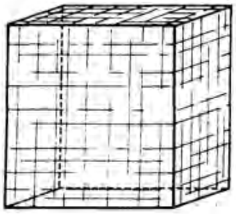
HALIDES

Halite NaCl ISOMETRIC



Halite

$n = 1.544$*

Colorless or very pale tints in thin section

COMPOSITION AND STRUCTURE. The structure of halite (Fig. 1-5) was the first to be determined by x-ray methods (Bragg, 1914). It is a very simple structure of alternating Na^+ and Cl^- ions in three mutually perpendicular directions; each ion is coordinated by six (octahedral coordination) ions of opposite charge.

Halite is nearly pure NaCl; massive rock salt, however, commonly contains admixed inclusions of clay, iron oxides, gypsum, sylvite, and other evaporite minerals. Brine inclusions are common. Minor Br^- or I^- may replace Cl^-. Very little K^+ replaces Na^+; however, halite NaCl and sylvite KCl commonly crystallize together and may form submicroscopic mixtures with intermediate properties.

PHYSICAL PROPERTIES. $H = 2\text{–}2\frac{1}{2}$. Sp. Gr. = 2.165. In hand sample, halite is usually white or colorless. It is often gray, yellow, brown, or reddish, due to admixed clays or iron oxides. Blue or violet coloration is commonly due to lattice disturbances by radiation and disappears with heating; it may also be due to free colloidal sodium. Luster is vitreous. Halite is water soluble, with a saline taste.

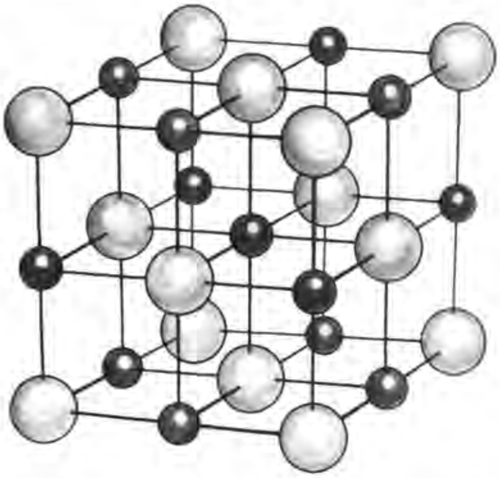


FIGURE 1-5. The structure of halite. Halite is an *AX*-type ionic compound having a medium-size cation appropriate to sixfold (octahedral) coordination. The structure is essentially a cubic close-packed configuration of Cl^- ions on {111}, with Na^+ ions filling all octahedral sites between close-packed layers. Light nontransition elements and weak ionic bonding favor a colorless mineral with a small index of refraction.

COLOR AND PLEOCHROISM. Halite is usually colorless in standard section or as fragments. Deep-colored crystals may show pale color usually in zones or color centers. Crystals under pressure may show weak pleochroism.

FORM. Halite crystals are cubic, rarely octahedral, and may show hopperlike forms. Halite is often coarse to fine granular as anhedral grains and is sometimes stalactitic.

CLEAVAGE. Perfect cubic cleavages {100} (three mutually perpendicular directions) form square to rectangular fragments.

TWINNING. Synthetic crystals are known to twin on {111} but twinning is not apparent in section or fragments.

---

* Halite may form submicroscopic mixtures with sylvite (KCl) and the refractive index of the mixture may range from that of halite ($n = 1.544$) to that of sylvite ($n = 1.490$).

BIREFRINGENCE. Maximum birefringence is very extreme (0.285–0.296), and even basal sections show high-order interference colors in the slightly convergent light of orthoscopic illumination. Interference colors appear essentially independent of thickness or crystal orientation and form a very high-order uniform white, usually masked by inherent mineral color.

TWINNING. Twinning is most common on {011}, yielding highly varied forms that may be simple contact (knee-shaped twins), cyclic (sixlings or eightlings), or, rarely, polysynthetic. Glide twinning is also known on {092}, and simple contact twins form, rarely, on {031}.

ZONING. Color zoning due to composition change may be anticipated, but birefringence is uniformly extreme. Rutile itself may be zonally included in ilmenite, biotite, and quartz and is also the cause of the misty "blue quartz" of granulities.

INTERFERENCE FIGURE. Interference figures commonly show a uniaxial cross on a field of many isochromes, and the entire field is often deep to pale red-brown, due to inherent mineral coloration.

OPTICAL ORIENTATION. Elongated crystals show parallel extinction and positive elongation (length-slow), which may be difficult to detect due to extreme birefringence.

DISTINGUISHING FEATURES. Red-brown color, extreme relief, and extreme birefringence are diagnostic. Cassiterite and baddeleyite (ZrO_2) have much lower birefringence. Anatase and hematite are optically negative, brookite is biaxial, and limonite is isotropic.

ALTERATION. Rutile is a very stable mineral and is itself a common alteration product of other Ti-bearing minerals. Rutile rarely alters to sphene, leucoxene, or anatase.

OCCURRENCE. Rutile is more common than the other TiO_2 polymorphs, anatase and brookite; it is the dense, high-temperature, high-pressure polymorph that occurs in both igneous and metamorphic plutonic rocks.

In igneous rocks, rutile appears as small accessory crystals or grains. It is common in hornblende-rich rocks, anorthosite, eclogite, pegmatites (granite and basic), and in quartz veins.

Rutile appears in many metamorphic rocks especially schist, gneiss, amphibolite, and marble.

Sedimentary rocks may contain rutile as tiny needles in recrystallized shales or as common detrital grains. Rutile is also a common alteration product of Ti-rich minerals (for example, ilmenite, sphene, and perovskite).

Leucoxene is largely fine-grained rutile.

REFERENCES: RUTILE

Abrahams, S. C., and J. L. Bernstein. 1971. Rutile. Normal probability plot analysis and accurate measurement of crystal structure. *Jour. Chem. Phys.*, *55*, 3206–3211.

Cardona, M., and G. Harbeke. 1965. Optical properties and band structure of wurtzite-type crystals and rutile. *Phys. Rev.*, *137*, 1467–1476.

Cromer, D. T., and K. Harrington. 1955. The structures of anatase and rutile. *Jour. Amer. Chem. Soc.*, *77*, 4708–4709.

Czanderna, A. W., C. N. Ramachandra Rao, and J. M. Honig. 1958. The anatase-rutile transition. I. Kinetics of the transformation of pure anatase. *Trans. Faraday Soc.*, *54*, 1069–1073.

Davis, T. A. 1968. Pressure dependence of the refractive indices of tetragonal crystals: Ammonium dihydrogen phosphate, potassium dihydrogen phosphate, calcium molybdate (VI), calcium tungstate (VI), and rutile. *Jour. Opt. Soc. Amer.*, *58*, 1446–1451.

MacChesney, J., and A. Muan. 1959. Studies in the system iron oxide-titanium oxide. *Amer. Mineral.*, *44*, 926–945.

Nodop, G. 1956. Anatase, rutile and cassiterite. *Hamburger Beitr. Angew. Mineral. u. Kristallphys.*, *1*, 239–284.

replace two Al^{3+} or Fe^{3+} to form ilmenite, and symmetry drops to $\bar{3}$ from $\bar{3}\ 2/m$. A magnesium isomorph, geikielite, $MgTiO_3$, and a manganese isomorph, pyrophanite, $MnTiO_3$, are known. Ilmenite, $FeTiO_3$, commonly contains significant MgO and or MnO and probably forms complete solid solution with both magnesium and manganese end members. Ilmenite usually contains a few weight percent Fe_2O_3 in partial solid solution above 1050 C. At lower temperatures, exsolution occurs, and ilmenite commonly shows lattice-type intergrowth, with hematite on the basal planes $\{0001\}$ and with magnetite on the $\{111\}$ magnetite planes

PHYSICAL PROPERTIES. H = 5–6. Sp. Gr. = 4.70–4.79 (ilmenite = 4.79, geikielite = 4.05, and pyrophanite = 4.54). Color in hand sample is iron-black. Streak is black or reddish, if rich in Mg-Mn.

COLOR AND PLEOCHROISM. In standard thin section, ilmenite is totally opaque. Very thin fragments may show deep red on thin edges. Geikielite, $MgTiO_3$, and pyrophanite, $MnTiO_3$, are somewhat more transparent and show reddish-violet and red-orange respectively on thin edges. Ilmenite shows whitish-gray in reflected light.

FORM. Ilmenite commonly occurs as thick tabular crystals, as anhedral masses imbedded in igneous or metamorphic rocks, or as opaque sand grains. In thin section, ilmenite grains are anhedral or lamellar plates with long rectangular outline. Ilmenite also commonly shows skeletal forms in thin section.

CLEAVAGE. None; however, ilmenite may show distinct parting on either $\{0001\}$ or $\{10\bar{1}1\}$ due to twinning. Geikielite shows good rhombohedral cleavage $\{10\bar{1}1\}$ and pyrophanite shows cleavage perfect on $\{02\bar{2}1\}$ and good on $\{10\bar{1}2\}$.

BIREFRINGENCE. Only very thin edges transmit any light. Only red light is transmitted with very large birefringence.

TWINNING. Ilmenite may show simple twinning on or repeated lamellar twinning on $\{10\bar{1}1\}$.

DISTINGUISHING FEATURES. Ilmenite is an opaque mineral that is white to gray in reflected light. Reflected light may also reveal partial alteration to a whitish aggregate called *leucoxene*, which is distinctive. Ilmenite is most likely to be confused with magnetite, which is strongly magnetic and isometric, commonly showing squares, triangles, diamonds, and other octahedron sections, in contrast to the long rectangular or skeletal sections of ilmenite. Graphite is an opaque mineral that is soft and of limited occurrence.

ALTERATION. The alteration product of ilmenite is called *leucoxene* and is a fine-grained aggregate of one or more titanium oxides. Rutile is most common, but leucoxene may contain only anatase or brookite or may represent a mixture with rutile. In thin section, leucoxene appears opaque, or nearly so, but in reflected light, it is white to grayish, yellowish, or red-brown, due to the presence of various ferric oxides.

OCCURRENCE. Although some anorthosite rocks may contain very large amounts of ilmenite, it is most common as an opaque accessory in a wide range of igneous and metamorphic rocks, especially gabbroic varieties, where it is associated more with pyroxenes than olivines.

Ilmenite is quite common in ore veins, where it appears most commonly with chalcopyrite and pyrrhotite. It is also a constituent of some pegmatites. Sandy sediments often contain weather-resistant ilmenite grains, and some black beach sands are largely ilmenite. Ilmenite is often intimately associated with hematite or magnetite as lattice-type intergrowths.

REFERENCES: ILMENITE

Gruner, J. W. 1959. The decomposition of ilmenite. *Econ. Geol.*, *54*, 1315.

Karkhanavala, M. D., and A. C. Momin. 1959. The alteration of ilmenite. *Econ. Geol.*, *54*, 1095.

Shvetsova, I. V. 1970. Mixed rutite-anatase leucoxene. *Dokl. Acad. Sci. USSR, Earth Sci. Sect.*, *194*, 130–133.

Wallace, R. M. 1953. A proposed petrographic method for the rapid determination of ilmenite. *Amer. Mineral.*, *38*, 729–730.

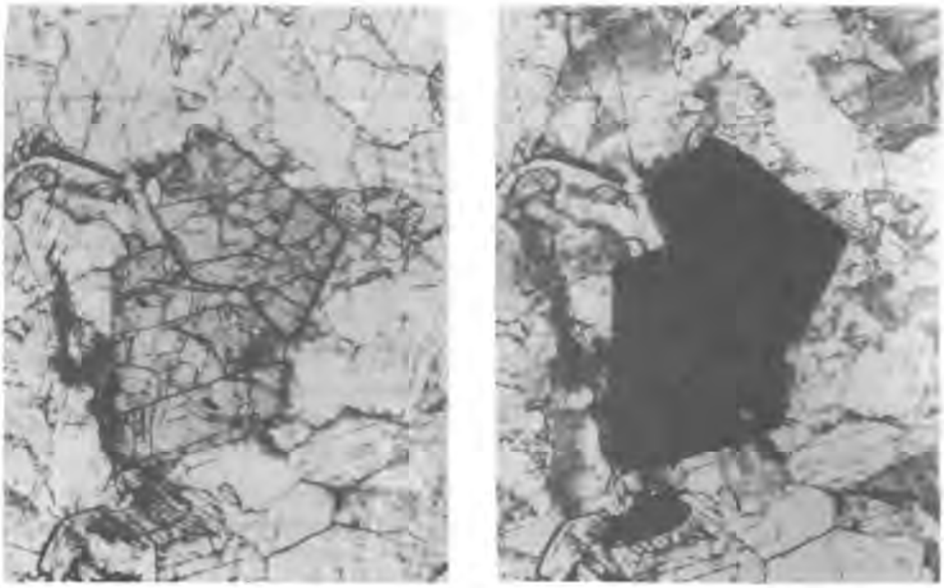


FIGURE 1-13. Spinel crystals are isotropic, with high relief, and may show isometric sections. Note the octahedral parting.

and, as pleonast, in emery deposits with magnetite, corundum, and hematite. Spinel is incompatible with quartz and occurs with it only when surrounded by a reaction rim.

Spinel occurs as accessory grains in mafic and subsilicic igneous rocks and is developed in aluminous xenoliths. It is a common detrital mineral where spinel-bearing rocks are weathered, and it may appear in gem gravels with corundum, zircon, diamond, and garnet.

Hercynite occurs largely in metamorphic rocks derived from iron-rich, argillaceous sediments (for example, laterites), in granitic granulites (hercynite can form in the presence of free silica), and, rarely, in ultramafic igneous rocks intergrown with magnetite.

Gahnite is found chiefly in granite pegmatites; less commonly, in contact carbonate zones and metasomatic zinc ores.

Galaxite occurs in Mn-vein deposits with rhodonite, spessartite, tephroite, and so on.

REFERENCES: THE SPINEL SERIES

Hoekstra, K. E. 1969. Crystal chemical considerations of the spinel structural group. Unpublished doctoral dissertation. Ohio State University, Columbus, Ohio.

Okamoto, S. 1971. Crystal chemistry of spinel compounds. *Kagaku Kogyo*, *22*, 814–824.

Ponomareva, M. N., N. V. Pavlov, and I. I. Chuprynina. 1964. Determination of the composition of some mineral species of chrome-spinelides by their refractive indexes. *Geol. Rudn. Mestorozhd.*, *6*, 103–106.

Satoh, T., R. Tsushima, and K. Kudo. 1974. Classification of normal spinel-type compounds by ionic packing factor. *Mater. Res. Bull.*, *9*, 1297–1300.

Zhelyazkova-Panaiotova, M. 1971. Rational classification of the spinel group from ultrabasic rocks. *Int. Mineral. Assoc., Proc. 7th Gen. Mtg., 1970*, 174–179.