral in igneous rocks and vein deposits.
Its structure is identical to that of corundum and hematite, with alternating layers of FeO_6 and TiO_6 octahedra sharing edges and faces.