Classification of minerals

The broadest divisions of the classification used in the present discussion are (1) native elements, (2) sulfides, (3) sulfosalts, (4) oxides and hydroxides, **(5) halides, (6) carbonates, (7) nitrates, (8) borates, (9) sulfates, (10) phosphates, and** (11) silicates.

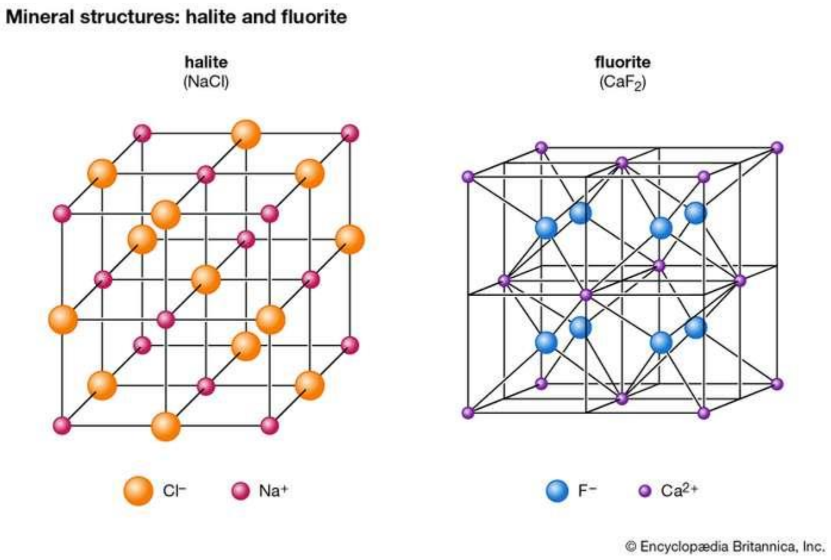
Halides

Members of this class are distinguished by the **large-sized anions** of the halogens chlorine, bromine, iodine, and fluorine. The ions carry an electric charge of negative one and easily become distorted in the presence of strongly charged bodies. When associated with rather large, **weakly polarizing cations of low charge**, such as those of the alkali metals, both anions and cations take the form of **nearly perfect spheres**. Structures composed of these spheres exhibit the **highest possible symmetry**.

Pure ionic bonding is exemplified best in the isometric halides, for each spherical ion distributes its weak electrostatic charge over its entire surface. These halides manifest relatively low hardness and moderate-to-high melting points. In the solid state they are poor thermal and electric conductors, but when molten they conduct electricity well.

Halogen ions may also combine with smaller, more strongly polarizing cations than the alkali metal ions. Lower symmetry and a higher degree of covalent bonding prevail in these structures. Water and hydroxyl ions may enter the structure, as in atacamite [$Cu_2Cl(OH)_3$].

The halides consist of **about 80** chemically related minerals with diverse structures and widely varied origins. The most common are halite (NaCl), sylvite (KCl), chlorargyrite (AgCl), cryolite (Na_3AlF_6), fluorite (CaF_2), and atacamite. No molecules are present among the arrangement of the ions in halite, a naturally occurring form of sodium chloride. Each cation and anion is in octahedral coordination with its six closest neighbours. The NaCl structure is found in the crystals of many XZ-type halides, including sylvite (KCl) and chlorargyrite (AgCl). Some sulfides and oxides of XZ type crystallize in this structure type as well—for example, galena (PbS), alabandite (MnS), and periclase (MgO).



© Encyclopædia Britannica, Inc.

Figure 11: (A) The structure of halite, NaCl. (B) The structure of fluorite, CaF_2.

Carbonates

The carbonate minerals contain the anionic complex $(CO_3)^{2-}$, which is triangular in its coordination—i.e., with a carbon atom at the centre and an oxygen atom at each of the corners of an equilateral triangle. These anionic groups are strongly bonded individual units and do not share oxygen atoms with one another. The triangular carbonate groups are the basic building units of all carbonate minerals and are largely responsible for the properties particular to the class.

The crystal structure of many carbonate minerals reflects the trigonal symmetry of the carbonate ion, which is composed of a carbon atom centrally located in an equilateral triangle of oxygen atoms. This anion group usually occurs in combination with calcium, sodium, uranium, iron, aluminum, manganese, barium, zinc, copper, lead, or the rare-earth elements. The carbonates tend to be soft, soluble in hydrochloric acid, and have a marked anisotropy in many physical properties (*e.g.*, high birefringence) as a result of the planar structure of the carbonate ion.

There are approximately 80 known carbonate minerals, but most of them are rare. The commonest varieties, calcite, dolomite, and aragonite, are prominent constituents of certain rocks: calcite is the principal mineral of limestones and marbles; dolomite occurs as a replacement for calcite in limestones, and when this is extensive the rock is termed dolomite; and aragonite occurs in some recent sediments and in the shells of organisms that have calcareous skeletons. Other relatively common carbonate minerals serve as metal ores: siderite, for iron; rhodochrosite, for manganese; strontianite, for strontium; smithsonite, for zinc; witherite, for barium; and cerussite, for lead.

Most such rock-forming carbonates belong to one of two structure groups—either calcite or aragonite. The calcite structure is usually described with reference to the sodium chloride structure in which the sodium and chloride of halite are replaced by calcium atoms and CO_3 groups, respectively.

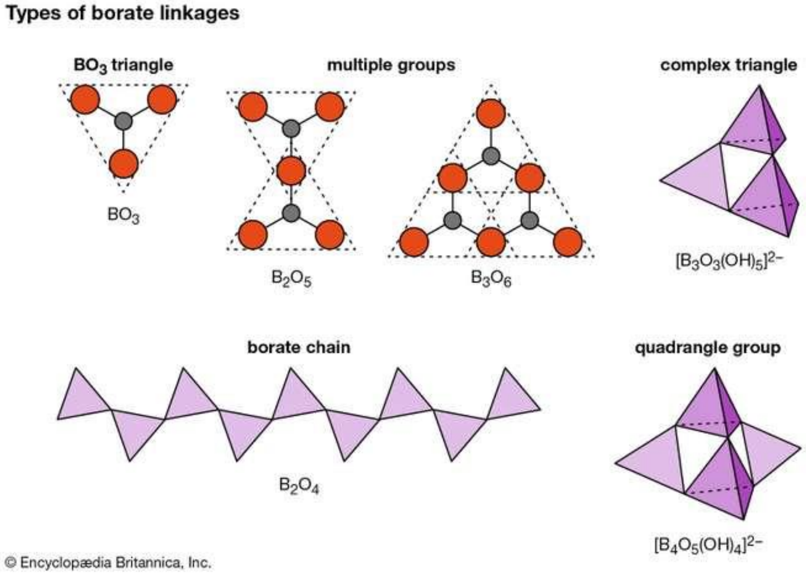
Nitrates

The nitrates are characterized by their triangular $(NO_3)^-$ groups that resemble the $(CO_3)^{2-}$ groups of the carbonates, making the two mineral classes similar in structure. The nitrogen cation (N^{5+}) carries a high charge and is strongly polarizing like the carbon cation (C^{4+}) of the CO_3 group. A tightly knit triangular complex is created by the three nitrogen-oxygen bonds of the NO_3 group; these bonds are stronger than all others in the crystal. Because the nitrogen-oxygen bond has greater strength than the corresponding carbon-oxygen bond in carbonates, nitrates decompose less readily in the presence of acids.

Nitrate structures analogous to those of the calcite group result when NO_3 combines in a 1:1 ratio with monovalent cations whose radii can accommodate six closest oxygen neighbours. For example, nitratite ($NaNO_3$), also called soda nitre, and calcite exhibit the same structure, crystallography, and cleavage. The two minerals differ in that nitratite is softer and melts at a lower temperature owing to its lesser charge; also, sodium has a lower atomic weight than calcium, causing nitratite to have a lower specific gravity as well. Similarly, nitre (KNO_3), also known as saltpetre, is an analogue of aragonite. These are two examples of only seven known naturally occurring nitrates.

Borates

Minerals of the borate class contain boron-oxygen groups that can link together, in a phenomenon known as polymerization, to form chains, sheets, and isolated multiple groups. The silicon-oxygen (SiO_4) tetrahedrons of the silicates polymerize in a manner similar to the $(BO_3)^{3-}$ triangular groups of the borates. (For further information on such structures, *see below* Silicates). A single oxygen atom is shared between two boron cations (B^{3+}), thereby linking the BO_3 groups into extended units such as double triangles, triple rings, sheets, and chains. The oxygen atom is able to accommodate two boron atoms because the small boron cation has a bond strength to each oxygen that is exactly one-half the bond energy of the oxygen ion.



© Encyclopædia Britannica, Inc.

Figure 12: Various possible linkages of (A) BO_3 triangles to form (B,C) multiple groups and (D) chains in borates. Complex (E) triangle and (F) quadrangle groups are also shown. The group depicted in (F) occurs in borax.

Sulfates

This class is composed of a large number of minerals, but relatively few are common. All contain anionic $(SO_4)^{2-}$ groups in their structures. These anionic complexes are formed through the tight bonding of a central S^{6+} ion to four neighbouring oxygen atoms in a tetrahedral arrangement around the sulfur. This closely knit group is incapable of sharing any of its oxygen atoms with other SO_4 groups; as such, the tetrahedrons occur as individual, unlinked groups in sulfate mineral structures.

Common sulfates

barite group	
barite	$BaSO_4$
celestite	$SrSO_4$
anglesite	$PbSO_4$
anhydrite	$CaSO_4$
gypsum	$CaSO_4 \cdot 2H_2O$

Members of the barite group constitute the most important and common anhydrous sulfates. They have orthorhombic symmetry with large divalent cations bonded to the sulfate ion. In barite ($BaSO_4$), each barium ion is surrounded by 12 closest oxygen ions belonging to seven distinct SO_4 groups. Anhydrite ($CaSO_4$) exhibits a structure very different from that of barite since the ionic radius of Ca^{2+} is considerably smaller than Ba^{2+}. Each calcium cation can only fit eight oxygen atoms around it from neighbouring SO_4 groups. Gypsum ($CaSO_4 \cdot 2H_2O$) is the most important and abundant hydrous sulfate.

Phosphates

Although this mineral class is large (with almost 700 known species), most of its members are quite rare. Apatite [$Ca_5(PO_4)_3$(F, Cl, OH)], however, is one of the most important and abundant phosphates. The members of this group are characterized by tetrahedral anionic $(PO_4)^{3-}$ complexes, which are analogous to the $(SO_4)^{2-}$ groups of the sulfates. The phosphorus ion, with a valence of positive five, is only slightly larger than the sulfur ion, which carries a positive six charge. Arsenates and vanadates are similar to phosphates.