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Materials Handbook

A Concise Desktop Reference

2nd Edition

Springer

Cardarelli, F. (2008) Materials Handbook. A Concise Desktop Reference. Springer, London UK

By the same author

Encyclopaedia of Scientific Units, Weight and Measures. Their SI Equivalences and Origin
Springer, New York, London (2005), xxiv, 848 pages
ISBN 978-1-85233-682-0

Materials Handbook: A Concise Desktop Reference
Springer, London, New York (2000), xi, 595 pages
ISBN 978-1-85233-168-9
(Out of print)

S*cientific Unit Conversion. A Practical Guide to Metrication, 2nd Edition*
Springer, London, New York (1999), xvi, 488 pages
ISBN 978-1-85233-043-9
(Out of print)

Scientific Unit Conversion: A Practical Guide to Metrication
Springer, London, Heidelberg (1997), xvi, 456 pages
ISBN 978-3-540-76022-1
(Out of print)

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Member of ACS, AIChE, ASM, ECS, MAC, MSA, OCQ, SFC and TMS

ISBN 978-1-84628-668-1 e-ISBN 978-1-84628-669-8

DOI 10.1007/978-1-84628-669-8

British Library Cataloguing in Publication Data
Cardarelli, Francois, 1966-
Materials handbook : a concise desktop reference. - 2nd ed.
1. Materials - Handbooks, manuals, etc.
I. Title
620.1'1
ISBN-13: 9781846286681

Library of Congress Control Number: #########

Cover design: eStudio Calamar S.L., Girona, Spain

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

12 Minerals, Ores and Gemstones

12.1 Definitions

In this section the main definitions, properties of minerals are detailed and explained.

Crystal. A crystal is a homogeneous solid with an ordered atomic space lattice which has developed a crystalline morphology when external crystallographic planes have had the possibility to grow freely without external constraints and under favorable conditions. Moreover, it is a chemical substance with a definite theoretical chemical formula. Nevertheless, the theoretical chemical composition is usually variable within a limited range owing to the isomorphic substitutions (i.e., diadochy), or/and low presence of traces of impurities.

Minerals. A mineral is defined as a naturally occurring, inorganic, and homogeneous crystal that has been formed as a result of geological processes with a definite but generally not fixed chemical composition. Therefore, minerals are the basic building entities of Earth's crust materials, i.e., rocks and soils. On the other hand, among the 4000 minerals species, the most abundant minerals found in common rocks (i.e., igneous, sedimentary, metamorphic and meteorites) are called by petrologists the ***rock forming minerals***.

Mineraloids. The mineraloids are naturally occurring substances having a structure which can be partially crystalline or noncrystalline, i.e., solids with an irregular atomic arrangement within the solid. For instance, compounds such as obsidian, opal, amber or succinite are defined as mineraloids.

Ores. An ***ore*** is a natural occurring mineral or association of minerals containing a high percentage of a metallic element, which form deposits from which this metal can be mined, extracted, and processed at a profit under favorable conditions. Therefore, it is

Table 12.1. Common gangue minerals

Class	Mineral
Oxides	Quartz
	Limonite
Carbonates	Calcite
	Dolomite
	Rhodocrosite
Sulfates	Baryte
	Gypsum
Halides	Fluorspar
Phosphates	Apatite
Silicates	Feldspars
	Clays
	Chlorites

economically defined. However, a distinction must be made between ore and ore minerals. A deposit of **ore minerals** in geological terms is not always an ore deposit, while an ore mineral is a mineral from which a metal can feasibly be extracted, and an **ore deposit** (or an **orebody**) is a mass of rock from which a metal or mineral can be profitably produced. What is, or is not, becomes dependent upon economic, technological, and political factors as well as geological criteria. A **protore** is a low-grade metalliferous material which is not in itself valuable but from which ore may be formed by superficial enrichment.

Gangue. The gangue is an earthy or nonmetallic mineral associated with the ore minerals of a deposit, i.e., a worthless material in which the ore mineral is disseminated and must be concentrated by classical ore beneficiation techniques (e.g., gravity separation, flotation, leaching). The most common gangue minerals are listed in Table 12.1.

Vein deposits. A ***vein*** is a mineral mass, more or less tabular, deposited by solutions in or along fracture of group of fractures. The ***country rock*** is the rock that encloses a metalliferous deposit. Vein ***walls*** are the rock surfaces on the borders of the veins. The ***footwall*** is the rock below an inclined vein, a bed, or a fault. The ***hanging wall*** is the rock above an inclined vein, bed or fault. A ***druse*** or ***vug*** is an unfilled portion of a vein usually lined with crystals. ***Gouge*** (*salbandes* in French) is a soft claylike material that occurs at some places as a selvage between a vein and country rock or in a vein.

Along with scientific and technical terms, prospectors, geologists and mining engineers have established various terms to describe and classify mineral resources. Some of these terms are defined hereafter based on standardized definitions introduced by the U.S. Geological Survey (USGS)[1].

Reserves. Amount of ore deposits economically recoverable at current prices using existing technologies. Because reserves include only recoverable materials, terms such as extractable or recoverable are redundant adjectives.

Marginal reserves. Part of the reserve base which, at the time of determination, borders on being economically producible.

[1] U.S. Geological Survey Circular 831, 1980.

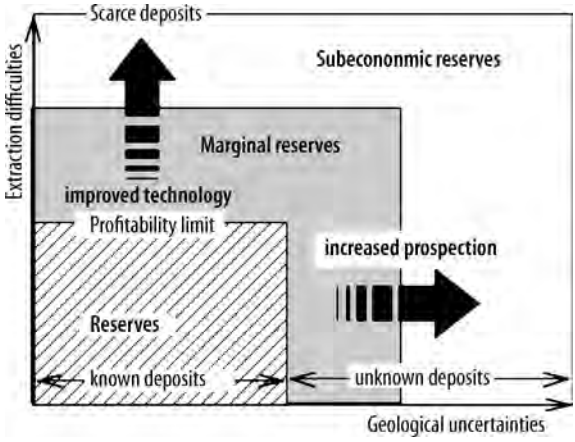

Figure 12.1. McKelvey diagram[2]

Subeconomic resources. Part of identified resources that does not meet the economic criteria of reserves and marginal reserves.

Reserve base. Part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those of grade, quality, thickness and depth. The reserve base includes those resources that are currently economic (reserves), marginally economic (marginal reserves) and finally those that are currently subeconomic (subeconomic resources).

Reserve base = Reserves + Marginal Reserves + Subeconomic Reserves

A schematic illustration of the economic viability of ore deposits based on the previous definitions is provided by the ***McKelvey diagram*** (see **Figure 12.1**).

Industrial minerals or nonmetallics. This designation includes all the minerals with economic importance, except those defined as ore, which are processed industrially. In fact, industrial minerals class also includes

(i) sedimentary rocks such as: limestone, dolomite, clays, sand, gravel, diatomite, and phosphates;
(ii) metamorphic rocks such as marble or slate; and
(iii) igneous rocks such as granite and basalt.

However in order to be rigorous from a mineralogical and petrological point of view it is preferable to split the previous group into two distinct subgroups:

(i) ***industrial minerals***, *sensu stricto*; and
(ii) ***industrial rocks***, *sensu stricto*.

A conventional listing of the more important nonmetallics is presented in Table 12.2.

Gemstones. A gemstone is a semi-precious or precious natural mineral with exceptional physical properties which, when cut and polished, can be used in jewelry. Only four minerals are considered as precious gemstones *sensu stricto*: ***diamond***, one gem variety of beryl (i.e., ***emerald***: green), and the two gem varieties of corundum (i.e., ***ruby***: deep red, and ***sapphire***: deep blue). Beside natural minerals synthetic gemstones and their simulants are also found in jewelry.

[2] McKelvey, V.E. – "Mineral Potential of the United States" in the Mineral Position of the United States 1975–2000 E.N. Cameron (Ed.) (1973) Univ. of Wisconsin Press, Madisson, Wi.

Table 12.2. Industrial minerals and rocks

Nonmetallics	Material	Industrial applications and uses
Industrial minerals s.s.	Asbestos (chrysotile, crocidolite, amosite, anthophyllite, tremolite, and actinolite)	(i) Spinning fibers: woven brake lining, clutch facing, fireproof and safety clothing, and blankets. (ii) Nonspinning fibers: roofing shingles, millboard, and corrugated panels for thermal insulation.
	Apatite (see also phosphate rock)	Fertilizers and chemical industry.
	Barite (baryte, heavyspar)	Oil-well drilling muds, filler in rubbers, paint extender, aggregate in speciality heavy weight concretes, flux in the glass industry, and barium chemicals
	Beryl and bertrandite	Beryllia, and beryllium chemicals
	Borax and borates (kernite, tincal, colemanite, and ulexite)	Fluxing agents in the manufacture of glass and vitreous enamel, borosilicated glasses (i.e., Pyrex®), borate fertlizers in agriculture, detergents and soaps, flame retardants, and in a lesser extent synthetic cubic boron nitride (i.e., Borazon®) for industrial abrasives, boron-doped semiconductors.
	Chalk	Aggregate
	Chromite (podiform and stratiform)	Only commercial source of chromium used in the metallurgical industry (85%) mainly as Fe–Cr for steelmaking, in the refractory and foundry market (8%) and in the chemical industry (7%).
	Cryolithe (cryolite)	Fluxing agent in the Hall–Heroult process in the aluminum industry.
	Diamond (bort varieties)	Abrasives, diamond drill in the mining industry, wire-drawing dies.
	Emery (corundum, magnetite, and spinel)	Abrasive for paper grit
	Feldspars (microcline, orthose, plagioclases)	Glass Industry for porcelain, enamels and glazes.
	Fluorspar (fluorite)	Foundry fluxes in steel making (metallurgical grade), preparation of hydrofluoric acid (acid grade), glass industry (ceramic grade).
	Garnets (pyrope, almandine, spessartine, uvarovite, grossular, spessartine)	Abrasives, blasting media, water jet cuttings, and water filtration.
	Graphite	Foundry molds facing (70%), crucibles, and lubricant.
	Gypsum and anhydrite	Gypsum wallboads for building purposes, fertilizers, sulfates and sulfuric acid.
	Kyanite	Refractories
	Magnesite	After calcination give periclase (MgO) used for refractories
	Manganese dioxide (psilomelane)	Primary batteries
	Micas (muscovite, phlogopite)	Electrical sheet insulators, furnaces windows, roofing materials.
	Nitrates (salpeter, niter, ammonium nitrate)	Fertilizers in agriculture, raw material for the chemical industry (i.e., pyrotechnics and explosives)

Table 12.2. *(continued)*

Nonmetallics	Material	Industrial applications and uses
	Olivine	Slag conditioner, refractories (brick, mortars and monolithic castables), foundry sands.
	Potash (sylvite, carnalite)	Fertilizer in agriculture and potassium chemicals (e.g., soaps, detergents, dyes, explosives).
	Pyrophillite (Rozeckite)	Refractories (e.g., firebricks, monolithics), whiteware ceramics, filler applications.
	Quartz	Piezoelectric crystals, optical lens, speciality glassware, optical fibers, silicon for semiconductors.
	Sillimanite	Refractories
	Staurolite	Sandblasting abrasives (90%), foundry sand
	Sulfur (native)	Chemical industry for the manufacture of sulfuric acid
	Talc (steatite)	Manufacture of whiteware and porcelain, inert extender in paint, lubricant in paper-making, absorbant in pharmaceutical and chemical Industry.
	Trona and nahcolite	Glass industry, raw material for the chemical industry, soaps and detergents.
	Vermicullite	Loose-fill insulation, and lightweight concrete.
Industrial rocks		
Igneous rocks	Aplite	Glassmaking and ceramic industry.
	Basalt and diabase (crushed)	Concrete aggregate, railroad ballast, and roofing granules.
	Granite and granodiorite	Monuments and memorials, building foundation blocks, steps, cubstones and paving blocks.
	Perlite (rhyolitic obsidian)	Aggregate in plasters, loose-fill insulation, filtration medium, paint filler, oil-well drilling muds, inert packing materials.
	Pumice	Abrasives, concrete building blocks, stone washing, polishing metals and woodworking.
Sedimentary rocks	Attapulgite and sepiolite (i.e., palygorskite or Fuller's earth)	Owing to its excellent sorbtive capabilities, decolorizing agent, binding and thickening together with non swelling behavior when wet and non floculating with electrolytes major uses are: pet litter, animal bedding, floor absorbents, oil spill-clean-up materials, tank cleaning
	Clays (bentonite, kaolinite, montmorillonite)	Filler material, oil-well drilling mud, waxes, fats and oils adsorbents, Portland-cement, enamels and ceramics, refractories, potery.
	Bauxite (i.e., gibbsite, boehmite, and diaspore)	(i) Metallugical grade (85%): Hall–Heroult process for aluminum metal. (ii) Non metallurgical grade (15%): High alumina refractories (briclks and monolithic castables), abrasives, welding flux, ceramic proppants, Bayer's alumina, aluminum based chemicals
	Diatomite (kieselguhr)	Filter aid, filler material.
	Dolomite	(i) crushed: aggregate in concrete, railroad ballast, sewage filter beds; (ii) fluxing agent in smelting and refining of steel;

Table 12.2. *(continued)*

Nonmetallics	Material	Industrial applications and uses
Sedimentary rocks	Dolomite	(iii) soil conditioner; (iv) source of lime and magnesia (dolime); (v) chemical raw material; (vii) high grade refractories; and (viii) dimension stone.
	Gypsum and anhydrite	Gypsum plasters for building purposes, fertilizers, sulfates and sulfuric acid.
	Limestone	(i) crushed: aggregate in concrete, railroad ballast, sewage filter beds; (ii) fluxing agent in smelting and refining of steel; (iii) soil conditioner; (iv) source of lime; (v) raw material for Portland-cement; (vi) chemical raw material; and (vii) dimension stone.
	Phosphate rocks (phosphorites)	Fertilizer in agriculture, raw material for the chemical and pharmaceutical industry for the manufacture of orthophosphoric acid, steelmaking and pyrotechnics.
	Quartzite	Ferrosilicon, refractories, abbrasives, potery and enamels.
	Rocksalt (halite)	Raw material for the chemical industry (e.g., chlor-alkali process)
	Sand and gravel (silica sand)	Aggregate in Portland-cement concrete, foundry sands, glass sands.
Metamorphic rocks	Marble	Achitectural and statuary, dimension stone
	Slate	Roofing stales and flagstones.

12.2 Mineralogical, Physical and Chemical Properties

Among the approximate 4000 minerals species found in nature, only the major rock forming minerals, chief metals ores and gemstones are listed in the Mineral Properties Table (roughly 400 minerals species) presented in Section 12.7, Mineral and Gemstone Properties, with their common physical and chemical properties useful for mineralogical identification. These properties are sufficient to identify common rock-forming and ore minerals occurring in common geological materials (e.g., rock, and soils) with common field laboratory equipment (i.e., magnification lenses, polarizing microscope, pycnometer, microchemical analysis spot tests). The selected properties of minerals detailed in the table are explained in detail the following paragraphs.

12.2.1 Mineral Names

Minerals are most commonly classified on the basis of the presence of a major chemical component (i.e., anion or anionic complex) into several mineral classes such as, for instance, native elements, sulfides and sulfosalts, oxides, carbonates, sulfates, phosphates, silicates, etc. Today, there exist two main mineralogical classifications of minerals according to either

the modernized **Dana's classes** (Table 12.16) or the **Strunz's classes** (Table 12.15). However, the naming of minerals is not based on such a logical scheme. The careful description and identification of minerals often requires highly specialized physical or/and chemical techniques such as inorganic spectrochemical analysis (i.e., AAS, AES, XRF) and measurement of common physical properties (e.g., density, microhardness, optical properties, X-ray lattice parameters, etc.). However, because of historical reasons, the names of minerals were not arrived at in an analogous scientific manner. Minerals may be given names on the basis of some physical property (e.g., barite from the Greek, *baryos*, meaning heavy due to its elevate density) or chemical composition (e.g., germanite from its germanium content), or they may be named after the locality of discovery (e.g., aragonite from the Spanish region of Aragon), a public figure (e.g., perovskite after the Russian Count Perowski), a mineralogist (e.g., haüyne after the French mineralogist René-Just d'Haüy), or almost any other subject considered appropriate. An international committee, the Commission on New Minerals and New Mineral Names of the *International Mineralogical Association* (IMA), now reviews all new mineral descriptions and judges the appropriateness of new mineral names as well as the scientific characterization of newly discovered mineral species. As for all the chemical compounds, each mineral can also be identified by its chemical abstract registered number [CAS RN].

12.2.2 Chemical Formula and Theoretical Chemical Composition

The theoretical chemical formula of a mineral is unique and identifies only one species. Nevertheless, the actual chemical composition is usually variable within a limited range owing to the isomorphic substitutions (i.e., diadochy), or/and low presence of traces of impurities. The relative atomic or molecular mass (based on $^{12}C = 12.000$) of minerals is calculated from the theoretical formula using the last value of atomic masses adopted by the *International Union of Pure and Applied Chemistry* (IUPAC) in 2001, and the theoretical chemical composition is commonly expressed in percentage by weight (wt.%) of elements and sometimes oxides for oxygenated minerals.

12.2.3 Crystallographic Properties

Minerals, with few exceptions (i.e., amorphous species), possess the internal, ordered arrangement that is characteristic of crystalline solids. When conditions are favorable, they may be bounded by smooth plane surfaces and assume regular geometric forms known as crystals. The study of crystalline solids and the principles that govern their growth, external shape, and external structure is called crystallography. Morphological crystallography refers to the study of the external form, or morphology of crystals. Crystals are formed from solutions, melts, and vapors. The atoms in these disordered states have a random distribution but with changing temperature and pressure (T, P), and concentration they may join in an ordered arrangement characteristic of the crystalline state. Most well-formed mineral crystals are the result of chemical deposition from a solid (or a melt) into an open space, such as a vug, or a cavity in a rock formation. The main crystallographic properties are the ***crystal system***, the ***space lattice parameters*** expressed in picometers ($1\ pm = 10^{-12}\ m$) and plane angle in degrees (°), the ***strukturbericht designation***, the ***Pearson's notation*** and the number of atoms or molecules per unit space lattice are listed. Finally, the ***space group*** and ***point group*** according to the international Hermann–Mauguin notation and the crystal ***space lattice structure type*** are also given when known.

12.2.4 Habit or Crystal Form

Some crystals grow in a characteristic morphological form called their **crystal habit** or **habit**. For example, quartz may grow to form crystals with a hexagonal outline and pyramid-like ends. Habit is generally well-developed only if a mineral is allowed to grow in an environment without space limitations and in this case it is called **euhedral** (i.e., idiomorph or automorph). On the contrary, it is called **anhedral** (i.e., xenomorph, or allotriomorph) if no external form can be identified. If the habit is partially developed, the mineral is called **subhedral** (i.e., subautomorph or hypidiomorph). The habit or appearance of single crystals as well as the manner in which crystals grow together in aggregates are of considerable aid in mineral recognition. Terms used to express habit and state of aggregation are given below. Single crystals, i.e., minerals in isolated or distinct crystals may be described as:

(i) **acicular** (i.e., needlelike);
(ii) **capillary** or **filiform** (i.e., hairlike or threadlike);
(iii) **bladed** (i.e., lamellar, tabullar); and
(iv) **columnar** (i.e., prismatic).

For aggregates, i.e., groups of distinct crystals the following terms are used:

(v) **dendritic** (i.e., branching);
(vi) **reticulated** (i.e., lattice-like);
(vii) **divergent** or **radiated** (i.e., radiating);
(viii) **drusy** (i.e., layer of small crystals on a surface).

Parallel or radiating groups of individual crystals are described as:

(ix) **columnar**;
(x) **bladed**;
(xi) **fibrous**;
(xii) **stellated** (i.e., starlike);
(xiii) **globular**;
(xiv) **botryroidal** (i.e., bunch of grapes);
(xv) **reniform** (i.e., kidney-shaped masses);
(xvi) **mammillary**;
(xvii) **colloform**.

A mineral aggregate composed of scales or lamellae is described as:

(xviii) **foliated**;
(xix) **micaceous**;
(xx) **lamellar** or **tabular**; and
(xxi) **plumose**.

Miscellaneous terms are:

(xxii) **stalactitic**;
(xxiii) **concentric**;
(xxiv) **pisolitic**;
(xxv) **oolitic**;
(xxvi) **banded**;

Table 12.3. Crystal habits grouped by the ratio of their longitudinal and transversal dimensions

Group	Crystal habit			
Equant or equiaxed crystal habits (i.e., form similarly developed in all three directions)	Equiaxed	Granular		
	Fluorite	Olivine		
Elongated crystal habits (i.e., one dimension dominates)	Fibrous (hair-like)	Acicular (needle-like)	Columnar (pilar-like)	Prismatic (barrel-like)
	Actinolite, Chrysotile	Stibnite	Beryl, tourmaline	Quartz, apatite
Flattened crystal habits	Tabular	Platy	Bladed	Lamellar
	Baryte	Baryte, gypsum	Ilmenite	Muscovite, graphite

(xxvii) **massive;**
(xxviii) **mygdaloidal;** and
(xxix) **geode.**

12.2.5 Color

The color variations of a nonmetallic mineral are often the result of ionic trace impurities in the crystal space lattice structure. Since the impurities vary from sample to sample, the color may vary. Some nonmetallic minerals have no color and are referred to as colorless. This variability in color, which can sometimes be extreme, means that color is one of the least useful properties for identifying nonmetallic minerals even though it is probably the most obvious. The origin of a mineral's color can be explained by three types of electronic transitions in the crystalline solids.

(i) According to the **Crystal Field Theory (CFT)** the color of nonmetallic minerals is often due to traces of transition element cations inside the crystal lattice of minerals. Actually, all the first group of first transition elements (i.e., from Ti to Cu) have partially filled 3d electron shell orbitals. The electrostatic interactions between the 3d electrons with the electric field imposed by the lattice of surrounding coordinating anions is responsible of the degenerescence of the electron energy levels found in the free atom.

(ii) Another possible origin of the color of nonmetallic minerals is due to the **Charge Transfer Transitions** (**CTT**). The charge transfer electronic transitions occur when valence electrons transfer back and forth between adjacent cations. Several important charge transfer transitions have energies within the visible region and therefore cause selective absorption. A characteristic of the absorption spectrum is that the intensity of absorption depends of particular orientations. This phenomenon gives rise to the important property of pleochroism discussed in the optical properties paragraph.

(iii) Finally, the third important electronic transition within minerals which causes color are both **electron color centers** and **hole color centers**. Actually, in some ionic solids having lattice defects such as anion vacancies, electrons occupy vacancies in order to preserve the overall electric neutrality. For instance, fluorite, and rock salt are common minerals exhibiting F-centers (from German, *Farben*, meaning color). In contrast, hole color centers arise when an electron is missing from a location normally occupied by an electron pair. Smoky quartz and amethyst are common examples of minerals

exhibiting hole color centers. On the contrary, color is much more useful in identifying metallic minerals. Actually the origin of color in metallic minerals depends on the energy involved in the electronic transition between the conduction band and valence band described in the theory of bands (see the chapter on semiconductors). Therefore, it directly depends of the energy gap of the minerals.

12.2.6 Diaphaneity or Transmission of Light

The interaction of electromagnetic radiation with minerals only depends on the particular region of the spectra considered. As a general rule, the visible region (i.e., light wavelength comprises between 380 nm and 780 nm) is considered in optical mineralogy. Two main categories of mineral can be clearly identified,

(i) transparent and translucent minerals which may transmit light to varying degrees; and
(ii) opaque minerals which do not transmit visible light at all.

Actually, minerals which are transparent transmit light much like glass. These minerals are essentially solids with ionic or covalent bond such as oxides, carbonates, silicates (e.g., calcite, quartz), or native element (e.g., diamond). Minerals which are translucent transmit light on thin edges or in thin section. By contrast, opaque minerals do not transmit light even in thin section and comprise solids with metallic or partially metallic bond characterized by a free electron cloud (i.e., Fermi gas) such as native element (e.g., Cu, Ag, Au), most iron and copper bearing sulfides (e.g., CuS, FeS_2), and several transition metal oxides (e.g., Fe_3O_4. $FeTiO_3$, $FeCr_2O_4$). As a general rule, all minerals with a metallic luster are commonly opaque.

12.2.7 Luster

The term luster refers to the external appearance of the mineral owing to the reflection of light by its surface. The most important distinction to be made is between minerals with a metallic luster and a non-metallic luster. Minerals with a **metallic** luster (e.g., pyrite) reflect visible light like polished metals and alloys, and are often very shiny. Nevertheless, some minerals with a metallic luster may tarnish on exposure to moist air and become less shiny taking on a darker color. Minerals with a **nonmetallic** luster do not reflect light such as metals. There are a variety of nonmetallic lusters, each being descriptive of its appearance. A luster resembling light reflected from the surface of broken window glass is termed **glassy** or **vitreous** (e.g., quartz). A mineral which reflects light as if it were coated by a thin film of oil has a **greasy** luster (e.g., calcite). A dull luster resembling the appearance of dry soil is termed **earthy** (e.g., limonite). Other non-metallic lusters include **pearly** (e.g., moonstone), **resinous** (e.g., garnets, and realgar), **waxy** (e.g., turquoise), **silky** (e.g., tigers eye quartz), and **adamantine** such a diamond luster.

12.2.8 Cleavage and Parting

Some minerals tend to break repeatedly along certain planes parallel to atomic planes (i.e., flat crystallographic surfaces) owing to the weakness in their atomic structure because of the lowest binding energy between adjacent atoms. These planes are referred to as cleavage surfaces quantified by Miller indices (hkl) with cleavage directions perpendicular to them [hkl].

The result is flat regular surfaces. Parallel cleavage surfaces represent a single cleavage direction.which may be very well developed (i.e., perfect) in some crystals (e.g. micas, calcite), or may be fairly obscure (e.g. beryl). Cleavage surfaces which are not parallel represent different cleavage directions. While cleavage surfaces tend to reflect light all in the same direction, rougher fracture surfaces scatter light reflected off of them. As a result, cleavage surfaces are generally shinier than fracture surfaces. Sometimes cleavage may appear as a series of surfaces on one side of a sample which are parallel to each other but at different heights somewhat like stair steps. Such parallel surfaces can be recognized as a cleavage direction by the fact that they will reflect light all at once. Many minerals may be identified by their number of cleavage directions and plane angle(s) between cleavage directions. **Parting** is like cleavage, but only occurs along planes of structural weakness in twinned crystals.

12.2.9 Fracture

The way in which a mineral breaks is determined by the arrangement of atoms in its crystal structure and the strength of the different types of chemical bonds between atoms. All minerals may break somewhat randomly in any direction across a crystal. This type of breakage is called fracture and this word refers to the way minerals break along an uneven surface when they do not yield along cleavage or parting surfaces. Different kinds of fracture are designated as:

(i) **conchoidal** – a curving shell-like fracture similar to the way glass breaks with concentric rings. It is named after the smooth curving surface of a conch shell.
(ii) **fibrous or splintery** – fracture producing long splintery fibers (e.g., nephrite);
(iii) **hackly**; and
(iv) **uneven or irregular** – fracture simply producing a rough, broken, and irregular surface.

12.2.10 Streak

Streak is the color of a mineral when finely powdered, found by rubbing the mineral against an unglazed, typically white, porcelain plate called a streak plate. Minerals with a Mohs hardness much greater than 6 do not give a streak owing to their hardness being higher than that of the silicate solids found in porcelain. Instead, they scratch the streak plate. Most soft colorless or pale colored minerals have a white streak which is only visible against a dark-colored streak plate or if the mineral is rubbed against a hard, dark-colored mineral such as pyroxene or amphibole. Although the color of a mineral may vary, the streak is usually constant and is thus useful in mineral identification. Actually, the streak color of a mineral is usually the same regardless of the color of the whole mineral (and may or may not be the same as the color of the whole mineral). Thus streak is a more reliable property than the color of the mineral. Streak is particularly useful for identifying metallic minerals. For instance, the mineral pyrite which is often referred to as "fools' gold" because of its resemblance to true gold has a black streak while the streak of true gold is yellow.

12.2.11 Tenacity

The cohesiveness of a mineral is known as tenacity. The following terms are used to describe tenacity in minerals:

(i) **brittle** (i.e., breaks and powders easily);
(ii) **malleable** (i.e., may be hammered into thin sheets);
(iii) **sectile** (i.e., can be cut into thin shavings with a knife);
(iv) **ductile** (i.e., can be drawn into a wire);
(v) **flexible** (i.e., can be bent without breaking); finally
(vi) **elastic** (i.e., will spring back after being bent, e.g. mica).

12.2.12 Density and Specific Gravity

Density (symbol d or ρ) is a physical quantity equal to the ratio of mass to volume expressed in SI as $kg.m^{-3}$ while specific gravity or relative density (*SG, D*) is a dimensionless physical quantity equal to the ratio of the density of a mineral at a given temperature to the density of water at a reference temperature, usually defined as the temperature of its maximum density (3.98°C). Qualitatively mineral specific gravities can be classified in petrology as: *barylites* (i.e., heavy or dense with a density above that of quartz i.e., 2650 $kg.m^{-3}$), and *coupholites* (i.e., light with a density below that of quartz i.e., 2650 $kg.m^{-3}$). The specific gravity of a mineral is frequently an important aid in its identification, particularly in working with fine crystals or gemstones, when other tests would injure the specimens. The specific gravity of a crystalline substance depends on:

(i) its chemical composition; and
(ii) its crystal space lattice structure type.

For instance, the two allotropic forms of carbon, such as diamond, and graphite, owing to their different space lattice structure exhibit different densities. Actually, diamond owing to its closely packed cubic structure has a specific gravity of 3.512 while the graphite with its loosely hexagonal lamellar packed structure has specific gravity 2.230.

12.2.13 Mohs Hardness

The resistance of a mineral to scratching and abrasion is called its hardness. Hardness is a direct measure of the binding energy of atoms in the solid. In mineralogy, a series of 10 common standard minerals was chosen arbitrarily by the German mineralogist Friedrich Mohs[3,4] in 1824 as a relative scale, by which the relative hardness of any mineral can be told. Hence, the following minerals arranged in order of increasing hardness comprise what is known as the Mohs scale of hardness:

1. talc;
2. gypsum;
3. calcite;
4. fluorite;

[3] Mohs, F. *Grundriss der Mineralogie*, 1824.
[4] Staples, L.F. Friedrich Mohs and the scale of Hardness *J. Geol. Education*, **12** (1964) 98–101.

5. apatite;
6. orthoclase;
7. quartz;
8. topaz;
9. corundum;
10. diamond.

However, the numbers of the Mohs scale do not have a linear relationship to hardness. Diamond is actually much more than 10 times the hardness of talc. The numbers only represent a simple qualitative ordering of minerals by hardness. A mineral's hardness may be determined by attempting to scratch an object of known hardness such as glass or a coin with the mineral. Alternately, one may attempt to scratch a mineral sample with an object of known hardness. A harder mineral can scratch a softer mineral, but a softer mineral cannot scratch a harder mineral. Often a powder is produced when attempting to make a scratch. This powder may be mistaken for a scratch. Remember that while a powder can be wiped away, a scratch must remain after the removal of powder. Usually, the groove of a scratch in glass can be felt with a fingernail. The following common materials serve in addition to the above scale: the hardness of the fingernail is roughly 2.5, a U.S. copper coin about 3, the stainless steel AISI 440C grade of a pocket knife blade a little over 6, window glass 5.5, and the quenched carbon steel of a knife blade file 6.5. A grit paper made of carborundum® (i.e., silicon carbide) 9.25. For more accurate and quantitative measurements, hardness of minerals can be measured such as for metal and alloys by micro-indentation testing such as microhardness Vickers and Knoop tests (see hardness tests definitions and scales in the appendices). Nevertheless, since 1824 several other scales for reporting hardness of minerals were established in order to improve the reliability and accuracy of hardness measurements. The Rosival scale is an improved version of the original Mohs scale using corundum in place of diamond as reference mineral, with a hardness number defined as 1000. Later in 1933, Ridgeway et al.[5] suggested an extended Mohs hardness. For this purpose, he had introduced the hardness of fused silica between those of feldspar and quartz and the hardness of garnet between those of quartz and topaz respectively. However, in the 1960s more precise scientific studies were performed, in the former Soviet Union, by Povarennykh[6,7]. His rational scale of hardness was established from accurate measurements of the hardness of minerals by the micro-Vickers diamond indenter. Hence, the original Mohs scale was increased by five additional synthetic minerals in order to decrease the gap existing between the hardness of corundum and that of diamond. Moreover, he had also reported the crystallographic plane used in the measurement in order to take into account the anisotropy of mechanical properties of crystals. A brief comparison of these scale is reported in Table 12.4.

[5] Ridgeway, R.R.; Ballard, A.H.; and Bailey, B.L. *Trans. Electrochem. Soc.* **63** (1933) 267.
[6] Povarennikh, A.S. A Fifteen Division Mohs Scale of Hardness *Zap. Ukr. Otd. Vses. Mineralog. Obshchestva Akad. Nauk. Ukr. SSSR* **1** (1962) 67–74.
[7] Povarennikh, A.S. Necessary Revisions to be made in the Mohs Scale of Hardness. *Dopovidi Akad., Nauk. Ukr. SSSR*, **6** (1964) 804–806.

Table 12.4. Comparison of scales hardness of minerals

Mineral or material (in **bold** the original Mohs minerals)	Mohs scale (1822)	Rosival scale	Ridgeway scale (1933)	Povarennykh scale (1962)	Vickers hardness		Knopp hardness	
					kg_f/mm^2	GPa	kg_f/mm^2	GPa
Talc	1	0.033	1	1 (001)	n.a.	n.a.	65	0.64
Graphite	1.5	n.a.	n.a.	n.a.	32.5	0.32	n.a.	n.a.
Gypsum	2	1.25	2	n.a.	68	0.67	32–125	0.31–1.23
Halite	2–2.5	n.a.	n.a.	2	n.a.	n.a.	n.a.	n.a.
Finger nail	2.5	n.a.	n.a.	n.a.	n.a.	n.a.	150	1.47
Galena	2.5	n.a.	n.a.	3 (100)	71–84	0.70–0.82	n.a.	n.a.
Calcite	3	4.5	3	n.a.	110	1.07	135–190	1.32–1.86
Fluorite	4	5	4	4 (111)	n.a.	n.a.	163–310	1.60–3.04
Scheelite	4.5–5	n.a.	n.a.	5 (111)	285–429	2.79–4.21	n.a.	n.a.
Apatite	5	6.5	5	n.a.	n.a.	n.a.	430–435	4.22–4.27
Knife blade	5.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Feldspar (Orthoclase)	6	37	6	n.a.	n.a.	n.a.	560–625	5.49–6.13
Magnetite	5.5–6	n.a.	n.a.	6 (111)	530–599	5.20–5.87	n.a.	n.a.
Pyrex glass	6.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Silica (fused)	n.a.	n.a.	7	n.a.	n.a.	n.a.	n.a.	n.a.
Quartz	7	120	8	7 (1011)	n.a.	n.a.	820–875	8.04–8.58
Garnet	6	n.a.	9	n.a.	n.a.	n.a.	1360	13.34
Stellite®	n.a.	n.a.	8	n.a.	n.a.	n.a.	n.a.	n.a.
Zircon	7.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Porcelain (hard)	8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Topaz	8	175	10	8 (001)	n.a.	n.a.	1340	13.14
Zirconia (fused)	9	n.a.	11	n.a.	n.a.	n.a.	1160	11.38
Tantalum carbide	n.a.	n.a.	11	n.a.	n.a.	n.a.	2000	19.61
Alumina (fused)	n.a.	n.a.	12	n.a.	n.a.	n.a.	n.a.	n.a.
Tungsten carbide (WC+Co cermet)	n.a.	n.a.	12	n.a.	n.a.	n.a.	1400–1800	13.73–17.65
Corundum	9	1000	n.a.	9 (1120)	2100	20.60	2100	20.59
Carborundum®	n.a.	n.a.	13	n.a.	n.a.	n.a.	2400	23.55
Titanium carbide	n.a.	n.a.	n.a.	10	n.a.	n.a.	n.a.	n.a.
Aluminum boride	n.a.	n.a.	n.a.	11	n.a.	n.a.	2470	24.22
Sialon®	9	n.a.	n.a.	12	n.a.	n.a.	2500	24.52
Boron carbide	n.a.	n.a.	n.a.	13	n.a.	n.a.	2750	26.97
Borazon®	n.a.	n.a.	14	14	n.a.	n.a.	4700	46.09
Diamond	10	140,000	15	15	8000	78.45	7000	68.65

12.2.14 Optical Properties

In optical mineralogy, transparent and translucent minerals are classified according to five possible classes (i.e., with different indicatrices) to which a crystal can belong: isotropic, uniaxial (+/–), or biaxial (+/–).The main physical quantity is the ***index of refraction*** or the ***refractive index*** (***RI***), denoted n. The refractive index of a substance at a given wavelength is the dimensionless ratio of the celerity of light in vacuum, c, to the celerity of light in the crystal, v, $n = c/v$. In most tables and databases, this index is measured, unless otherwise specified, for monochromatic radiation having a standardized wavelength usually taken equal to that of the D-line of the resonance atomic transition of the sodium metal vapor ($\lambda_D = 589.3$ nm). Therefore, the right symbol is n_D. The three-dimensional surface describing the variation in refractive index with relationship to the vibration direction of incident light is called the **indicatrix**. **Isotropic** materials have the same refractive index regardless to vibrations directions and, the indicatrix is a sphere. Isotropic materials are:

(i) crystals with a cubic crystal lattice;
(ii) amorphous materials (i.e., vitreous or glassy); or
(iii) fluids (e.g., liquids and gases).

On the contrary, a solid material with more than one principal refractive index is called anisotropic. **Anisotropic** materials are divided into two subgroups:

(i) solid materials having a tetragonal, hexagonal, and rhombohedral crystal space lattice structure are called **uniaxial**;
(ii) solid materials having an orthorhombic, monoclinic, and triclinic crystal space lattice structure are called **biaxial**.

Uniaxial crystals belong to either the rhombohedral, the hexagonal or tetragonal crystal systems and possess two mutually perpendicular refractive indices, ε, and ω, which are called the principal refractive indices. Intermediate values occur and are called ε', a non-principal refractive index. The uniaxial indicatrix is an ellipsoid, either *prolate* ($\varepsilon > \omega$), termed positive (+), or *oblate* ($\varepsilon < \omega$), termed negative (–). In either case, ε coincides with the single optic axis of the crystal, yielding the name uniaxial. The optic axis also coincides with the axis of highest symmetry of the crystal, either the 4-fold for tetragonal minerals or the 3- or 6-fold of the hexagonal class. Because of the symmetry imposed by the 3-, 4-, or 6-fold axis, the indicatrix contains a circle of radius ω perpendicular to ε (i.e., perpendicular to the optic axis). Light vibrating parallel to any of the vectors would exhibit the refractive index ω. Light vibrating parallel to the optic axis would exhibit ε. Light that does not vibrate parallel to one of these special directions within the uniaxial indicatrix would exhibit a refractive index intermediate between ε and ω and is termed ε'. Biaxial crystals belong to the orthorhombic, monoclinic, or triclinic crystal systems and possess three mutually perpendicular refractive indices (α, β, and γ), which are the principal refractive indices. Intermediate values also occur and are labeled α' and γ'. The relationship between these values are $\alpha < \alpha' < \beta < \gamma' < \gamma$. The three principal refractive indices coincide with three mutually perpendicular lattice vectors directions, **a**, **b**, and **c**, which form the framework for the biaxial indicatrix. The point group symmetry of the biaxial indicatrix is 2/m 2/m 2/m. In orthorhombic minerals the **a**, **b**, and **c** vectors coincide with either the 2-fold axes or normals to mirror planes. In monoclinic minerals, one of the **a**, **b**, or **c** axes coincides with the single symmetry element. In triclinic minerals, no symmetry elements necessarily coincide with the axes of the indicatrix. The **birefringence** (i.e., double refraction), δ, is the physical quantity equal to the mathematical difference between the largest and smallest refractive index for an anisotropic mineral. The **pleochroism** is the property of exhibiting different colors as a function of

the vibration direction. **Dichroism** refers to uniaxial minerals while **trichroism** refers to biaxial minerals. **Dispersion** is the variation of the refractive index with the wavelength of incident light. Opaque minerals are more commonly studied in reflected light and that study is generally called ore microscopy or ore-metallography, the main parameter is the reflective index (R_λ) for a given wavelength, λ (generally taken as 650 nm), expressed in percentage of intensity of light reflected to intensity of incident light.

12.2.15 Static Electricity and Magnetism

The electrostatic charging properties of insulating materials were historically split into vitreous electricity, that is, materials that acquire a positive charge (+) due to a loss of electrons upon friction with a wool fabric (e.g., quartz, glass), and resinous electricity, those acquiring a negative charge (–) , that is a gain of electron upon friction (e.g., ebonite, amber).

Some minerals could be strongly ferromagnetic, i.e., readily attracted by a permanent magnet. For instance, lodestone or magnetite, ilmenite and pyrrhotite are the most common ferromagnetic minerals found both in igneous and sedimentary rocks. Sometimes, hematite may be contaminated by magnetite and appear to be ferromagnetic.

12.2.16 Luminescence

The effect is noticed when some minerals when submitted to long (366 nm, Wood's light) or short (256 nm) wavelength UV-light irradiation could simultaneously emit visible light (i.e., **fluorescence**) or emit light after the irradiation has stopped (i.e., **phosphorescence**). In particular case, minerals owing to the relaxation of point defects (e.g., Schottky, Frenkel, or F-center) in their crystal lattices can also emit light when submitted to heating (i.e., **thermoluminescence**), or when scratched or rubbed to a rough surface (i.e., **triboluminescence**). **Cathodoluminescence** is displayed by some particular minerals when they are irradiated by a beam of high-energy charged particles (i.e., electrons, protons, etc.). For instance, several uranium ores are fluorescent, while sphalerite bombarded by an electron beam is cathodoluminsecent and was the first compound used as screen-phosphor is spynthariscopes, while fluorspar (i.e., fluorite) is thermoluminescent and was used in the dating of archeological stoneware.

12.2.17 Piezoelectricity and Pyroelectricity

The property of piezoelectricity refers to the development of a momentary electric current when crystals are squeezed suddenly in certain crystallographic directions. The strain caused by squeezing is very small and purely elastic. Some common rock-forming minerals exhibit piezoelectricity such as low temperature quartz, tourmaline, sphalerite, boracite and topaz. The property of pyroelectricity refers to the development of a momentary electric charge displacement when crystals are submitted of a sudden change in temperature. The effect is proportional to the magnitude of the temperature change. Like piezoelectricity, pyroelectricity is strongly dependent on the crystal symmetry. Tourmaline is the most common pyroelectric mineral.

12.2.18 Play of Colors and Chatoyancy

Interference of light either at the surface or in the interior of a mineral may produce a series of colors as the angle of incident light changes. **Iridescence:** when an incident ray of light falls upon a thin transparent layer, some fraction of incident light is reflected, whilst the remainder fraction is refracted and is subsequently reflected back along a different path parallel to the first. Owing to the path difference between the two rays, interference occur with either cancelation when in phase opposition or intensification when in phase. The color effects caused by this phenomena are called iridescence. **Opalescence** consists of the reflection of incident light by small lamellar, or spherical inclusions in the mineral giving a milky or pearly aspect (e.g. precious opal). Some specimens of labradorite show colors ranging from blue to green or yellow with changing angle of incident light. This iridescence, also called **schiller** and **labradorescence**, is the result of light scattered by extremely fine exsolution lamellae. **Chatoyancy** consists of a wavy band of light that is seen to pass accross the mineral at right angles to the direction of the fibers. **Asterism** is a star-like effect of minerals cut in cabochon, caused by the reflection of light from fibers or fibrous cavities crossing at 60° (six-rayed star) or 90° (four-rayed star).

12.2.19 Radioactivity

Several uranium and thorium containing minerals and ores are obviously radioactive owing to the decay of the actinides and particularly uranide elements that they contain, while some minerals such as zircon which should not be radioactive, owing to the isomorph (i.e., diadochy) substitution of cations Zr(IV) by U(IV) and Th(IV), are often radioactive. The metamict (i.e., amorphization) habit is due to the destruction of the crystal lattice structure by self-irradiation and atom recoil following emmission of an alpha particle.

12.2.20 Miscellaneous Properties

Halite tastes salty, while epsomite exhibit a bitter taste. Some sulfides when rubbed exhibit the odor of sulfur. Talc feels slippery like soap. Plagioclase may have tiny parallel grooves called striations on cleavage surfaces. Striations are best seen when a cleavage surface is oriented to reflect light. Micas break into thin sheets which are elastic. The sheets may be bent and will spring back. Transparent varieties of gypsum with obvious cleavage may be flexible. They can be bent but will not spring back. Some varieties of alkali feldspar may have an irregular pattern of veins.

12.2.21 Chemical Reactivity

Reaction to common strong mineral acids (e.g., HCl, HNO_3, H_2SO_4, HF, or aqua regia) either diluted or concentrated is another important and rapid identification test. A few minerals effervesce, i.e., they produce bubbles, when a few drops of dilute hydrochloric acid are placed on a sample. Calcite vigorously evolves carbon dioxide and can easily be detected using this test, while dolomite must be powdered (i.e., streak powder) or the acid must be concentrated and heated to produce the same strong effervescence. When fluorite is heated in concentrated sulfuric acid it evolves hazardous hydrogen fluoride gas which strongly corrodes the test tube glassware.

12.2.22 Pyrognostic Tests or Fire Assays

The ***pyrognostic tests*** also called ***fire assays*** are simple qualitative laboratory techniques used by mineralogists in the field or in a laboratory to indentify quickly without complex equipment the chemical elements present in an unknown mineral sample. Five major types of fire assays are used:

(i) the flame test;
(ii) the fusibility or blowpipe test;
(iii) the reduction on charcoal;
(iv) the open and closed tube tests; and finally
(v) the bead test.

12.2.22.1 The Flame Test

The vapor of certain chemical elements imparts a characteristic color to the flame of burning gas (e.g., Bunsen burner). This property is used for identifying qualitatively various metallic elements. The flame coloration is caused by electronic transitions occurring between the energy levels of the atoms of the chemical element. For a particular chemical element the flame coloration is always the same, regardless of whether the chemical element is in the free atomic state or chemically in molecules. For example, free sodium metal, sodium chloride, sodium carbonate and sodium sulfate all impart an intense yellow color to the flame (D-line of 589 nm). This yellow color is characteristic of sodium in any form, and hence can be used as a test for sodium. In the making of flame tests, chlorides of the metals are commonly used, since chlorides are more volatile than other salts.

Procedure. Usually a thin wire of pure platinum metal is embeded into the tip of a borosilicated glass rod. Prior to conduct the test the Pt-wire must be cleaned thoroughly. Hence the Pt-wire is dipped into a solution of dilute hydrochloric acid (HCl) and placed into the hottest part of the Bunsen flame to burn off impurities. This operation must be repeated until no color is imparted to the flame. The unknown mineral is ground in an agate mortar and its powder is dissolved into an appropriate strong mineral acid (e.g., HNO_3, HCl) and the resulting solution is analyzed. The Pt-wire is dipped into the solution and the test is conducted by holding the Pt-wire in the hottest part of a non-luminous Bunsen burner flame. It is important to observe if sodium is present through a cobalt-glass filter. Insoluble mineral samples are only ground and a pinch of the finely ground solid is put on a watch glass. A few drops of 6 M hydrochloric acid are added to moisten the powder and stirred with a clean platinum wire and hold in the hottest part of a non-luminous Bunsen burner flame. Note that a trace of sodium is found as an impurity in practically all substances, especially in solutions that have been standing in glass bottles. Do not report sodium unless a very vigorous yellow flame is observed. For comparison draw the cold wire between your fingers. The sodium flame should be more intense than that obtained from the trace of sodium on the fingers. The chemical elements which impart characteristic colors to flame are listed in Table 12.5.

Table 12.5. Flame coloration tests

Flame coloration	Wavelength lines (intensity)	Chemical element	Comments
Red (Crimson)	610.36 nm (orange) **670.78** nm (red, m)	Lithium (Li)	The lithium minerals, which are either silicates or phosphates, do not become alkaline after ignition. If strontium is suspected it can be detected using a blue cobalt glass. Masked by Ba and Na. Violet through blue cobalt-glass and invisible through green glass.
Red (Carmin)	**605.0** nm (orange, m) **460.73** nm (blue)	Strontium (Sr)	Carbonates and sulfates show the strontium reaction, and become alkaline after ignition. Silicates and phosphates do not give the strontium flame. Masked by Ba. Greenish through blue cobalt-glass and yellowish through green glass.
Red yellowish or orange	**622.0** nm (red, m) 553.5 nm (green)	Calcium (Ca)	Only a few minerals give this calcium color decisively when heated alone. Often, however, the color shows distinctly after moistening the assay with hydrochloric acid. Masked by Ba. Greenish through blue cobalt-glass and green through green glass.
Yellow intense	597.3 nm (yellow) **589.2** nm (yellow, s)	Sodium (Na)	This test for sodium is so delicate that great care must be exercised in using it. Glass blowers Didymium Safety Glasses may be used to block out this emission to observe the less intense colors while the blue cobalt glass masks the color.
Green bright		Boron (B)	The addition of 3 parts potassium hydrogenosulfate ($KHSO_4$) and 1 part calcium fluoride (CaF_2) impart an emerald green coloration. Boron compounds rarely show an alkaline reaction after ignition. Green color is due to the blue and orange in the spectrum.
Green (emerald)	535.05 nm (green)	Thallium (Tl)	Presence of sodium impart a pale green color. Not often observed due to the rarity of thallium-bearing minerals.
Green yellowish	**524.2** nm (green, w) **513.7** nm (green)	Barium (Ba)	Carbonates and sulfates show the reaction, and become alkaline after ignition. Silicates and phosphates do not give the barium flame. The flame appears bluish through a green glass.
		Molybdenum (Mo)	If the molybdenum is in the form of the oxide or the sulfide.
Green pale	451.1 nm 410.1 nm	Tellurium (Te) Antimony (Sb)	
Green bluish		Phosphorus (P)	The phosphorus color is not very decisive, but often aids in the identification of a phosphate. Adding concentrated sulfuric acid it gives a yellowish flame.
		Zinc (Zn)	Zinc appears as bright streaks in the flame.
Violet pale	**769.90 nm (red)** **766.5 nm (red)** 404.5 nm (violet, w)	Potassium (K)	The potassium color is often masked by the more prominent yellow from sodium. Silicates, phosphates and borates do not give the potassium flame. Purple-red through blue glass and bluish green through green glass.
	794.76 nm (red) **780.0** nm (red) 775.8 nm (red) 740.8 nm (red) **421.56** nm (violet) **420.2** nm (indigo)	Rubidium (Rb)	The rubidium color is often masked by the more prominent yellow from sodium.

Table 12.5. *(continued)*

Flame coloration	Wavelength lines (intensity)	Chemical element	Comments
Violet pale	**697.3** nm (red) 672.3 nm (red) 621.3 nm (orange) **459.3** nm (blue) **455.54** nm (indigo)	Caesium (Cs)	The cesium color is often masked by the more prominent yellow from sodium. The first element found using a spectroscope.
Blue azure	510.55 nm (green, m)	Copper (II) chloride	The copper flame color is dependent on the presence of halide (i.e., F, Cl, Br, or I). The color can be used to detect halides by using copper oxide moistened with the test solution (e.g., flame blue-purple with Cl, blue-green with Br, and emerald-green with I). The outer darts of the flame are tinted with emerald-green.
	(weak)	Selenium (Se)	The selenium color is accompanied by the characteristic odor of rotting radishes.
	(weak)	Lead (Pb)	In reducing flame.
Blue		Indium (In)	The element Indium is named for the prominent blue lines in its spectrum.
		Arsenic (As)	The arsenic color is accompanied by the characteristic odor of garlic.

12.2.22.2 The Fusibility Test

The fusibility test is also a qualitative assay that consists of observing the melting ability of a tiny mineral fragment held in the dart of the blowpipe flame. Historically this simple test was based on the experimental observation made by the first mineralogists and chemists that

Table 12.6. Von Kobell's fusibility scale of minerals

Classification	No.	Melting point	Mineral	Description
Easy fusible	1	525°C	Stibnite $[Sb_2S_3]$	Coarse splinters that fuse easily in the flame of a candle or a match.
	2	800°C	Chalcopyrite $[CuFeS_2]$	Small fragments that fuse slowly in the Bunsen burner flame or in a closed glass tube at red heat.
Fusible	3	1050°C	Almandine $[Fe_3Al_2(SiO_4)_3]$	Coarse splinters easily fuse to give a globule at the tip of the blowpipe, and only finest splinters rounded in a Bunsen burner.
	4	1200°C	Actinolite $[Ca_2(Fe,Mg)_5(Si_8O_{22})(OH,F)_2]$	Fine splinters rounded under the blowpipe and only fine splinter form a globule.
Fusible with difficulties	5	1300°C	Orthoclase $[KAlSi_3O_8]$	Fused only in fine splinters or on thin edges underthe blowpipe.
	6	1400°C	Hemimorphite $[Zn_4Si_2O_7(OH)_2]$ Bronzite $[(Mg,Fe)_2(Si_2O_6)]$	Finest edge only rounded in the hottest part of the dart of the blowpipe.
Infusible	7	1760°C	Quartz $[SiO_2]$	Entirely infusible under the dart of the blowpipe, and retaining the edge in all its sharpness.

every mineral like any other chemical compound with a definite chemical composition exhibits a fixed melting point which is observed and compared to other reference minerals. Actually, some minerals melt under the flame of the blowpipe as easily as wax (e.g., stibnite) while others are quite infusible (e.g., quartz) even when exposed to the hottest, most oxidizing region of the flame (ca. 1500°C). Moreover, there are other special mineral characteristics that can be determined from the fusibility test and these are discussed in Section 12.2.22.5. Table 12.6 presents the practical scale of fusibility first devised by Von Kobell to differentiate how fusable some minerals are compared to others.

12.2.22.3 The Reduction on Charcoal

The reduction test on charcoal involves the heating of a powdered mineral mixed with a flux made of sodium carbonate (Na_2CO_3) and powdered charcoal on a cube of charcoal. During this test most sulfidic minerals give off a metal globule after reduction, and the coating color is related to the metal.

12.2.22.4 Tests with Cobalt Nitrate and Sulfur Iodide

During the charcoal test is possible to add a drop of reagent to produce a typical coloration related to a particular chemical element. The most common reagents are:

(i) an aqueous solution containing 5 wt.% of cobalt nitrate used on charcoal;
(ii) sulfur iodide produced *in situ* by mixing stoichiometric amounts of iodine and sulfur with the powdered mineral that must be used on a plate of Plaster of Paris.

Table 12.7. Coloration obtained with $Co(NO_3)_2$ on charcoal

Coloration	Chemical elements
Gray to black	Baryum, strotium, calcium and niobium
Bluish-gray	Beryllium
Pinkish-gray	Tantalum
Pink	Magnesium
Blue	Aluminum (Thenard blue)
Dark blue	Silicium
Yellowish green	Titanium
Greenish blue	Tin
Grayish green	Antinony
Emerald green	Zinc
Dark violet	Zirconium, arsenic, boron, and phosphorus

Table 12.8. Coloration obtained with sulfur iodide on plaster

Coloration	Chemical elements
Ultramarine	Molybdenum
Blue-green	Tungsten
Orange	Arsenic, antimony
Reddish brown	Selenium
Purple-brown	Tellurium
Chocolate	Bismuth
Brownish-Green	Cobalt
Gold	Lead
Yellow	Silver
Yellow-brown	Tin
Yellow and red	Mercury

12.2.22.5 The Closed Tube Test

In the closed tube test, a powdered mineral sample is placed at the bottom of a glass test tube and heated. The following characteristics must be reported:

(i) the change in the appearance;
(ii) the formation of gases which collect in the tube;
(iii) the formation of sublimates or condensed liquids on the cold walls of the tube.

Table 12.9. Mineral changes during the closed tube test

Characteristics	Reactions
Boiling	Some hydrayed minerals containing hydratation water release their water and gives the filling of boiling. Zeolithes are the most common examples.
Discoloration or darkening	The color of a mineral can changes due to the healing of lattice defects on moderate heating, mostly from dark colors to lighter ones. Such bleaching is a common practice used for treating raw gemstones, especially metamict zircons. But minerals may also change color after heating, owing to decomposition. For example the carbonates of copper, iron, and manganese become black on heating, due to the formation of black oxides. A dark red color frequently occurs when hematite is formed.
Decrepitation	Minerals containing liquid inclusions may explode owing to the evolution of steam during heating. Other such as baryte break into smaller crystal while milky quartz breaks into very fine powder or dust.
Exfoliation	Several minerals having a lamellar structure, including many phyllosilicates delaminate or exfoliate.
Melting	Only minerals having a low melting point melt in the closed tube.
Thermoluminescence	Some minerals emit a bright, often colored light (e.g., fluorescence and phosphorescence) when heated below redness, that is, above 300°C. The effect can be observed only in darkness. It is caused by the relaxation of lattice defects upon heating. The lattice defects are always due to radiation dammage that the crystal undergoes since its formation. This effect is called thermoluminescence, it is often found on fluorite, quartz, calcite, apatite, zircon, and diamond.

Table 12.10. Gases evolved during the closed tube test

Gases	Reactions
Arsenic and antimony oxides	A garlic-like odour points to the presence of arsenic, while selenium causes a peculiar odour resembling the smell of a rotten radishes.
Carbon dioxide (CO_2)	Carbon dioxide is originates from the decomposition of most carbonates during firing. The gas can be identified by introducing a drop of a clear solution of barium hydroxide or calcium hydroxide onto the inner wall of the tube next to the open side. The drop becomes white owing to the formation of the respective carbonates.
Hydrogen fluoride (HF)	Minerals containing fluorine along with hydroxyl groups (e.g., topaz) can evolves hydrogen floride upon intense heating at high temperature. The HF gas has a pungent odor, etches the glass and gives an acidic reaction with litmus paper.
Organic vapors	Mineraloids develop upon heating a brown smoke, mostly accompanied by dark distillation products and an empyreumatic odour. Only amber or natural resins produce an aromatic odour.
Oxygen (O_2)	Oxygen gas may be formed by the decomposition of pyrolusite and other manganese oxides. To detect it, light a wooden toothpick with a torch flame, blow out the flame of the burning wood and insert the still glowing end of the toothpick into the tube. The presence of oxygen causes the glow to intensify or the flame to re-appear.
Sulfur dioxide (SO_2)	Sulfur dioxide exhibits a strong pungent odour and it may be formed by the decomposition of sulfates or the partial oxidation of sulfides. It is detectable by the acid reaction it imparts to moistened litmus paper or by the decoloration of wet brown permanganate paper.
Water (H_2O)	Water is given off under moderate heating from zeolites and mineral hydrates like gypsum Minerals containing the hydroxyl group, like clay minerals, micas or amphiboles lose their water under firing only at higher temperatures.

Table 12.11. Sublimates during the closed tube test

Sublimates	Reactions
Black-like	Black like a black mirror, next to the assay dark gray crystals indicates As Black similar to As, transferred to a streak plate and rubbed it turns red indicates HgS Black fusible globules indicates Se or Te, small globules of Se transmit a reddish light
Gray	Gray metallic globules, which may be united by rubbing with a strip of paper indicates mercury.
Oily	When sulfates decompose, small drops of concentrated sulfuric acid may sometimes occur, they look like oil.
Red to brown	They oint to sulfides of As or Sb , hot they look nearly black, the As compounds are readily volatile
White	White sublimates could be either ammonium salts or As_2O_3 or Sb_2O_3 or lead chloride or Hg_2Cl_2. Repeat the test adding five times the amount of dry sodium carbonate to the assay, ammonium salts give off ammonia (NH_3) while mercury chloride decomposes to metallic mercury. To distinguish between As- and Sb-oxides use the open tube test.
Yellow	Sublimates that appears orange-red on heating and then yellow after cooling indicates the presence of sulfur as that produced by heating minerals such as pyrite or marcasite.

Borosilicate glass test tube 8–12 cm long, and 3–6 mm inside diameter are commonly used. The ground mineral sample is introduced at the bottom of the tube. The tube held by a wooden clamp is put near the vertical position and placed over a Bunsen burner. If any water condenses in the upper part, put some cotton wool in the upper part to avoid water drops rolling back to the hot parts and causing cracks due to thermal shock. The mineral changes, the gases evolved, the colors of the coating and sublimates that form on the cold sides of the tube are all important characteristics to identify mineral classes.

12.2.22.6 The Open Tube Test

In the open tube test a powdered mineral sample is placed inside a glass tube, open at both ends, and heated. The combination of heat and the circulation of air leads to the roasting of the mineral, thus bringing it to oxidation. Oxygen from the air oxidizes the mineral and the reaction products (e.g., As_2O_3, SbO_3, SO_2, H_2O, etc.) escape as gases. Therefore, heating in an open tube is one of the most important tests for minerals which are suspected to belong to the sulfides and sulfosalts; the test will give a reliable proof if S, As, Sb, Hg, Te, or Se are main constituents. The borosilicated glass tubes used are 12 cm long and 4 mm in diameter with

Table 12.12. Open tube test characteristics

Element	Reaction
Antimony (Sb)	Antimonides are oxidized to Sb_2O_3, which is white and slowly volatile. The sublimate forms as a dense, white smoke, which passes up the tube and partly settles on the upper side, partly it leaves the tube. It is volatile, but on further heating it changes to Sb_2O_4, this compound is non-volatile, infusible, and its color is pale straw-yellow when hot.
Arsenic (As)	All arsenides are oxidized to give off arsenic trioxide (As_2O_3) which is white and readily volatile. The sublimate forms as a ring in the cold part of the tube, and where it deposits on the warm glass it is distinctly crystalline. With a good magnifying lens tiny octahedrons can be visually observed. The typical garlic odour should not occur, since this is an indication of incompletely oxized samples.
Bismuth (Bi)	When sulfides are present, bismuth combines with SO_2 forming a small white sublimate of bismuth sulfate. When heated it melts to brown drops, the cooled drops are yellow and opaque. On increased heating they vanish due to the formation of Bi-silicates. The test for Bi is not very reliable and should be confirmed by heating on charcoal
Lead (Pb)	Sulfides with a considerableamount of lead such as galena may give a small amount of a sublimate of $PbSO_4$. The color is white when cold, on strong heating it vanishes due to the formation of colorless lead silicate. The test for Pb is not very reliable and should be confirmed by heating on charcoal.
Mercury (Hg)	Mercury minerals produce gray metallic globules of free mercury which are volatile on further heating. By rubbing the minute globules with a strip of paper, they may be made to unite.
Selenium (Se)	Selenides gives-off SeO_2 has a typical odour of rotten radish. Only large amounts produce a gray sublimate of Se next to the sample. It may turn to red at a distance, and, far from the sample there appears a sublimate of SeO_2 made up of white, radiating, prismatic crystals, which are readily volatile on heating.
Sulfur (S)	All sulfide minerals are oxidized and sulfur dioxide (SO_2) is formed, which can be detected by its odour or by the color change of wet pH-paper. Again brown moistened pyrolusite paper can be used to detect the formation of sulfur dioxide, which will bleach the brown paper. Sphalerite (ZnS) and molybdenite (MoS_2) are difficult to roast, and they should be finely ground for this test.
Tellurium (Te)	Tellurides produce a dense white smoke, part of which passes through the tube and part of which settles as a thick, white sublimate on the lower side. On heating of the sublimate of TeO_2 small oil-like drops are formed.

both open sides. They should be held in a standing position of 30° in order to ensure a sufficient draft of air on heating. Straight tubes may be used, but the powder of the assay tends to fall out of the tube hence bent tubes are preferred. The coarsely powdered sample is placed next to the open end. The flame of the Bunsen burner is moved under the mineral and allows oxidization to take place. The most important reactions occurring in the open tube test are summarized in Table 12.12.

12.2.22.7 The Bead Tests

The ***bead tests***, sometimes called the ***borax bead*** or ***blister tests***, are an old and straightforward qualitative analytical method first introduced by Berzelius in 1812 and widely used to test for the presence of certain metals in minerals and inorganic compounds since then. Historically, they were conducted with fluxing salts such as ***borax*** [i.e., sodium tetraborate, $Na_2B_4O_7.10H_2O$] which melts at 742°C. Actually, when a minute amount of borax is heated to redness it loses its water of crystallization and it forms a transparent glass bead. Small amounts of metal oxides dissolve readily in fused borax to form a colored glass. Upon cooling many chemical elements produce a characteristic color in the borax glass bead. Since then other salts were also used as fluxing agent such as sodium carbonate (Na_2CO_3), sodium fluoride (NaF). Among them the ***salt of phosphorus*** also called ***microcosmic salt*** [sodium ammonium hydrogenophosphate, $NaNH_4HPO_4.4H_2O$] which after losing water and ammonia form $NaPO_3$ which melts at 628°C is the most important after borax.

Bead test procedure. Make a loop in the end of a platinum wire. Heat the Pt-wire to redness and then dip it into borax or microcosmic salt powder. A small amount of salt is coated

Table 12.13. Bead test made with borax ($Na_2B_4O_7.10\ H_2O$)

Bead coloration	Oxidizing	Reducing
Colorless	**hc:** Al, Si, Sn, Bi, Cd, Mo, Pb, Sb, Ti, V, W **ns:** Ag, Al, Ba, Ca, Mg, Sr	Al, Si, Sn, alk. earths, earths **h:** Cu **hc:** Ce, Mn
Gray/Opaque	sprs: Al, Si, Sn	Ag, Bi, Cd, Ni, Pb, Sb, Zn s: Al, Si, Sn sprs: Cu
Blue	c: Cu hc: Co	hc: Co
Green	c: Cr, Cu h: Cu, Fe+Co	Cr hc: U sprs: Fe c: Mo, V
Red	c: Ni h: Ce, Fe	c: Cu
Yellow/Brown	h, ns: Fe, U, V h, sprs: Bi, Pb, Sb	W h: Mo, Ti, V
Violet	h: Ni+Co hc: Mn	c: Ti

The following abbreviations are used in the tables: **h:** hot; **c:** cold; **hc:** hot or cold; **ns:** not saturated; **s:** saturated; **sprs:** supersaturated.

References: (i) Haller, A.; Girard, Ch. (1907) *Mémento du chimiste (Ancien agenda du Chimiste). Recueuil de tables et documents divers indispensables aux laboratoires officiels et industriels*. H. Dunod & E. Pinat Ed., Paris, pp. 200–210. (ii) Brush, G. (1926) *Manual of Determinative Mineralogy with an Introduction on Blowpipe Analysis*. John Wiley & Sons, New York.

Table 12.14. Bead test made with microcosmic salt ($NaNH_4HPO_4$)

Bead coloration	Oxidizing zone	Reducing zone
Colorless	Si (undissolved) h: Mg, Ca, Sr, Ba, Al, Sn ns: Bi,Cd,Mo,Pb,Sb,Ti, Zr,Zn, Y, La, Th	Si (undissolved) Ce, Mn, Sn, Al, Ba, Ca, Mg Sr (sprs, not clear)
Gray/Opaque	s: Al, Ba, Ca, Mg, Sn, Sr	Ag, Bi, Cd, Ni, Pb, Sb, Zn
Blue	c: Cu hc: Co	c: W hc: Co
Green	U c: Cr h: Cu, Mo, Fe+(Co or Cu)	c: Cr h: Mo, U
Red	h, s: Ce, Cr, Fe, Ni	c: Cu h: Ni, Ti+Fe
Yellow/Brown	c: Ni h, s: Co, Fe, U	c: Ni h: Fe, Ti
Violet	hc: Mn	c: Ti

The following abbreviations are used in the tables: **h:** hot; **c:** cold; **hc:** hot or cold; **ns:** not saturated; **s:** saturated; **sprs:** supersaturated.
References: (i) Haller., A; Girard, Ch. (1907) *Mémento du chimiste (Ancien agenda du Chimiste). Recueuil de tables et documents divers indispensables aux laboratoires officiels et industriels*. H. Dunod & E. Pinat Ed., Paris, pp. 200–210. (ii) Brush; Penfield (1906) Determinative Mineralogy and Blowpipe Analysis.

onto the Pt-wire loop and the loop is then heated again in the flame of a Bunsen burner until it melts down into a small transparent bead. If the bead is too small repeat the procedure until a bead of about 1–2 mm in diameter is obtained. A very small amount of the crushed substance to be tested and previously roasted in the case of sulfide minerals is touched by this hot bead, which is then heated again to redness in the oxidizing flame and then in the reducing flame of dart of the blowpipe. If the bead is black in color, dip it into more salt and reheat to dilute the concentration of metal. The bead is allowed to cool and is examined. The element present is determined by matching the color of the glass bead thus formed with known color according to the the zone of the flame. Coloration of borax and microcosmic salt are given in Tables 12.13 and 12.14 respectively.

12.2.23 Heavy-Media or Sink-float Separations in Mineralogy

The separation of heavy minerals by the sink-float techniques is usually performed by immersing a mixture of mineral grains into a glass separatory funnel containing a dense liquid (heavy liquor or medium) of known specific gravity. Under the standard acceleration of gravity the minerals distribute according to their own density, i.e., light minerals float while heavy minerals sink to the bottom of the flask[8]. The most common dense liquids in commonest use are brominated and iodided organic liquids usually diluted with a solvent to adjust the density, to a lesser extent aqueous solutions of inorganic salts and low temperature molten salts are also used for specific purposes. For high density solutions, slurries made by a suspension of a dense solid in a liquid of the same density have been especially studied by Retgers and Gossner in view of their applicability to density determinations of crystals.

[8] Browning, J.S. (1961) Heavy Liquids and Procedures for Laboratory Separation of Minerals. *U.S. Bureau of Mines*, Inform. Circ. No. 8007.

12.2.23.1 Selection of Dense Media

The appropriate liquid used as dense media must meet the following requirements:

- elevate density at least above that of quartz (i.e., 2.650 $g.cm^{-3}$);
- no chemical reactivity with most common minerals;
- thermal and photochemical stability;
- miscibility with usual solvents and diluents (e.g., acetone, benzene, ethanol);
- transparent;
- low dynamic viscosity, i.e., close to that of water at room temperature (1 mPa.s);
- non-hazardous properties (toxic, flammable) and easy to dispose;
- low cost.

12.2.23.2 Common Heavy Liquids Used in Mineralogy

The three most common heavy liquids used in routine mineralogical identification are brominated and iodided organic compounds, among which the three solvents listed below are the most common:

- **tribromomethane** (syn. bromoform) with chemical formula $CHBr_3$ and $d^{20}_4 = 2.89$;
- **tetrabromo-1,1,2,2-ethane** (syn. acetylene tetrabromide) with chemical formula $C_2H_2Br_4$ and $d^{20}_4 = 2.965$);
- **diiodomethane** (syn. methylene iodide) with chemical formula CH_2I_2 and $d^{20}_4 = 3.325$.

These dense liquors allow us to separate grains of minerals easily into two distinct groups:

(i) a **light fraction** with minerals exhibiting a density lower than 2.9 $g.cm^{-3}$ that includes the light igneous-rock-forming silicates, e.g., quartz, feldspars, and feldspathoids (***coupholites***[9]);

(ii) **two heavy fractions** with minerals exhibiting densities greater than 2.9 $g.cm^{-3}$ (***barylites***). The heavy fractions are:

  (1) a medium-density fraction with minerals having a density ranging from 2.9 $g.cm^{-3}$ to 3.3 $g.cm^{-3}$ that corresponds to major silicate minerals;

  (2) a denser fraction with heavy minerals having densities greater than 3.3 $g.cm^{-3}$ and that are of economic importance (ores).

Detailed physical properties of these heavy media along with other less common dense organic and inorganic liquids are described in Chapter 20.

12.3 Strunz Classification of Minerals

The modern systematic classification of minerals was introduced by Prof. Hugo Strunz and is briefly listed in Table 12.15.

[9] According to the French Mineralogist Eugène Lacroix, the coupholites denote the light rock forming minerals having an apparent density lower than 2.77$g.cm^{-3}$ (e.g., quartz, feldspaths, feldspathoids). By contrast heavier minerals having a density greater than the previous values are baylites named after Greek, *baryos*, heavy and *lithos*, stones.

Table 12.15. Strunz classification of minerals

Strunz class	Subclass
1/Class I: Native elements	1/A1 Metals and intermetallic alloys
	1/A2 Semimetals and nonmetals
2/Class II: Sulfides and sulfosalts	2/A1 Alloys and alloylike compounds
	2/B1 Sulfides, selenides, and tellurides (M:S,Se,Te > 1:1)
	2/C1 Sulfides, selenides, and tellurides (M:S,Se,Te = 1:1)
	2/D1 Sulfides, selenides, and tellurides (M:S,Se,Te <1:1)
	2/E1 Sulfosalts ($M_mX_nY_p$ with X=As,Sb,Bi and Y=S,Se,Te)
	2/F1 Arseno-sulfides
3/Class III: Halides (i.e., fluorides, chlorides, bromides, and iodides)	3/A1 Simple halides [M_mX_n]
	3/B1 Anhydrous double halides [$M_mX_nY_p$]
	3/C1 Hydrous halides [$M_mX_n.pH_2O$]
	3/D1 Oxyhalides, and hydroxyhalides [$M_mX_nO_p(OH)_q$]
4/Class IV: Oxides, and hydroxides	4/A1 Oxides [M_2O], and [MO]
	4/B1 Oxides [M_3O_4], spinel type
	4/C1 Oxides [M_2O_3]
	4/D1 Oxides [MO_2]
	4/E1 Oxides [M_2O_5], and [MO_3]
	4/F1 Hydroxides and hydrated oxides [$M_m(OH)_n$ and $M_mO_n.pH_2O$]
	4/G1 Vanadium oxides (V^{4+}/V^{5+})
	4/H1 Uranyl hydroxides and hydrates, with $[UO_2]^{2+}$
	4/J1 Arsenites
	4/K1 Sulfites, selenites, and tellurites
	4/L1 Iodates
5/Class V: Nitrates, carbonates, and borates	5/A1 Nitrates with [NO_3]
	5/B1 Anhydrous carbonates [CO_3], without additional anion
	5/C1 Anhydrous carbonates [CO_3], with additional anions
	5/D1 Hydrous carbonates [CO_3], without additional anion
	5/E1 Hydrous carbonates [CO_3], with additional anions
	5/F1 Uranylcarbonates with $[UO_2]^{2+}$ and [CO_3]
	5/G1 Nesoborates with [BO_3] with [BO_4]
	5/H1 Soroborates with [B_2O_5] to [B_2O_7] with [B_3O_5] to [B_6O_{10}]
	5/J1 Inoborates [B_2O_4] to [B_6O_{10}]
	5/K1 Phylloborates with complex [$B_x(O,OH)_y$] Groups
	5/L1 Tectoborates with [BO_2] to [B_6O_{10}]
6/Class VI: Sulfates, chromates, molybdates, and tungstates	6/A1 Anhydrous sulfates [SO_4], without additional anion
	6/B1 Anhydrous sulfates [SO_4], with additional anions (e.g., F, Cl, O, OH)
	6/C1 Hydrous sulfates [SO_4], without additional anion
	6/D1 Hydrous sulfates [SO_4], with additional anions
	6/F1 Chromates [CrO_4]
	6/G1 Molybdates [MoO_4], wolframates (tungstates) [WO_4]

Table 12.15. *(continued)*

Strunz class	Subclass
7/Class VII: Phosphates, arsenates, and vanadates	7/A1 Anhydrous phosphates [PO_4], without additional anion
	7/B1 Anhydrous phosphates [PO_4], with additional anions (F, Cl, O, OH)
	7/C1 Hydrous phosphates without additional anion
	7/D1 Hydrous phosphates with additional anions
	7/E1 Uranylphosphates and vanadates [UO_2] and [PO_4],[AsO_4], [UO_2] and [V_2O_8]
8/Class VIII: Silicates	8/A1 Nesosilicates (i.e., isolated tetrahedrons) [SiO_4]
	8/B1 Nesosubsilicates with tetrahedron's additional anion
	8/C1 Sorosilicates (i.e., paired tetrahedrons) [Si_2O_7]
	8/D1 Unclassified silicates
	8/E1 Cyclosilicates (i.e., ring tetraedrons) [SiO_3], [Si_3O_9], [Si_4O_{12}], [Si_6O_{18}]
	8/F1Inosilicates (i.e., layers, chains, bands and ribbons of tetrahedrons) [SiO_3], [Si_4O_{11}]
	8/J1 Tectosilicates (i.e., framework or network tetraedrons) [$(Si,Al)O_2$], [SiO_2]
	8/H1 Phyllosilicates (i.e., foliated)
9/Class IX: Organic compounds and mineraloids	9/A1 Salts of organic acids
	9/B1 Hydrocarbon without nitrogen
	9/C1 Resins and waxes compounds
	9/D1 Hydrocarbons with nitrogen

12.4 Dana's Classification of Minerals

The systematic classification of minerals according to the American Chemist and Mineralogist James Dwight Dana was the first to be established in 1837 using the Linnaen principles of taxonomy modified by Friedrich Mohs and the Berzelius system for the notation of chemical formulae. Since 1837, it was modernized to take into account recent discoveries.

Table 12.16. Dana's classification of minerals

Dana's class	Subclasses
I – Native elements	I – 1 Native elements
II – Sulfides and sulfosalts	II – 2 Sulfide minerals II – 3 Sulfides – sulfosalts
III – Oxides and hydroxides	III – 4 Oxide minerals III – 5 Oxides containing uranium and thorium III – 6 Hydroxides and oxides containing hydroxyl III – 7 Multiple oxides III – 8 Multiple oxides with Nb, Ta, and Ti
IV – Halides	IV – 9 Halide minerals IV – 10 Oxyhalides and hydroxyhalides IV – 11 Halide complexes; alumino-fluorides IV – 12 Compound halides

Table 12.16. *(continued)*

Dana's class	Subclasses
V – Carbonates, borates and nitrates	V – 13 Carbonate minerals V – 14 Anhydrous carbonates V – 15 Hydrated carbonate V – 16 Carbonates – hydroxyl or halogen V – 17 Compound carbonates V – 18 Simple nitrates V – 19 Nitrates – hydroxyl or halogen V – 20 Compound nitrates V – 21 Iodates – anhydrous and hydrated V – 22 Iodates – hydroxyl or halogen V – 23 Compound iodates V – 24 Borates – anhydrous V – 25 Anhydrous borates containing hydroxyl or halogen V – 26 Hydrated borates containing hydroxyl or halogen V – 27 Compound borates
VI – Sulfates, arsenates, and chromates	VI – 28 Sulfate minerals VI – 29 Hydrated acid and sulfates VI – 30 Anhydrous sulfates containing hydroxyl or halogen VI – 31 Hydrated sulfates containing hydroxyl or halogen VI – 32 Compound sulfates VI – 33 Selenates and tellurates VI – 34 Selenites – tellurites – sulfites VI – 35 Anhydrous chromates VI – 36 Compound chromates
VII – Phosphates, vanadates, molybdates, and tungstates	VII – 37 Phosphate minerals VII – 38 Anhydrous phosphates, etc. VII – 39 Hydrated acid phosphates, etc. VII – 40 Hydrated phosphates, etc. VII – 41 Anhydrous phosphates, etc., containing hydroxyl or halogen VII – 42 Hydrated phosphates, etc., containing hydroxyl or halogen VII – 43 Compound phosphates, etc. VII – 44 Antimonates VII – 45 Acid and normal antimonites, arsenites and phosphites VII – 46 Basic or halogen-containing antimonites, arsenites and phosphites VII – 47 Vanadium oxysalts VII – 48 Anhydrous molybdates and tungstates VII – 49 Basic and hydrated molybdates and tungstates
VIII – Silicates	VIII – 51 Nesosilicate minerals VIII – 52 Nesosilicates with Insular SiO_4 groups and O, OH, F, and H_2O VIII – 53 Nesosilicates with insular SiO_4 groups and other anions of complex cations VIII – 54 Nesosilicates nesosilicate borosilicates and some beryllosilicates VIII – 55 Sorosilicate minerals VIII – 56 Sorosilicates with Si_2O_7 groups and O, OH, F. and H_2O VIII – 57 Sorosilicates with insular Si_3O_{10} and larger noncyclic groups VIII – 58 Sorosilicates with insular, mixed, single, and larger tetrahedral groups VIII – 59 Cyclosilicate minerals VIII – 60 Cyclosilicates with four-membered rings VIII – 61 Cyclosilicates with six-membered rings VIII – 62 Cyclosilicates with eight-membered rings VIII – 63 Cyclosilicates with condensed rings

Table 12.16. *(continued)*

Dana's class	Subclasses
VIII – Silicates	VIII – 64 Cyclosilicates with rings with other anions and insular silicate groups VIII – 65 Inosilicate minerals VIII – 66 Inosilicates with double-width unbranched chains, W=2 VIII – 67 Inosilicates with unbranched chains with W>2 VIII – 68 Inosilicates with structures with chains of more than one width VIII – 69 Inosilicates with chains with side branches or loops VIII – 70 Inosilicates with column or tube structures VIII – 71 Phyllosilicate minerals VIII – 72 Phyllosilicates with 2D infinite sheets with other than six-membered rings VIII – 73 Phyllosilicates with condensed tetrahedral sheets VIII – 74 Phyllosilicates with modulated layers VIII – 75 Tektosilicate minerals
IX – 50 Organic minerals	IX – 50 Organic minerals

12.5 Gemstones

A ***gemstone*** is a natural mineral that can be cut and polished or otherwise treated for use as jewelry or other ornament. A ***precious gemstone*** has beauty, durability, and rarity, whereas a ***semiprecious gemstone*** has only one or two of these qualities. A ***gem*** is a gemstone that has been cut and polished. Diamond, corundum (i.e., ruby and sapphire varieties) and beryl (i.e., emerald and aquamarine varieties) are generally classified as precious gemstones while all other gemstones are usually classed as semiprecious. A ***gemmologist*** or ***gemologist*** is a mineralogist with proven skills in identifying and evaluating gemstones. A ***lapidary*** is a cutter, polisher, or engraver of precious stones. From a geological point of view, gemstones occur in various geologic materials but most gemstones are found in particular igneous rocks (e.g., pegmatites, kimberlites, and lamproites) and in sedimentary alluvial gravels (e.g., placers deposits), but metamorphic rocks may also contain gem materials. The major precious and semiprecious gemstones are listed in Table 12.17.

Table 12.17. Precious and semiprecious gemstones

Mineral	Gem varieties	Color
Benitoite	Benitoite	Deep blue color
Beryl	Emerald	Intense green or bluish green
	Aquamarine	Greenish blue or light blue
	Morganite	Pink, purple pink, or peach
	Heliodore	Golden yellow to golden green
	Goshenite	Colorless, greenish yellow, yellow green, brownish
Chrysoberyl	Chrysoberyl	Transparent yellowish green to greenish yellow and pale brown
	Alexandrite	Red in incandescent light and green in daylight
Corundum	Ruby	Intense red
	Sapphire	Blue
Diamond	Diamond	Colorless, yellow canary, green, deep blue

Table 12.17. *(continued)*

Mineral	Gem varieties	Color
Plagioclases	Labradorite	Colorful, iridescent, also transparent stones in yellow, orange, red, and green
	Sunstone	Gold spangles from inclusions of hematite
	Peristerite	Blue white iridescence
Orthoclases	Amazonite	Yellow green to greenish blue
	Moonstone	Colorless; also white to yellowish, and reddish to bluish gray
Garnets	Almandine	Orange red to purplish red
	Andradite	Yellowish green to orangy yellow to black:
	Demantoid	Green to yellow green
	Grossular	Colorless; also orange, pink, yellow, and brown
	Hessonite	Yellow orange to red
	Malaia	Yellowish to reddish orange to brown
	Pyrope	Colorless also pink to red
	Rhodolite	Purplish red to red purple
	Spessartine	Yellowish orange
	Topazolite	Yellow to orangy yellow
	Tsavorite	Green to yellowish green
	Uvarovite	Emerald green
Jadeite	Nephrite	White, leafy and blue green, emerald green, lavender, dark blue green and greenish black, deep emerald-green
Lazurite	Lapis lazuli[10]	Deep blue, azure blue, greenish blue (bluish color with flecks of white and gold)
Opal	White opal	Opaque, porcelain-like white material; colors resemble flashes or speckles
	Black opal	Flashes and speckles appear against black background
	Water opal	A transparent, colorless opal is the background for brilliant flashes of color
	Fire opal	Reddish or orange opa
Olivine	Peridot	Olive to lime green
Quartz	Rock crystal	Colorless
	Amethyst	Violet
	Citrine	Yellow to amber
	Morion	Black
	Smoky quartz	gray to brown
	Rose quartz	Translucent pink
Silica (cryptocrystalline)	Chalcedony and Jasper	White to black
	Agate	Various
	Onyx	Black
	Bloodstone	Red

[10] An aggregate of lazurite with variable amounts of pyrite and calcite

Table 12.17. *(continued)*

Mineral	Gem varieties	Color
Spinels	Balas ruby	Red
	Almandine spinel	Purple red
	Rubicelle	Orange
	Sapphire spinel and ghanospinel	Blue
	Chlorspine	Green
Spodumene	Kunzite	Pink to lillac
	Hiddenite	Yellow to green
Tanzanite	Tanzanite	
Topaz	Topaz	Wine yellow, pale blue, green, violet, or red
Tourmaline	Achorite	Colorless
	Brazilian emerald	Green
	Dravite	Brown
	Indicolite	Dark blue
	Rubellite	Pink to red
	Siberite	Violet
	Verdilite	Green
Turquoise	Turquoise	Deep blue to greenish blue
Zircon	Jargon	Brown
	Malacon	Metamict
	Matura diamond	Colorless
	Hyacinth	Yellow, orange, red, brown

Note: amber, coral and pearl are organic materials also considered with gem materials

12.5.1 Diamond

12.5.1.1 Introduction

Diamond [7782-40-3] with the relative atomic molar mass of 12.0107 is the high-pressure and high-temperature allotrope of carbon (i.e., P >20 GPa and T >4000 K), but at ambient pressure it is metastable owing to the high temperature (2000 K) needed to initiate the phase change to graphite. The word diamond originates from the Greek, *adamas*, meaning invincible due to its hardness. Diamond crystallographic structure consists to a face centered cubic crystal lattice where the carbon atoms occupy the eight corners, the centers of the six faces and half of the tetrahedral crystallographic sites (Z = 8). The most common crystal habits for euhedral crystals found in nature are the octahedron {111}, the cube {100}, and the dodecahedron {110} sometimes rounded due to etching. Diamond normally cleaves on the (111) plane but cleavage has been observed on the (110) plane and to a lesser extent some other crystallographic planes. Diamond luster is adamantine by definition and depending of the diamond type and impurities diamonds can be colorless, yellow, blue, or green. Polycrystalline diamond is also found in nature as multigranular masses called ***boart*** or ***bort.*** These polycrystalline aggregates are especially named ***carbonado*** after the Portuguese word meaning burned for black polycrystalline aggregates coming from the Congo-Kasai craton in the Central African Republic and in the São Francisco craton in Brazil, while ***framesite*** denotes randomly oriented microcrystalline diamonds found in kimberlites worldwide.

12.5.1.2 Diamond Types

Depending on the levels of trace impurities occurring in their crystal lattice, diamonds are classified into two major types, that is, those bearing nitrogen as major impurity (**Type I**) and those without nitrogen (**Type II**). These two subgroups are further subdivided into Types Ia, Ib, IIa, and IIb respectivelly. A brief description of these various types is presented in Table 12.18.

Table 12.18. Classification of major types of diamonds

Main type	Subdivision	Description
Type I (with nitrogen)	**Type Ia**	**Type Ia** diamonds with an occurrence of 98%, the are the most common type of naturally occurring diamonds. They contain nitrogen (10–3000 ppm at. N) which is present into small aggregates of two to four atoms, including platelets.
	Type Ib	**Type Ib** diamonds are naturally scarce (ca. 0.1 %). They have a low nitrogen content (25–30 ppm at. N) which is dispersed substitionally. Usually, most synthetic diamonds tend to be of the Type Ib, with up to 0.05 wt.% N as single atoms, often giving rise to a brilliant yellow color (e.g., canary diamonds).
Type II (without nitrogen)	**Type IIa**	**Type IIa** diamonds are relatively free of nitrogen imputity and they contain less than 10 ppm at. N. They are all colorless (e.g., the Cullinan and the Koh-i-Noor) and exhibit enhanced optical and thermal properties.
	Type IIb	**Type IIb** diamonds are extremely rare. Due to minute amounts of boron impurities and with nitrogen below 0.1 ppm at. N they behave as a **p-type** semiconductors. They exhibits a blue color (e.g., the blue Hope diamond) due to the absorption band in the tail of the infrared absorption spectrum combined with the acceptor center.

Notes: about 22 mineral species have been identified as tiny inclusions in diamonds among those majorite garnet, ferropericlase, magnesioperovskite, and stishovite.

Recently, a classification based on the measure of the variation of the carbon and nitrogen stable isotopes was introduced[11] as a geochemical fingerprint of the deep origin of natural diamonds. The classification utilizes the delta isotopic function (δ‰) of a given stable isotope (e.g., ^{13}C, ^{15}N but also ^{18}O and ^{34}S). The delta isotopic function expresses the deviation of a given isotopic ratio for instance ($^{13}C/^{12}C$) or ($^{15}N/^{14}N$) relative to a standard reference material such as the ***Standard Pee Dee Belemnite*** (SPDB) the ***standard mean ocean water*** (SMOW) or the ***Cañon Diablo Troilite*** (CDT) and expressed in parts per thousand (‰). Geochemists have analyzed the isotopic composition of carbon (the ratio of carbon-13 to carbon-12) in diamonds and compared it to carbon in other minerals and rocks. Their work suggests diamonds are made of carbon that comes from two sources. Some diamonds have carbon that is identical to that in carbonate minerals (e.g., calcite in limestone) and hydrocarbons, suggesting they were derived from ocean floor or near-surface sediments that were recycled, through the process of subduction, into the mantle. Others contain carbon that is more like that expected if it were derived directly from parts of the mantle (peridotite) that still contain carbon from when the Earth first formed, 4.5 billion years ago.

12.5.1.3 Diamond Physical and Chemical Properties

The properties of diamond require many superlatives to describe them as diamond exhibits a unique set of physical and chemical properties, among those the most remarkable characteristics are:

[11] Cartigny, P. Stable isotopes and the origin of diamond. *Elements*, **1** (2) (2005) 79–84.

(i) Diamond is the hardest known natural solid still unsurpassed.
(ii) Diamond has the highest Young's modulus.
(iii) Diamond exhibits the highest thermal conductivity near room temperature of all the known materials.
(iv) Diamond has the lowest coefficient of linear thermal expansion.
(v) Diamond is an excellent electrical insulator due to the strong covalent bonding except for the type IIb doped with boron which is a p-type semiconductor.
(vi) Diamond is corrosion-resistant to strong acids, alkalis, and molten salts and resist graphitization up to high temperatures.
(vii) Diamond is transparent from near-UV until far IR electromagnetic radiation.

Table 12.19. Diamond physical properties and characteristics

Properties (SI unit)		Value
General properties	Crystal lattice	Cubic
	Strukturbericht and Pearson's symbol (atoms per formula unit)	A4, *cF8* ($Z = 8$)
	Lattice parameter (a/pm)	356.71
	Space group (Hermann–Mauguin)	Fd3m
	Relative atomic molar mass ($^{12}C = 12$)	12.0107
Mechanical properties	Density (ρ/kg.m^{-3})	3515
	Young's or elasticity modulus (E/GPa)	1050
	Coulomb's or shear modulus (G/GPa)	300
	Bulk or compression modulus (K/GPa)	500
	Poisson's ratio (ν/nil)	0.100
	Sound longitudinal velocity (V_l/m.s^{-1})	17,500
	Tensile strength (/MPa)	>1200
	Compressive strength (/GPa)	>110
	Dynamic friction coefficient (μ)	0.1
	Mohs hardness (HM)	10 (definition)
	Knoop hardness (H_K/GPa)	56–115
Thermal	Thermal conductivity (k/Wm^{-1}K^{-1})	500–2500 (300)
	Specific heat capacity (c_p/J.K^{-1}.kg^{-1})	502
	Coefficient linear thermal expansion (α/10^{-6} K^{-1})	0.8 (300 K)
		4.4 (700 K)
Electrical	Electrical resistivity (ρ/Ω.m)	10^{11}–10^{14}
	Energy band gap (E_g/eV)	5.45
	Relative electric permittivity (at 27°C and 0.3 kHz)	5.58–5.70
	Loss tangent factor (tanδ at 140 GHz)	$<2.0 \times 10^{-5}$
Optical	Refractive index at 589 nm (n_D)	2.4175–2.4178
	Refractive index at 546.1 nm ($n_{H\gamma}$)	2.4237
	Refractive index at 656.3 nm ($n_{H\alpha}$)	2.4099
	Optical transparency range (λ/μm)	0.225–80
	Refractive index at 226.5 nm (n)	2.7151

For all these reasons diamond is an inescapable strategic industrial mineral for providing the superabrasive market for manufacturing drilling bits required by the oil and mining industry and for fabricating machining tools. Most natural diamond becomes fluorescent when exposed to X-rays which property is extensively used to sort diamond during mineral dressing operations. The major physical properties and characteristics of diamond are summarized in Table 12.19.

12.5.1.4 Diamond: Origins and Occurrence

The high density of diamond (3520 $kg.m^{-3}$) compared to that of the other carbon allotrope graphite (2200 $kg.m^{-3}$) indicates clearly that diamond crystallize only under both high pressure and high temperature conditions. These extreme conditions are those encountered at least in the upper mantle in the narrow depth range between 150 km and 200 km, that is, under lithostatic pressures ranging from 4 to 7 GPa, and temperatures well above 1000°C. Moreover, the nature of their silicate inclusions indicates that diamonds form usually in the region of maximum thickness of the lithosphere which is only found beneath the oldest roots of our continents, called the cratons. However, diamonds are also formed at greater depths in the deep upper mantle (410 km), the transition zone (410–660 km) and even in the lower mantle (660–2900 km). The source of carbon in the mantle can be explained by plate tectonics. Actually, the dense oceanic lithospheric slabs are subducted back into the mantle where they sink by gravity into the asthenosphere and transition zone to the top of the lower mantle and even deeper, to the core-mantle boundary as confirmed by seismic tomography. The sinking oceanic crust brings its deposited carbonaceous and carbonated sediments to zones where the high temperature, the high pressure conditions together with a low fugacity of oxygen (f_{O2}) are suitable to the formation of diamond from hydrocarbon-bearing fluids and the decomposition of carbonates. Once the diamonds form in the mantle they are brought to the Earth's surface as xenocrystals by ascending magma plumes that lift the diamonds to the surface fast enough to avoid either the deleterious phase transformation of diamond into graphite or its dissolution into the ascending magma. Hence the occurrence of diamonds at the surface of the Earth must be regarded as accidental and it presence is mainly attributed to its high corrosion resistance during the ascending process. The types of magma that bring diamonds give rise to extremely rare ultramafic volcanic igneous rocks such as ***kimberlites*** and ***lamproites***. Kimberlites, originally named after the town of Kimberley, Republic of South Africa, are ultramafic igneous rocks of volcanic origin made of the following major minerals: olivine, monticellite, phlogopite, chromian diopside and spinel, serpentine and minor minerals such as apatite, chromian pyrope, magnetite and diamond. Kimberlites usually form a carrot-shaped intrusive body called diatremes or pipes from mantle depths (>30 km) having roughly 2–3 kilometer diameter (e.g., Kimberley, South Africa). The walls of the diatreme dip at angles of 75–85° from the horizontal; the crater walls exhibit shallower dip. The crater is the widest part of the pipe, but it seldom exceeds 2 km in diameter. The concentration of diamond is usually low and ranges from 0.5 to 5 carat per tonne among which less than 5% are of gem quality. From the nature of the silicate inclusions (e.g., coesite) found in diamonds it was found that kimberlites form usually in the region of maximum thickness of the lithosphere which is only found beneath cratons older than 2.5 Ga (***Clifford's rule***) also called ***archons***. Kimberlite diatremes are known on every continent but most do not contain diamonds. Southern and Western Africa (e.g., Democratic Republic of Congo, Botswana, Namibia, and South Africa) contains the largest concentrations of diamond-bearing kimberlites. Other important sources are in Northern Russia, Australia, Brazil and, since 1997, the Northwest Territories in Canada. By contrast, ***lamproites*** (e.g., Argyle, Australia) are phaneritic igneous rocks with olivine, leucite, and phlogopite forming wider crater than kimberlite having fewer than 500 metres in depth. Some diamonds also originates during metamorphism or impact from meteorites. Once these primary diamond

Figure 12.2. Major diamond deposits

deposits are eroded by means of meteoric and geomorphological processes, the diamonds due to their outstanding hardness and chemical inertness are transported by rivers and finally forms detrital placer grains that concentrate with other heavy minerals in alluvial placer deposits (e.g., Sierra Leone) or even beach mineral sands (e.g., Namibia) derived from the parent kimberlite or lamproite rocks.

Kimberlite and lamproite craters and kimberlite diatremes are usually mined as open-pit operations because the host rocks are usually friable. Underground production is frequently initiated with increases at depth. Alluvial sources are mined as open-pit operations.

Most of the production of diamond is concentrated geographically in a few regions worldwide (see Figure 12.2) usually in the oldest continents: Africa (e.g., Angola, Botswana, Congo, Namibia, and Republic of South Africa), Asia (e.g., northeastern Siberia and Yakutia in Russia), Australia, North America (e.g., Northwest Territories in Canada), and South America (e.g., Brazil and Venezuela). Botswana is the world's leading diamond producer in terms of output value and quantity and the total diamonds produced worldwide both industrial and gems reached 150 million carats (30 tonnes).

12.5.1.5 Industrial Applications

Because it is the hardest substance known, diamond has been used for centuries as an abrasive in cutting, drilling, grinding, and polishing. Industrial grade diamond continues to be used as a superabrasive for many industrial applications. Despite being expensive, diamond has proven to be more cost-effective in many industrial processes even compared to cubic boron nitride or borazon (cBN) and silicon nitride (Si_3N_4) because it cuts faster and lasts longer than alternative superabrasive materials. More recently, CVD of thin diamond films has opened the way to a range of new applications. The space shuttle uses diamond-coated parts to produce wear-resistant, lubricant-free bearings, and similar technology is expected to be used before long in terrestrial vehicles. But the use of diamond as both an abrasive and a wear-resistant coating is limited by the solubility of carbon in ferrite. In 2004 according to D.W. Olson from the USGS, circa 800 millions carats[12] (i.e., 160 tonnes) were used for superabrasives and the United States remained the world's leading market for the production of industrial diamond.

[12] 1 carat = 200 mg (E)

12.5.1.6 Diamond Prices

According to the U.S. Geological Survey, natural industrial diamond normally has a more limited range of values. Its price varies from about 0.30 US$/carat for bort-size material to about 7–10 US$/carat for most stones, with some larger stones of gem quality selling for up to 200 US$/carat. Synthetic industrial diamond has a much larger price range than natural diamond. Prices of synthetic diamond vary according to particle strength, size, shape, crystallinity, and the absence or presence of metal coatings. In general, synthetic diamond prices for grinding and polishing range from as low as $0.40–$1.50 per carat. Strong and blocky material for sawing and drilling sells for $1.50–$3.50 per carat. Large synthetic crystals with excellent structure for specific applications sell for many hundreds of dollars per carat. There are more than 14,000 categories used to assess rough diamond and more than 100,000 different combinations of carat, clarity, color, and cut values used to assess polished diamond.

12.5.1.7 Treatments

Color in diamonds arises from trace amounts of nitrogen (yellow) and/or boron (blue) that substitute for carbon and act as either electron donors or acceptors with electron energy transition levels that are within the visible spectrum. Color can be induced or changed by irradiation and/or heating. Irradiation by high energy particles (e.g., electrons, neutrons, protons, gamma rays, alpha particles) is known to change pale yellow stones to fancy blue, green, brown, orange, very dark green, and yellow. Heating following irradiation can further modify the color. Treatment by all but gamma rays and neutrons colors only the outer few microns of a diamond's surface, producing an umbrella-like color zonation near the culet or an unevenness of color elsewhere. Heating changes the absorption spectra and can usually be detected with a spectroscope. Color change induced by bombardment of neutrons (e.g., nuclear reactor) is most difficult to detect; most stones turn green but show no color zoning or characteristic change in their absorption spectra.

Coatings or backings have also been used to improve color. Coating applied to the pavilion girdle area can be used to mask a pale yellow color or give a blue or pink tint. Well applied coatings can be difficult to detect but sometimes give a grayish tint to the stone's color.

12.5.1.8 Diamond Shaping and Valuation

Because of its extreme hardness, diamond cutting is a highly specialized process. Preforming usually involves cutting but not cleaving with a diamond-impregnated saw, followed by further rough-shaping by a process known as bruting. Bruting is done by affixing the diamond to a dop stick, and shaping the stone with a diamond-tipped cutting tool called the brute. The principal cutting centers for diamond are in New York, Antwerp, and Tel Aviv. Most cutting of very small diamonds called melee is done in India. Smaller cutting centers exist in Amsterdam, London, Johannesburg, San Juan, and Puerto Rico.

Unlike colored stones, the wide availability of diamonds over a large range of quality has led to highly standardized grading practices. One of the most widely used rating schemes is the grading system introduced by the GEMOLOGICAL INSTITUTE OF AMERICA (GIA) known as the 4 C's standing for Color, Cut proportions, Clarity, and Caratage. This system yields highly reproducible results, is easily understood, and requires little subjectivity.

Color. The GIA color grading scale is used to grade "colorless" diamonds, those showing varying shades of yellow, gray or brown tint. The most desirable are the truly colorless stones, which receive a grade of D. Color differences are extremely slight, so much so that the difference between a D and G-rated diamond is not discernable to the untrained eye. To grade color accurately requires comparisons with a set of pre-graded, "master stones". The highest master stone is an E; any stone that falls on or above an E is a D. Without masters,

a loose diamond can only be approximated within two grades. A mounted stone can only be approximated within three grades, with or without a master.

Clarity. Inclusions, fractures, and incipient cleavage cracks all fall under the general heading of "flaws" that affect a diamond's clarity. In grading, no distinction is made among them, except with respect to the extent each affects appearance. White inclusions are preferred to black, and those near the girdle are not of the consequence of flaws near the table or culet. The scale is characterized by a series of abbreviations: flawless (FL), internally flawless (IF), very, very slightly included (VVSI), etc. By most definitions, no flaws are visible to the naked eye until a grade of I1. Flaws in stones above this grade are visible only with a 10X loupe.

Cut proportions. Although a wide variety of cuts have been used and continue to be used to facet diamond, by far the standard in this country is the ***Standard Brilliant Cut*** or ***American Cut***. The cut proportions are extremely important to the value of a diamond. For standard brilliants, the ***table percentage***, that is, the diameter of table vs. the diameter of girdle, should be 52–58%. The ***depth percentage***, that is, the distance from table to culet vs. diameter of girdle should ideally be between 61% and 63% for standard round brilliants. The depth percentage parameter includes the girdle thickness, which is less than desirable inasmuch as all girdles are not a uniform percentage of the diameter.The girdle should be thick enough to prevent chipping during mounting and wear and no thicker, and should be of uniform thickness around the stone. A guideline for maximum girdle thickness is 3% of the stones diameter with a minimum of 0.05 mm.

Caratage. The mass of diamond is expressed in carat (200 mg). In practice, the girdle diameters can be used to estimate weights. For instance, 0.5 carat diamonds have a girdle diameter close to 5 mm, 0.75 close to 6 mm, 1 carat close to 6.5 mm, 1.5 carats close to 7.5 mm, 2 carats close to 8 mm, and 2.5 carats close to 9 mm. A fairly precise formula that can be used to estimate the weight of a mounted standard round brilliant diamond with a girdle diameter, D, in mm and depth h, in mm is given belows:

$$\text{Caratage of diamond} = 0.0061 \cdot D^2 \cdot h$$

Another useful formula for well proportioned stones when the depth is unknown is:

$$\text{Caratage of diamond} = 0.0037 \cdot D^3$$

12.5.2 Beryl Gem Varieties

Beryl [1302-52-9] named after the Greek, *beryllos*, a word designating various green gemstones with the chemical formula $Be_3Al_2[Si_6O_{18}]$ and the relative molar mass of 537.50182 is a hexagonal cyclosilicate mineral that occurs exclusively in high-temperature hydrothermal veins, in granitic pegmatites, at the contact zone of intrusive mafic igneous rocks with aluminous schists, shales or limestones and in a lesser extent in vugs inside rhyolites. The departure from its theoretical chemical formula is common due to the isomorphous substitution of the hexacoordinated aluminum cations (Al^{3+}) in the crystal lattice by chromophoric metal cations. These substitutions impart a wide variety of vivid allochromatic colors, each of which is responsible of a particular beryl gem variety. For instance, substitution by chromium (Cr^{3+}) or rarely vanadium (V^{3+}) imparts a medium to dark green color and the resulting gem beryl is called ***emerald***. Ferrous iron (Fe^{2+}) imparts a blue color and the gem variety is called ***aquamarine*** while ferric iron (Fe^{3+}) imparts a golden yellow color and is named ***heliodor***. Manganous cations (Mn^{2+}) furnishes a pink hue to ***morganite*** or a deep red color such as in ***red beryl***, while ***goshenite*** is the colorless gem variety of beryl. The distinguishing physical properties of beryl are:

(i) a low mass density;
(ii) low refractive indices;
(iii) dichroism; and
(iv) a low birefringence.

On the other hand, the main properties of the gem varieties of beryl are summarized in Table 12.20.

Table 12.20. Major properties of the gem varieties of beryl

Properties	Emerald	Aquamarine	Morganite	Heliodore	Goshenite
Crystal space lattice	Hexagonal a = 920.5 pm – 927.4 pm c = 918.7 pm – 924.9 pm				
Symmetry	Space group: *P6/mmc* Atoms per formula unit: Z = *2* apfu				
Habit	Well formed prismatic or tabullar hexagonal crystals, with pinacoidal {1010}, {0001}, or prism {1120} or pyramidal terminations				
Color (dopant)	Dark green (Cr^{3+}, V^{3+})	Blue (Fe^{2+})	Pink (Mn^{2+})	Golden yellow (Fe^{3+})	Colorless (none)
Pleochroism (weak)	Green to blue green	Blue to darker blue	Light red to light viole	Greenish yellow to yellow	none
Crystalline optics	Uniaxial (–) ε = 1.568 ω = 1.564	Uniaxial (–) ε = 1.576–1.593 ω = 1.569–1.586	Uniaxial (–) ε = 1.576 ω = 1.570	Uniaxial (–) ε = 1.567 ω = 1.590	Uniaxial (–) ε = 1.568 ω = 1.564
Birefringence (δ)	0.004	0.005–0.007	0.006		0.004
Dispersion	0.014				
Fluorescence under UV light	none to weak orange-red or green	very weak to none			
Density (/kg.m^{-3})	2670–2780	2680–2700	2710–2900	2680–2700	2630–2970
Mohs hardness (HM)	7.5–8				
Vickers hardness (HV/GPa)	11.7–14.2				

12.5.2.1 Emerald

Description. The emerald is a gem variety of beryl doped by either chromium or vanadium providing its green color. The velvety appearance and lime color of the best emeralds is unique among all natural gems. Nearly all emeralds contain tiny inclusions, with the best colored stones sometimes being the most included. The term ***jardin*** named after the French word for garden, is used for the mossy-appearing, densely included gemstones. Emeralds with high clarity and color are extremely rare in sizes above 2–3 ct. Unlike other beryl gem varieties, emeralds are nearly always mined *in situ* except in Brazil where placer deposits exist. Actually, due to the abundance of inclusions, which decreases their toughness, most crystals are too fragile to survive the mechanical stresses encountered during fluvial transport.

Natural occurrence and deposits. About 60% of the world production of emerald comes from Colombia. The production is mainly located in two mining districts, i.e., northeast and east of Bogota, called Muzo and Chivor respectivelly. These two gem deposits were originally mined by Aztecs and then rediscovered by Spanish in 1537 (Chivor) and 1559 (Muzo). The Muzo mine was once the most prolific emerald mine in the world. At Muzo, emerald beryl occurs in calcite veins through black shale. At Chivor, the emerald beryl occurs in quartz-albite-apatite veins that invade a gray calcareous shale. Both Muzo and Chivor emeralds are characterized by three-phase inclusions, that is, entrapped fluid and gas bubbles with tiny crystals of halite (NaCl). Muzo emeralds often contain inclusions of calcite and yellow-brown needles of the mineral parisite. Emeralds are also mined in Brazil from alluvial placer deposits where the major producing areas are: the Salininha and Carnaibu Districts (State of Bahia); the Santa Terezinha District (State of Goias); the Nova Era and Itabira Districts (State of Minas Gerias). The majority of Brazilian gemstones contain vanadium as chromophore and are typically lighter-toned and much yellower compared to other sources. In Africa emeralds come from two major locations: in the Sandawana Valley (Zimbabwe) the emerald occurs in schists crossed by pegmatites veins and quartz stockwerks. In the Miku deposit near Kitwe (Zambia) that was once a major producer, the emerald also occurred in schists adjacent to pegmatites. Others minor production worldwide is also reported in the Ural Mountains (Russia), India, Tanzania, Australia, Pakistan (Swat Valley), Afghanistan (Panjshir Valley), in the United States in North Carolina near Hiddenite, South Africa, Austria, and Madagascar.

Shaping and treatment. Usually the step-cuts called the emerald cut are used. Heavily flawed stones are sometimes cut *en cabochon*. Some emerals are oiled to improve their clarity. Canada balsam and cedarwood oil fill cracks and cavities, and due to the refractive index close to that of the gemstone, cracks vanished.

Synthetic emeralds. Emeralds can be synthesized either by flux-growth or hydrothermal processes. The flux-growth techniques is used by Chatham Research Laboratories in San Francisco, United States and Les Établissements Céramiques Pierre Gilson, while the hydrothermal synthesis once utilized by Union Carbide (1965–1970) is currently employed by Biron and Vacuum Ventures. Synthetic emeralds are easily distinguished from naturals by their lower indices of refraction and densities, and by their distinct inclusions.

12.5.2.2 Aquamarine

Description. Aquamarine is a greenish-blue to bluish-green gem variety of beryl. The color is imparted by ferrous cations. It is important to note that most raw aquamarines especially those mined in Brazil exhibit a strong yellow component and thus they appear green when viewed. Therefore, most commercial aquamarine with a deep blue color have followed a heat treatment between 250°C and 720°C in order to deepen the color and to drive off green overtones. Aquamarine can be distinguished from blue topaz by its hardness, the indices of refraction and its density. Aquamarine occurs exclusively in granitic pegmatites, or pebbles or cobbles in stream gravels. Single giant crystals weighing up to 110 kg are also known.

Natural occurrence and deposits. Brazil is the most important source of aquamarine. The most famous gem deposits are all located in the pegmatite region of the state of Minas Gerais. Four districts have produced major amount of aquamarine:

(i) Teofilo Otoni-Marambaia;
(ii) Jequitinhonha river valley;
(iii) Araçuai river-Capelinha-Malacacheta; and
(iv) Governador Valadares.[13]

[13] Proctor, K. Gem pegmatites of Minas Gerais, Brazil: eploration, Occurrence, and aquamarine deposits. *Gems & Gemology*, Summer 1994, pp. 78–100.

The Brazilian aquamarine is found either in primary or secondary gem deposits. In primary deposits, aquamarine is found in gem pockets hosted by granitic pegmatites. In secondary deposits, aquamarine along with other gem varieties of beryl, topaz, and tourmaline is found in the weathered material coming from the parent pegmatite and they can be subdivided into:

(i) *eluvial*;
(ii) *colluvial*; and
(iii) *alluvial* type gem deposits.

Eluvial deposits usually lie on hilltops close to parent granitic pegmatite dykes. The aquamarine crystals are found in *in situ* moderatly decomposed and eroded host rock. Colluvial deposits are found usually on the hillsides and are covered by a thick lateritic soil, aquamarine is found in the clay-like softened material produced by the intense meteoric weathering of the host rock common under the tropical climate. Finally, alluvial type deposits are found in the valleys far away from the original host pegmatite, and aquamarine along with other hard gem minerals are found as rounded stones into the gravel. Aquamarines are also found in Africa at Kleine Spitzkopje (Namibia), in Nigeria, Zambia, Zimbabwe, in Madagascar and in a lesser extent in Afghanistan, Northern Ireland, Russia, Sri Lanka, Pakistan, India, and United States.

12.5.2.3 Morganite

Description. Morganite is a pink to peach-colored gem variety of beryl, named after J.P. Morgan, the famous financier and banker. The color is due to the doping by manganous cations. A deep red gem variety of beryl occurring at the Ruby Violet Mine in the Wah Wah mountains Utah, is not called morganite, but red beryl. Heat treatment of some specimens renders them colorless, in others heating may be used to drive off a yellow overtone produced by a yellow color center to yield a nice pink.

Natural occurrence and deposits. Morganite occurs in granitic pegmatites along with tourmaline. The major locations are in the United States at Pala and Mesa Grande districts in San Diego County, California; in Brazil in the State of Minas Gerias, Brazil at Urucum and Bananal Mines and finally in Madagascar in the Mount Bity region in Madagascar.

12.5.2.4 Heliodor

Heliodor is the golden yellow gem variety of beryl due to the isomorphous substitution of aluminum by ferric cations. It is also known as yellow beryl if the golden tint lacking. Good colored material is relatively rare. As other gem varieties of beryl it is found in granitic pegmatites in Brazil; in the Ural Mountains (Russia), and Namibia.

12.5.2.5 Goshenite

Goshenite is the colorless gem variety of beryl. It occurs in the Ural Mountains (Russia), in Brazil and Madagascar.

12.5.3 Corundum Gem Varieties

Corundum [1344-28-1] with the chemical formula Al_2O_3 and the relative molar mass of 101.96127 is named after the Hindi, *kurund*, or the Tamil, *kurundam*. Corundum with a trigonal space lattice is the second hardest mineral on the Mohs scale just after diamond. The well-known gem varieties are the blood-red ruby while all other colors are named sapphire (e.g., pink sapphire, yellow sapphire) despite it is commonly used to denote the blue

gem variety. The name star sapphire denotes asteriated blue corundum. Paradoxically, star stones that are not blue are sometimes referred to as star ruby, even those that are not red. Padparadscha, meaning the lotus flower is an ill-defined name for rare pinkish orange sapphire. Because pure corundum is a colorless crystal, the colors of the gem varieties are due to the presence of chromophore. For instance, chromium (Cr^{3+}) and ferric iron (Fe^{3+}) impart the blood red color of ruby, ferrous iron (Fe^{2+}) is responsibles of the color of blue sapphire, ferric iron (Fe^{3+}) and titanium (Ti^{4+}) impart the color of the yellow sapphire. Padparadscha is colored by trace impurities of chromium and iron, with or without a yellow color center. Some green sapphire contains trace amounts of nickel (Ni^{2+}) as chromophore. Due to its hardness and toughness, gem varieties of corundum are mined almost exclusively from gem gravel deposits. These deposits are derived from the weathering of high temperature metamorphic (e.g., marble, gneiss) or volcanic igneous rocks (e.g., basalts). Historically, the most famous and prolific production has been mined from Myanmar, Thailand, India and Sri Lanka. Today important gem deposits are found in Australia and the East African countries of Tanzania and Kenya. Synthetic corundum was the first gem mineral to be synthesized in in 1902 at the laboratory scale by a process known today as flame fusion or Verneuil's process. A somewhat more difficult process, flux growth, is also used to synthesize gem corundum. Synthetic rubies and sapphires are presently manufactured in enormous quantities for both industrial and gem application.

Table 12.21. Major properties of the gem varieties of corundum

Properties	Corundum	Sapphire	Ruby
Crystal space lattice	Rhombohedral (Trigonal) a = 513.29 pm and 55°17'		
Symmetry	Strukturbericht: $D5_1$ Pearson's symbol: hR10 Space Group: R3c		
Habit	well-formed hexagonal prisms with or without rhombohedral terminations. Sapphire often as elongate prisms; ruby usually stubby, flat prisms		
Color (dopant)	Colorless	Violet-blue to lighter greenish-blue (Fe^{2+}, Fe^{3+})	Intense blood-red to lighter orange-red (Cr^{3+})
Pleochroism (weak)		Indogo blue to light blue	Deep purple to light yellow
Crystalline optics	Uniaxial (–) ε = 1.765–1.776 ω = 1.757–1.767		
Birefringence (δ)	0.008–0.009		
Dispersion	0.018		
Fluorescence under UV light	Moderate light red to orange	None to red or orange in LWUV	Strong red under LWUV
Density (/kg.m^{-3})	3980–4020		
Mohs hardness (HM)	9		
Vickers hardness (HV/GPa)	19.6		

12.5.3.1 Ruby

Description. Ruby is the red gem variety of corundum, the deep red color is imparted by chromium (Cr^{3+}) and sometimes also by ferric iron (Fe^{3+}). Burmese gemstones of the highest quality are the most expensive of all gemstones. Color is of principal importance in pricing for rubies. The ill-defined adjective ***pigeon blood*** has been used to describe the intense, medium, pure to slightly purplish red color of ***Burmese rubies***. These true Burmese rubies show a red, warm glow in direct sunlight, a consequence of strong ultraviolet fluorescence peculiar to these stones that are colored only by chromium without any trace of iron. ***Thai ruby*** is commonly darker, with a more brownish- or purplish-red color imparted by traces of iron. ***Ceylon ruby*** was once a common term for light red to pinkish ruby that in most cases could more properly be referred to as pink sapphire. It should be emphasized that these names today have very little to no meaning with regard to a ruby's origin.

Natural occurrence and deposits. These deposits of ruby are derived from the weathering of high temperature metamorphic (e.g., marble) or volcanic igneous rocks. Historically, the ruby was mined in several geographical area worldwide mainly concentrated in the far-east. Since at least 1597 A.D. ruby was mined from the Mogok Stone tract in Myanmar (formerly Burma). This gem deposit yield the worlds finest rubies. The rubies originated from a marble resulting of contact metamorphism of impure limestones. The rubies were mined from gravel deposits derived from marble. Thailand (formerly the Kingdom of Siam) which represented once about 70% of world production was also an important location. The rubies were found in lateritic soils above a Plio-Pliestocene basalt, or in gem gravels derived from basalt. Finally, in Sri Lanka (formerly Ceylon) rubies were mined from gem gravels in the Ratnapura district near Colombo, and Elahera district. Ruby is also mined in Cambodia at the Pailin Gem Fields. Others locations include Vietnam, Kenya, Tanzania, India, Madagascar, Pakistan, Afghanistan, and Nepal.

Shaping and treatment. Step or brilliant cut; heavily flawed or star stones are cut *en cabochon*. Heating is used to remove dark brownish or purplish overtones and lighten the color. CO_2 inclusions will not survive high temperature treatment; their presence is good indication of no heat treatment. Discoid fracture patterns around natural mineral inclusions are also a sign of heating. Asterism can be induced in stones containing sufficient titanium by heating for an extended period at about 1300°C to form needle-like crystals of rutile. A surface diffusion process is also used to enhance color in weakly colored material.

12.5.3.2 Sapphire

Description. Sapphire occurs in a wide range of colors such as blue, pink, padparadscha orange, yellow, green, purple, black. Color is due to trace impurities of Fe^{2+}, Fe^{3+}, Ti, and yellow color centers. The most expensive color is an intense cornflower blue; these are sometimes referred to as "Kashmir" sapphires having a highly saturated, slightly milky, violet blue color. Padparadscha is next in value, followed by pink, then orange, purple and yellow, respectively. Nowadays 400–500 tonnes of synthetic sapphire are produced by the Verneuil process each year.

Natural occurrence and deposits. Sapphire is exclusively mined from gem gravels or clay resulting of the weathering of basalt. Major deposits are similar to those for mining ruby, that is, Myanmar, Thailand, Sri Lanka, Australia and East Africa (i.e., Tanzania, Kenya, Nigeria, with lesser amounts from Malawi and Burimundi). Historically, sapphire have been mined from pegmatite veins in marble in the Jamu-Kashmir region (India) since 1881.

Thermal treatment. Thermally treated sapphires are widespread while gamma irradiated stones are less common. Usually, pale yellow or colorless sapphires are heat treated in air in the temperature range 1500–1900°C to yield a dark yellow, golden, golden-brown, orange, or reddish-brown color due to the oxidation of Fe^{2+} into to Fe^{3+}. Pink sapphire containing traces of chromium can be heat treated to yield a padparadscha orange-pink color, while dark blue

stones can be clarified by heating them briefly at 1200°C in air. On the other hand, pale blue sapphire containing embeded rutile needles can be heat treated in air at 1200°C to remove blue; while heating them up to 1900°C will restore the blue color and dissolve rutile forming a solid solution of tialite (Al_2TiO_5). Heating irradiated sapphires will restore their original color. Another treatment, to darken the color of pale blue sapphire consists to coat a thin layer of TiO_2 and Fe_2O_3 powders and heat up to 1950°C. At that temperatures, Ti^{4+} and Fe^{3+} cations diffuse fastly in the outer layer of the sapphire, yielding a very thin, skin-like layer of blue color.

12.5.4 Synthetic Gemstones

Almost all gems can be synthesized, either from melts, from molten salts, ceramic and other techniques, and at high temperature and pressure. These techniques are briefly described here.

12.5.4.1 Synthesis from Melts

The Verneuil melt growth technique (flame fusion). This containerless process was first developed on a commercial scale in 1902 in Paris (France) by Auguste Victor Louis Verneuil especially for producing synthetic ruby, sapphire and spinel required at that time for the large scale fabrication of jewel bearings. The flame-fusion technique now called the ***Verneuil method*** consists to melt powdered high purity aluminum oxide (alumina) into the intense flame (2200°C) of an inverted vertical oxygen-hydrogen torch. The alumina powder is contained into a perforated basket. Periodically a small hammer hits the basket leading to the regular delivery of a given amount of alumina that passes through the coaxial tubes of the torch and melts into the high temperature oxygen-hydrogen flame. The molten dropplets fall onto a fire-clay support and crystallize in a cone-shaped crystal called the boule that is lowered as it grows. After the boule reaches several hundred carats, the torch is shut down and the boule allowed to cool rapidly and it is then removed still hot. The final color is controlled by careful addition of chemical additives (e.g., Cr_2O_3). Gems produced by this technique is rather easy to distinguish from natural gemstones by the presence of curved growth striations and spherical gas bubbles or by the Plato method, in which repeated twinning lines appear when the material is immersed in high refractive index liquid and examined under magnification between crossed polars.

The Czochralski (CZ) melt growth technique (crystal pulling). The Czochralski pulled-growth method first devised in 1917 by J. Czochralski is often used to make rod-shaped single crystals especially ruby, sapphire, spinel, yttrium-aluminum-garnet (YAG), gadolinium-gallium-garnet (GGG), and alexandrite. In the Czochralski method, inorganic powders and doping agents are first melted in a large platinum, iridium, graphite, or advanced ceramic crucible depending on the corrosiveness of the molten material. Afterwards, a seed crystal is attached to the tip of a rotating rod, the rod is then lowered into the crucible until the seed just touches the surface of the melt, and then the rod is slowly withdrawn. The crystal grows as the seed pulls materials from the melt, and the material cools and solidifies. Due to the interfacial tension between the melt and the seed crystal, the growing crystal remains in contact with the molten material and it continues to grow until the melt is depleted. Typically, the seed is pulled from the melt at a rate of 1–100 millimeters per hour. Crystals grown using this method can be very large, more than 50 millimeters in diameter and one meter in length, and of very high purity (see chapter on processing single crystals for semiconductors).

The Bridgman–Stockbarge melt growth technique. This method is named after P.W. Bridgman (United States) and D.C. Stockbarge (Germany) with the collaboration of three

Russian scientists, J. Obreimov, G. Tammann, and L. Shubnikov, who discovered and perfected the process between 1924 and 1936. Currently, the method is used primarily for growing inorganic halides, sulfides, and various metallic oxide crystals, one of the metallic oxides being aluminum oxide or sapphire. The Bridgman–Stockbarge process uses a specially shaped crucible, which is a cylindrical tube open at one end and capped at the other by a small, pointed cone. The crucible is filled with the powdered mineral to grow and is lowered slowly through a heat resisting furnace. The small, pointed end of the cone cools first because it is the first part of the crucible that moves from the hottest part of the furnace into cooler regions and it is the first part to emerge from the furnace. As the crucible cools, the molten materials solidify, hopefully in a single crystal, in the point of the crucible. The crystal then acts as a seed around which the remainder of the molten material solidifies until the entire melt has frozen, filling the container with a single crystal. This process is simple, and crystals of various sizes can be grown. The crystals are typically about 50 millimeters in diameter and 15 millimeters in length, but large ones exceeding 890 millimeters in diameter and weighing more than 1000 kilograms have been grown. The crystals exhibit the same shape as the crucible.

The floating zone (FZ) melt growth technique. This technique was developed in the 1950s for the production of high-purity silicon, it is also used to grow gems from a sintered rod of fine powder. The rod is held vertically at the top and rotated clockwise while a seed crystal is held vertically at the bottom and rotated counterclockwise. Both are partially melted at the molten interface either by induction heating or by infrared heating provided by glass mirrors combined to a high pressure xenon lamp. At the next step, this molten zone is gradually upwards rotating with the seed crystal until the entire polycrystalline rod has been converted to single crystal. High purity rutile single crystals are commonly produced by this technique.

Skull melting melt growth technique. This technique ressembles that used to melt titanium and other refractory metals, and it is only used for preparing synthetic gems that exhibit exceptionally high melting points or that are highly chemically reactive (e.g., cubic zirconia). The set-up consists to a water-cooled jacketed copper mold filled with the powdered material and heated by induction until the powders melt. Due to the intense heat transfer provided by the water cooling, the powdered materials next to the walls forms a frozen layer or skull. Therefore, the highly reactive or high-temperature melt is contained within itself. When the heat source is removed and the system is allowed to cool, crystals form by nucleation and grow until the entire melt solidifies. Crystals grown using this system vary in size, depending on the number of nucleations. In growing cubic zirconia, a single skull yields about 1 kg of material per cycle.

12.5.4.2 Synthesis from Solutions

In these techniques the crystals precipitate from a saturated or supersaturated solution.

Hydrothermal growth technique. The principle is to increase the solubility of an inorganic compound using the same supercritical conditions encountered during the formation of gem-bearing pegmatites. The set-up consists of a pressure vessel called an autoclave or bomb capable to withstand both high pressure and temperature. At the begining water and feed material along with seed crystals are introduced into the autoclave. The seed is suspened to a fixture in the upper part of the autoclave while water and the crystal feed remain at the bottom. In the hotter regions of the autoclave the feed material dissolves while the crystallization occurs in cooler areas., that is on seed crystals, located in the cooler portion, forming synthetic crystals. This technique is especially suited for synthesis of high purity quartz for piezoelectric components, and in a lesser extent emerald, and some unusual beryls. In the particular case of quartz, the feed material is known as ***lascas*** and it consists of natural quartz crystals of gem quality found in Brazil. The process usually takes 30–60 days

for the crystals to reach the desired size. The process can produce rock crystal, amethyst, and citrine, or in some cases blue or green quartz with no natural counterpart.

Flux growth technique. This technique consists of dissolving the feed mineral having a high melting point into an appropriate molten salt called ***flux*** due to its ability to dissolved oxides. The contents are melted until a homogeneous melt is obtained and then the molten material is allowed to cool very slowly. Upon cooling the supersaturation of the melt occurs and the crystals of the high-melting compound crystallizes while the flux is still molten. Sometimes seed crystals are used to initiate the nucleation. Flux growth is especially useful for synthesis of refractory compounds having a high melting point. Common fluxing agents are lithium molybdate ($Li_2Mn_2O_7$) or lead fluoride (PbF_2) mixed with the mineral powder into a crucible (e.g., Pt, Ir, Au-lined crucible). Common gemstones produce by this technique are ruby, sapphire, emerald, and alexandrite.

Sol–gel growth techniques. The most common example is the production of synthetic opal. The first step consists to produce a suspension of monodisperse silica nanospheres in ethanol obtained by the direct hydrolysis of tetraethyl ester of orthosilicic acid, $Si(OC_2H_5)_4$ with ethanol using ammonia as a catalyst according to the following reaction:

$$Si(OC_2H_5)_4 + 4H_2O \text{ —> } Si(OH)_4 + 4C_2H_5OH$$

Simultaneously, the polymerization of orthosilicic acid occurs by the reaction:

$$nSi(OH)_4 \text{ —> } (SiO_2)n + 2nH_2O$$

By adding further amounts of reactant, the particles of silica grow up to the diameter desired-that is to about 300 nm size. Secondly, the raw opal precursor is precipitated either by spontaneous sedimentation or by centrifugation. Finally, the opal precursor is then dried in order to remove liquid from its pores. Afterwards, the dried opal precursor is sintered by thermal treatment at 400–800°C in a furnace. For the production of synthetic opal of gem quality, it is then necessary to complete the process by filling pores in the opal substance with a silica gel.

12.5.4.3 Diamond Synthesis

High pressure high temperature (HPHT). The first commercial synthesis of diamonds occured in 1955 by the GE Corporation using high P, T synthesis techniques. Today, 100 million carats of industrial quality diamond are produced by synthesis. Flawless gem-quality crystals are produced in pressure chambers. Today's method uses C source (crystals) and a seed crystal and Fe catalyst. These are kept in a pressure vessel (high temperature and pressure) for some time. Synthetic diamonds have been produced industrially since the first commercialization in 1955 of a proprietary High Pressure and High Temperature Process (HPHTP) from General Electric (GE). Today GE Superabrasives, Worthington, OH is one of the world's largest producers of industrial diamond with in a lesser extent Mypodiamond, Inc. located in Smithfield, PA. Since 2003 by Chemical Vapor Deposition (CVD) by Apollo Diamond Inc.

Chemical vapor deposition (CVD). The fundamental problem of diamond synthesis is the allotropic nature of carbon. Under ordinary conditions graphite, not diamond, is the thermodynamically stable crystalline phase of carbon. Hence, the main requirement of diamond CVD is to deposit carbon and simultaneously suppress the formation of graphitic sp2-bonds. This can be realized by establishing high concentrations of non-diamond carbon etchants such as atomic hydrogen. Usually, those conditions are achieved by admixing large amounts of hydrogen to the process gas and by activating the gas either thermally or by a plasma. The common CVD deposition conditions are: 1 vol.% methane in hydrogen as source gas, an operating temperature 700–1000°C deposition temperature and gas pressures in the range 30–300 torr.

12.6 IMA Acronyms of Rock-forming Minerals

Table 12.22. IMA acronyms of rock-forming minerals

Acronym	Mineral name	Acronym	Mineral name	Acronym	Mineral name
Ab	Albite	Brk	Brookite	Dol	Dolomite
Act	Actinolite	Brl	Beryl	Drv	Dravite
Adr	Andradite	Brt	Barite	Dsp	Diaspore
Ae	Aegirine	Bry	Beryllonite	Dum	Dumortierite
Ak	Akermanite	Bst	Bustamite	Eck	Eckermannite
Alm	Almandine	Bt	Biotite*	Ed	Edenite
Aln	Allanite	Cal	Calcite	Elb	Elbaite
Amp	Amphibole*	Cbz	Chabazite	En	Enstatite
An	Anorthite	Cc	Chalcocite	Ep	Epidote
And	Andalusite	Ccl	Chrysocolla	Fa	Fayalite
Anh	Anhydrite	Ccn	Cancrinite	Fac	Ferro-actinolite
Ank	Ankerite	Ccp	Chalcopyrite	Fcl	Ferrocolumbite
Anl	Analcime	Chl	Chlorite*	Fed	Ferro-edenite
Ann	Annite	Chn	Chondrodite	Fl	Fluorite
Ant	Anatase	Chr	Chromite	Fo	Forsterite
Ap	Apatite	Chu	Clinohumite	Fs	Ferrosilite
Apo	Apophyllite	Cld	Chloritoid	Ftn	Ferrotantalite
Apy	Arsenopyrite	Cls	Celestite	Fts	Ferrotschermakite
Arf	Arfvedsonite	Coe	Coesite	Gbs	Gibbsite
Arg	Aragonite	Cpx	Clinopyroxene*	Gdd	Grandidierite
Asp	Aspidolite	Crd	Cordierite	Ged	Gedrite
Atg	Antigorite	Crn	Corundum	Gft	Graftonite
Ath	Anthophyllite	Crs	Cristobalite	Gh	Gehlenite
Aug	Augite	Cst	Cassiterite	Gln	Glaucophane
Bet	Betatife	Ctl	Chrysotile	Glt	Glauconite
Beu	Beusite	Cum	Cummingtonite	Gn	Galena
Bhm	Boehmite	Cv	Covellite	Gp	Gypsum
Bn	Bornite	Czo	Clinozoisite	Gr	Graphite
Bor	Boralsilite	Dg	Digenite	Gre	Greenalite
Brc	Brucite	Di	Diopside	Grs	Grossular
Grt	Garnet*	Lop	Loparite	Opx	Orthopyroxene*
Gru	Grunerite	Lpd	Lepidolite*	Or	Orthoclase
Gt	Goethite	Ltp	Latrappite	Osm	Osumilite
Ham	Hambergite	Lue	Lueshite	Pct	Pectolite
Hbl	Hornblende	Lws	Lawsonite	Per	Periclase
Hc	Hercynite	Lz	Lizardite	Pg	Paragonite

Table 12.22. *(continued)*

Acronym	Mineral name	Acronym	Mineral name	Acronym	Mineral name
Hd	Hedenbergite	Mc	Microcline	Pgt	Pigeonite
Hem	Hematite	Mcl	Manganocolumbite	Phk	Phenakite
Hl	Halite	Mel	Melilite	Phl	Phlogopite
Hlv	Helvite	Mgh	Maghemite	Pl	Plagioclase*
Hrd	Herderite	Mgs	Magnesite	Pmc	Plumbomicrolite
Hs	Hastingsite	Mgt	Magnetite	Pmp	Pumpellyite
Hu	Humite	Mic	Microlite	Pn	Pentlandite
Hul	Heulandite	Min	Minnesotaite	Po	Pyrrhotite
Hyn	Haüyne	Mkt	Magnesiokatophorite	Pol	Pollucite
Ill	Illite*	Mlb	Molybdenite	Prg	Pargasite
Ilm	Ilmenite	Mnt	Montmorillonite	Prh	Prehnite
Jd	Jadeite	Mnz	Monazite	Prl	Pyrophyllite
Jh	Johannsenite	Mrb	Magnesioriebeckite	Prm	Prismatine
Jsv	Johnsomervilleite	Mrg	Margarite	Prp	Pyrope
Kfs	Orthoclase*	Ms	Muscovite	Prv	Perovskite
Kin	Kaolinite	Mtc	Monticellite	Py	Pyrite
Kis	Kalsilite	Mtn	Manganotantalite	Qtz	Quartz
Km	Kornerupine	Mul	Mullite	Rbk	Riebeckite
Krs	Kaersutite	Ne	Nepheline	Rdn	Rhodonite
Ktp	Katophorite	Nrb	Norbergite	Rds	Rhodochrosite
Ky	Kyanite	Nsn	Nosean	Rt	Rutile
Lct	Leucite	Ntr	Natrolite	Sa	Sanidine
Lmt	Laumontite	Ol	Olivine*	Sar	Sarcopside
Lol	Löllingite	Omp	Omphacite	Scp	Scapolite
Sd	Siderite	Sti	Stishovite	Ttn	Titanite
Sdl	Sodalite	Stl	Stellerite	Tur	Tourmaline
Sil	Sillimanite	Stm	Stibiomicrolite	Umc	Uranmicrolite
Skn	Sekaninaite	Stp	Stilpnomelane	Usp	Ulvöspinel
Sp	Sphalerite	Str	Strontianite	Ves	Vesuvianite
Spd	Spodumene	Tap	Tapiolite	Vrm	Vermiculite
Spl	Spinel	Tep	Tephroite	Vtm	Viitaniemiite
Spr	Sapphirine	Thm	Thomsonite	Wai	Wairakite
Sps	Spessartine	Toz	Topaz	Wo	Wollastonite
Srl	Schorl	Tph	Triphylite	Wrd	Werdingite
Srp	Serpentine*	Tr	Tremolite	Wth	Witherite
St	Staurolite	Trd	Tridymite	Wus	Wüstite
Stb	Stibiobetafite	Tro	Troilite	Zo	Zoisite
Stb	Stilbite	Ts	Tschermakite	Zrn	Zircon

Notes: (*) denotes a mineral series.

12.7 Mineral and Gemstone Properties Table

In this section a table containing the description of the most common minerals and gemstones (ca. 400 species among the 3700 mineral species known today) is presented with their main physical, chemical and mineralogical properties.

- **Column 1** presents the **mineral name** accoring to the *International Mineralogical Association* (IMA), moreover, its **Chemical Abstract Registered Number** in brackets [CAS RN], the **synonym(s)** (syn.), its **etymology** and the **Powder Diffraction File** (PDF) and in the **Inorganic Crystal Structure Datafile** (ICSD) are also indicated when available,
- **Column 2** presents: (1) the theoretical **chemical formula**, (2) the relative **atomic or molecular mass** (^{12}C=12.000) of minerals based on the previous theoretical formula using the last value of atomic masses adopted by the IUPAC in 2001, (3) the theoretical **chemical composition** expressed in mass percentage (wt.%), (4) the common **traces impurities**, (5) the **coordinence number** of major cations, and finally (6) the Strunz's **mineralogical class**,
- **Column 3** present the main crystallographic properties: (1) the **crystal system**, (2) the **space lattice parameters** expressed in picometers (1 pm = 10^{-12} m) and plane angle in degrees (°), (3) the **strukturbericht designation**, (4) the **Pearson's notation**, (5) the number of atoms or molecules per unit space lattice (Z). Finally, (6) the **space** and (7) **point group** according to the international Hermann–Mauguin notation and the crystal **space lattice structure type** are also listed when known,
- **Column 4** lists the mineral optical properties either in transmisted light with refractive index for isotropic (n_D), uniaxial (ε, ω), or biaxial (α, β, γ, *2V*), with the birefringence (δ), at 589 nm or in reflected light the reflective index (R) at 650 nm,
- **Column 5** lists the Mohs hardness and Vickers hardness (kg_f/mm^2) in brackets when available,
- **Column 6** lists the density or range of density in $kg.m^{-3}$ (X-ray density or calculated in brackets),
- **Column 7** details the common habit, the color, the diaphaneity, the luster, the luminescence, the streak, the cleavage planes, the fracture, the tenacity, the twinning planes, the chemical reactivity, the deposits and other miscellaneous chemical and physical properties of the mineral.

Table 12.23. Properties of selected minerals by alphabetical order

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Acanthite [21548-73-2] (syn., silver glance, argentite) [Named from the Greek, *akanta*, arrow, and after the Latin, *argentum*, silver] (ICSD 30445 and PDF 14-72)	Ag_2S $M = 247.8024$ 87.06 wt.% Ag 12.94 wt.% S Coordinence Ag(4) (Sulfides and sulfosalts)	Monoclinic $a = 422.9$ pm $b = 692.8$ pm $c = 786.2$ pm $\beta = 99.58°$ C34, mC6 ($Z = 4$) S.G. P2/m $AuTe_2$ type	Biaxial (n.a.) $R = 29.0\%$	2–2.5 (HV 20–30)	7300	**Habit:** acicular, octahedral, blocky, skeletal, arborescent. **Color:** black or lead gray. **Streak:** shining black. **Diaphaneity:** opaque. **Luster:** metallic. **Fracture:** subconchoidal, sectile. **Cleavage:** {001} poor, {110} poor. Argentite (cubic) is stable above 179°C while acanthite is stable below 179°C. melt at 825°C. Electric resistivity $1.5–2.0 \times 10^5$ μΩ.cm.
Actinolite (syn., byssolite, nephrite, smaragdite: emerald green, abestos) [Named from the Greek, *aktinos*, meaning, ray, and *lithos* meaning stone in reference to its fibrous nature that forms bundles of radiating needles] (ICSD 24900 and PDF 41-1366)	$Ca_2Mg_5Fe_2Si_8O_{22}(OH)_2$ $M = 875.45$ 9.16 wt.% Ca 8.33 wt.% Mg 12.76 wt.% Fe 27.66 wt.% Si 0.23 wt.% H 43.86 wt.% O Traces Mn and Al. (Inosilicates, double-width unbranched chains and band)	Monoclinic $a = 984$ pm $b = 1810$ pm $c = 5278$ pm $\beta = 104.75°$ ($Z = 2$) P.G. 2/m S.G. C2/m Amphibole group Tremolite series	Biaxial (–) $\alpha = 1.613–1.628$ $\beta = 1.627–1.644$ $\gamma = 1.638–1.655$ $\delta = 0.017–0.0270$ $2V = 84–73°$	5–6	3020– 3440 (3200)	**Habit:** acicular, splintery and bladed crystals to fibrous mass (asbestos). **Color:** colorless to pale green, green with a blue hue. **Luster:** glassy. **Diaphaneity:** transparent to translucent. **Cleavage:** (110) perfect with angle of 124°. **Fracture:** subconchoidal to uneven. **Streak:** white. **Others:** not attacked by hot HCl, dielectric permittivity of 6.60 to 6.82. Not fluorescent under UV radiation. Magnetic susceptibility between 15 to 25×10^{-6} cgsemu. **Occurrence:** regional metamorphism in schists talc-bearing rocks and marbles, altered into chlorite.
Aegirine (syn., acmite) [Named after the Teutonic god of the sea. Acmite is from the Greek, point, in allusion to the pointed crystals] (ICSD 9671 and PDF 34-185)	$NaFe[Si_2O_6]$ $M = 231.00416$ 9.95 wt.% Na 24.18 wt.% Fe 24.32 wt.% Si 41.56 wt.% O (Inosilicates, double-width unbranched chains and band)	Monoclinic $a = 965.8$ pm $b = 879.5$ pm $c = 529.4$ pm 107.42° ($Z = 4$) Diopside type	Biaxial (–) $\alpha = 1.72–1.778$ $\beta = 1.74–1.819$ $\gamma = 1.757–1.839$ $\delta = 0.037–0.061$ $2V = 60–90°$ O.A.P. (010)	6–6.5	3550	**Habit:** acicular. **Color:** blackish green or reddish brown. **Diaphaneity:** transparent to opaque. **Luster:** vitreous, resinous. **Streak:** yellowish gray. **Fracture:** brittle. **Occurrence:** sodium-rich igneous nepheline syenites.
Agate (syn., chalcedony) [Named after the River Achates, now Drillo in Sicily, where it was originally found]	SiO_2 $M = 60.0843$ 46.74 wt.% Si 53.26 wt.% O Coordinence Si(4) (Oxides, and hydroxides)	Amorphous	Isotropic	6	2600	Mixture of cryptocrystalline and amorphous silica consisting mainly of chalcedony.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Akermanite [Named after the Swedish metallurgist Anders Richard Akerman (1837–1922)] (ICSD 39924 and PDF 35-592)	$Ca_2Mg[Si_2O_7]$ $M = 272.63$ 29.40 wt.% Ca 8.92 wt.% Mg 20.60 wt.% S 41.08 wt.% O (Sorosilicates)	Tetragonal $a = 784.35$ pm $c = 501.0$ pm ($Z = 2$) P.G. 42m S.G. $P\bar{4}2_1m$ Melilite-Fresnoite group	Uniaxial (+) $\varepsilon = 1.638$ $\omega = 1.631$ $\delta = 0.007$	5–6	2944	**Habit:** anhedral equant grains. **Color:** colorless to green. **Luster:** vitreous to resinous. **Diaphaneity:** transparent to translucent. **Cleavage:** (001) and (110). **Fracture:** uneven. **Streak:** white. **Others:** it gelatinizes in conc. HCl. **Occurrence:** near-end members rare and only intermediate members are found in volcanic rocks but they are commonly found in metallurgical slags and synthetic products.
Alabandite [Named after its locality Alabanda] (ICSD 18007 and PDF 6-518)	MnS $M = 87.00$ 63.14 wt.% Mn 36.86 wt.% S May contains up to 22 wt.% Fe and 7 wt.% Mg (Sulfides and sulfosalts)	Cubic $a = 521$ pm ($Z = 4$) P.G. 432 S.G. Fm3m Galena group	Isotropic $R = 22.8\%$	3.5–4 (HV 240–251)	4000–4100 (4080)	**Habit:** massive or granular. **Color:** Brownish black to black, tarnish upon exposure to moist air. **Luster:** submetallic. **Diaphaneity:** opaque. **Cleavage:** (110) perfect. **Fracture:** uneven. **Streak:** green. **Occurrence:** epithermal sulfide vein deposits.
Albite (syn., clevelandite) [from the Latin, *alba*, in allusion to the common white color] Albite high (ICSD 100496 and PDF 10-393) Albite low (ICSD 201649 and PDF 19-1184) Albite Ca (ICSD 34916 and PDF 41-1480)	$Na[Si_3AlO_8]$ An0-Ab100 $M = 263.02222$ 8.30 wt.% Na 0.76 wt.% Ca 10.77 wt.% Al 31.50 wt.% Si 48.66 wt.% O Coordinence Na(7), Si(4), Al(4) (Tectosilicates, framework)	Triclinic $a = 814.4$ pm $b = 1278.7$ pm $c = 716$ pm $\alpha = 93.17°$ $\beta = 115.85°$ $\gamma = 87.65°$ ($Z = 4$) P.G. 1 S.G. P1	Biaxial (+) $\alpha = 1.527–1.533$ $\beta = 1.531–1.536$ $\gamma = 1.538–1.542$ $\delta = 0.009–0.010$ $2V = 76–82°$	6–6.5	2620	**Habit:** blocky, striated, granular. **Color:** white, gray, greenish gray, bluish green, or gray. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Cleavage:** (001) perfect, (010) good. **Twinning:** Albite [010], Pericline [010]. **Fracture:** uneven. **Streak:** white. **Occurrence:** magmatic and pegmatitic rocks.
Allanite [Named after the Scottish mineralogist Thomas Allan (1777–1833)] (ICSD 15190 and PDF 25-169)	$(Ca,Ce,Th)_2(Al,Fe,Mn,Mg)(Al,Fe)_2O.OH[Si_2O_7][SiO_4]$ (Neso-Sorosilicates)	Monoclinic $a = 898$ pm $b = 575$ pm $c = 1023$ pm $115°$ Epidote group	Biaxial (–/+) $\alpha = 1.690–1.791$ $\beta = 1.700–1.815$ $\gamma = 1.706–1.828$ $2V = 40–123°$ O.A.P. (010)	5–6.5	3400–4200	**Habit:** massive granular grains. **Color:** brown to reddish brown and black. **Luster:** vitreous to greasy. **Diaphaneity:** translucent to opaque. **Cleavage:** (001) and (100). **Fracture:** conchoidal. **Streak:** grayish-brown. **Occurrence:** near-end members rare and only intermediate members are found in volcanic rocks but they are commonly found in metallurgical slags and synthetic products.
Almandine (syn., almandite) [Named after the locality, *Alabanda*, in Asia Minor] (ICSD 28030 and PDF 41-1423)	$Fe_3Al_2(SiO_4)_3$ $M = 497.75338$ 10.84 wt.% Al 33.66 wt.% Fe 16.93 wt.% Si 38.57 wt.% O Coordinence Fe(8), Al(6), Si(4) (Nesosilicates)	Cubic $a = 1152.6$ pm ($Z = 8$) P.G. 432 S.G. Ia3d Garnet group (Pyralspites series)	Isotropic $n_D = 1.830$	7–8	4318	**Habit:** massive, lamellar, granular. **Color:** reddish black or brownish red. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy), resinous. **Fracture:** brittle, conchoidal. **Parting:** {110}. **Chemical:** soluble in HF. **Occurrence:** metamorphic and pegmatitic rocks.
Alunite [Named from French *alun* itself from Latin, *alumen*, meaning alum]	$KAl_3(SO_4)_2(OH)_6$ $M = 414.214334$ 9.44 wt.% K	Trigonal (Rhombohedral) $a = 697$ pm	Uniaxial (+) $\varepsilon = 1.592$ $\omega = 1.572$	3.5–4	2600–2900	**Habit:** rhombohedral. **Color:** white, gray. **Streak:** white, gray. **Diaphaneity:** transparent to translucent. **Luster:** vitreous. **Fracture:** conchoidal. **Cleavage:** good (001), poor (101).

(ICSD 12106 and PDF 13-136)	19.54 wt.% Al 15.48 wt.% S 54.08 wt.% O 1.46 wt.% H Coordinence K(12), Cu(6), S(4) (Sulfates, chromates, molybdates, and tungstates)	c = 1738 pm (Z = 3) P.G. 3m S.G. P3m	δ= 0.020			
Amber (syn., succinite, bernstein) [Named from French *ambre* itself from Arabic *anbar* meaning ambergris]	$C_{10}H_{16}O$ M = 152.23692 10.59 wt.% H 78.90 wt.% C 10.51 wt.% O (Mineraloids)	Amorphous	Isotropic n_D = 1.539–1.545	2–2.5	1050–1090	Fossil resin found buried in the countries along the Baltic sea and in Madagascar. **Fluorescence:** bluish white to yellow green
Amblygonite [Named from the Greek, *amblys*, obtuse and *gonia* meaning angle, in reference to cleavage angle] (ICSD 26513 and PDF 22-1138)	(Li, Na)PO_4(F,OH) Coordinence Li(6), Na(6), P(4) (Phosphates, arsenates, and vanadates)	Triclinic a = 519 pm b = 712 pm c = 504 pm α= 112.02° β= 97.82° γ= 68.12° (Z = 2) P.G. 1 S.G. P1	Biaxial (–) α= 1.590 β= 1.600 γ= 1.620 δ= 0.03 2V = 52–90°	6	3000	**Habit:** equant. **Color:** white, green. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous, greasy. **Fracture:** subconchoidal. **Cleavage:** (100) perfect, (110) good, (011) perfect. **Twinning:** (111).
Analcime (syn., analcite, analcidite) [from the Greek, *analcis*, weak, referring to a weak electrical charge developed on rubbing or heating] (ICSD 2930 and PDF 42-1378)	$NaAlSi_2O_6{\cdot}H_2O$ M = 220.15398 10.44 wt.% Na 12.26 wt.% Al 25.51 wt.% Si 0.92 wt.% H 50.87 wt.% O Coordinence Na(6), Si(4), Al(4) (Tectosilicates)	Cubic a = 1373.3 pm (Z = 16) P.G. 432 S.G. $I4_1ad$	Isotropic n_D = 1.479–1.493	5.5	2260	**Habit:** euhedral crystals, granular, massive. **Color:** white, grayish white, greenish white, yellowish white, or reddish white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Luminescence:** fluorescent. **Streak:** white. **Cleavage:** (100) poor. **Fracture:** Subconchoidal, uneven. **Twinning:** {100}, {110}. **Occurrence:** occurs frequenty in basalts and other basic igneous rocks associated with other zeolites.
Anatase [1317-70-0] [from the Greek, *anatasis*, tall direction owing to the great vertical space lattice parameter c compared with other tetragonal minerals] (ICSD 9852 and PDF 21-1272)	TiO_2 M = 79.8788 59.94 wt.% Ti 40.06 wt.% O Traces Fe, Sn Coordinence Ti(6) (Oxides and hydroxides)	Tetragonal a = 379.3 pm c = 951.2 pm C4, *tP6* (Z = 4) P.G. 422 S.G. $I4_1/amd$ Anatase type Packing fraction = 70%	Uniaxial (+) ε = 2.4880 ω= 2.5612 δ= 0.073 Dispersion strong	5.5–6.0	3877	**Habit:** acicular, prismatic, massive. **Color:** reddish brown, yellowish brown, black or bluish violet. **Diaphaneity:** transparent, translucent to opaque. **Luster:** adamantine. **Streak:** grayish black. **Fracture:** uneven. **Cleavage:** [111]. **Chemical:** insoluble in water, slightly soluble in HCl, HNO_3, sol. HF and in hot H_2SO_4 or $KHSO_4$. Attacked by molten Na_2CO_3. **Other properties:** dielectric constant 48. Transition temperature to rutile 700°C.
Andalusite [12183-80-1] (syn., chiastolite: carbonaceous inclusions) [Named after the province of Andalucia, Spain] (ICSD 24275 and PDF 39-376)	$Al_2O[SiO_4] = Al_2SiO_5$ M = 162.04558 33.30 wt.% Al 17.33 wt.% Si 49.37 wt.% O Traces of Fe, Mn Coordinence Al(5), Al(6), Si(4) (Nesosubsilicates)	Orthorhombic a = 779.59 pm b = 789.83 pm c = 555.83 pm (Z = 4) P.G. mmm S.G. Pnnm	Biaxial (–) α= 1.629–1.640 β= 1.633–1.644 γ= 1.638–1.650 δ= 0.009–0.010 2V = 73–86°	6.5–7.5	3130–3160	**Habit:** acicular, blocky, prismatic, euhedral crystals. **Color:** usually pink, white, rose, dark green, gray, brown, red, or green or with clouded inclusions. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Cleavage:** (110) distinct, (100) indistinct, (010) poor. **Fracture:** uneven, splintery, brittle. **Streak:** white. **Chemical:** insoluble in strong mineral acids but attacked by molten alkali-metal hydroxides (e.g., NaOH) and carbonates (e.g., Na_2CO_3). Heated in $Co(NO_3)_2$ give the Thénard blue color. Non fusible but transforms to sillimanite on heating. **Other properties:** Unfusible but when heated above 1200°C transforms to a mixture of silica and mullite ($Al_6Si_2O_{13}$). Dielectric constant of 8.28. Diamagnetic with a specific magnetic susceptibility of -10^{-10} $m^3.kg^{-1}$. **Occurrence:** metamorphosed peri-aluminous sedimetary rocks.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Andesine (syn., acmite) [Named after Andes Mountains, South America]	$(Na,Ca)(Si,Al)_4O_8$ An40-Ab60 $M = 268.61671$ 5.14 wt.% Na 5.97 wt.% Ca 14.06 wt.% Al 27.18 wt.% Si 47.65 wt.% O (Tectosilicates, framework)	Triclinic $a = 815.5$ pm $b = 129$ pm $c = 916$ pm $Z = 6$	Biaxial (+/–) $\alpha = 1.543–1.554$ $\beta = 1.547–1.559$ $\gamma = 1.552–1.562$ $\delta = 0.008–0.009$ $2V = 78–84°$	7	2670	**Habit:** granular, crystalline. **Color:** white, gray, or gray. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (001) perfect, (010) good. **Fracture:** uneven. **Occurrence:** magmatic and metamorphic rocks.
Andradite (syn., demantoid: green, melanite: black, topazolite: yellow) [Named after the Brazilian mineralogist J.B. de Andrada e Silva (1763–1838). Demantoid is named after its adamantine luster] (ICSD 27370 and PDF 10-288)	$Ca_3Fe_2(SiO_4)_3$ $M = 508.1773$ 23.66 wt.% Ca 21.98 wt.% Fe 16.58 wt.% Si 37.78 wt.% O Coordinence Ca(8), Fe(6), Si(4) (Nesosilicates)	Cubic $a = 1204.8$ pm $(Z = 8)$ P.G. 432 S.G. Ia3d Garnet group (Ugrandite series)	Isotropic $n_D = 1.887$	6.5–7	3859	**Habit:** Dodecahedral crystals, massive. **Color:** black, yellowish brown, red, greenish yellow, or gray. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Fracture:** subconchoidal. **Occurrence:** igneous and metamorphic rocks.
Anglesite [7446-14-2] (syn., lead spar, lead vitriol) [Named after the island of Anglesey, Wales, UK] (ICSD 100625 and PDF 36-1461)	$PbSO_4$ $M = 303.2636$ 68.32 wt.% Pb 10.57 wt.% S 21.10 wt.% O Coordinence Pb(6), S(4) (Sulfates, chromates, molybdates, and tungstates)	Orthorhombic $a = 848.0$ pm $b = 539.8$ pm $c = 695.8$ pm $(Z = 4)$ P.G. mmm S.G. $P2_1nma$ Barite type	Biaxial (+) $\alpha = 1.878$ $\beta = 1.883$ $\gamma = 1.894$ $\delta = 0.017$ $2V = 68–75°$ Dispersion strong	2.5–3	6380	**Habit:** tabular, prismatic, granular, stalactitic. **Color:** white, gray, gray, or yellow. **Diaphaneity:** transparent to translucent. **Luster:** adamantine. **Streak:** white. **Cleavage:** perfect (001) good, (210). **Twinning:** {011}. **Fracture:** conchoidal, brittle. Decomposes upon heating in air above 637°C yielding PbO and SO_3 fumes. **Occurrence:** secondary, weathered deposits of lead ore.
Anhydrite [7778-18-9] (From the Greek, *anhydros*, meaning dry, in contrast to gypsum, which is hydrated) (ICSD 16382 and PDF 37-1496)	$CaSO_4$ $M = 136.1416$ 29.44 wt.% Ca 23.55 wt.% S 47.01 wt.% O Coordinence Ca(6), S(4) (Sulfates, chromates, molybdates, and tungstates)	Orthorhombic $a = 699.1$ pm $b = 699.6$ pm $c = 623.8$ pm $(Z = 4)$ P.G. mmm S.G. Ccmm Anhydrite type	Biaxial (+) $\alpha = 1.569–1.574$ $\beta = 1.574–1.579$ $\gamma = 1.609–1.618$ $\delta = 0.040–0.045$ $2V = 36–45°$	3–3.5	2980	**Habit:** massive, granular, fibrous, plumose. **Color:** colorless, white, bluish white, violet white, or dark gray. **Luster:** vitreous, pearly. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (010) perfect, (001) good. **Fracture:** conchoidal, brittle. **Chemical:** decomposes at 1200°C into CaO and SO_x. **Occurrence:** sedimentary beds, gangue in ore veins, and in traprock zeolite occurrences.
Ankerite [Named after Austrian mineralogist, Mathias Joseph Anker (1771–1843)] (ICSD 100417 and PDF 41-586)	$Ca(Mg,Fe,Mn)(CO_3)_2$ $M = 206.39$ 19.42 wt.% Ca 3.53 wt.% Mg 2.66 wt.% Mn 16.24 wt.% Fe 11.64 wt.% C 46.51 wt.% O	Trigonal (Rhombohedral) $a = 482$ pm $c = 1614$ pm $a_{Rh} = 605.0$ pm 47°00' $(Z = 3)$ P.G. 3	Uniaxial (–) $\varepsilon = 1.500–1.548$ $\omega = 1.690–1.750$ $\delta = 0.182–0.202$ Dispersion strong	3.5–4	2930–3100	**Habit:** crystalline, massive. **Color:** white, gray, reddish white, brownish white, or gray. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Streak:** white. **Fracture:** brittle, subconchoidal. **Cleavage:** (1011) perfect. **Twinning:** {0001}, and {1010}.

	Coordinence Ca(6), Fe(6), C(3) (Nitrates, carbonates, and borates)	S.G. R3 Dolomite type				
Annabergite (syn., Nickel Bloom) [Named after the locality Annaberg, Germany] (ICSD 81386 and PDF 35-568)	$Ni_3(AsO_4)_2{\cdot}8H2O$ $M = 598.03064$ 29.44 wt.% Ni 25.06 wt.% As 2.70 wt.% H 42.81 wt.% O (Phosphates, arsenates and vanadates)	Monoclinic P.G. 2/m	Biaxial (–) $\alpha = 1.622$ $\beta = 1.658$ $\gamma = 1.687$ $\delta = 0.065$ $2V = 78°$ Dispersion weak	2	3000–3100	**Habit:** earthy, encrustations, massive. **Color:** green, green white, apple green, or green. **Luster:** pearly. **Diaphaneity:** transparent to translucent. **Streak:** light green. **Cleavage:** [010] perfect. **Fracture:** brittle.
Anorthite (syn., Indianite) [from the Greek, *an*, and *orthos*, not upright in allusion to the oblique crystals] (ICSD 654 and PDF 41-1486)	$Ca_1[Si_2Al_2O_8]$ $An_{100}\ Ab_0$ $M = 277.40806$ 0.41 wt.% Na 13.72 wt.% Ca 18.97 wt.% Al 20.75 wt.% Si 46.14 wt.% O Coordinence Ca(7), Si(4), Al(4) (Tectosilicates, framework)	Triclinic $a = 817.7$ pm $b = 1287.7$ pm $c = 1416.9$ pm $\alpha = 93.33°$ $\beta = 115.60°$ $\gamma = 91.22°$ ($Z = 8$) P.G. 1 S.G. P1	Biaxial (–) $\alpha = 1.577$ $\beta = 1.585$ $\gamma = 1.590$ $\delta = 0.013$ $2V = 78°$ Dispersion weak	6	2760	**Habit:** granular, euhedral crystals, striated. **Color:** white, gray, or reddish white. **Diaphaneity:** transparent to translucent. **Luster:** pearly, vitreous (i.e., glassy). **Cleavage:** (001) perfect, (010) good. **Twinning:** Albite [010], Pericline [010]. **Fracture:** uneven. **Streak:** white. **Occurrence:** magmatic and metamorphic rocks.
Anosovite (type I) [12065-65-5]	α-Ti_3O_5 $M = 223.0070$ 64.1 wt.% Ti 35.9 wt.% O (Oxides and hydroxides)	Monoclinic $a = 975.2$ pm $b = 380.2$ pm $c = 944.2$ pm $\beta = 91.55°$ mC32 ($Z = 4$) S.G. C2/m	Biaxial (?)*	n.a.	4900	**Habit:** needle-like crystals. **Color:** blue-dark. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** black. **Other properties:** melting point 1777°C. It can be prepared by the hydrogen reduction of solid TiO_2 at temperature around 1300°C or by mixing intimatelly stoichiometric quantities of titanium metal and titanium dioxide in an electric arc furnace under argon atmosphere. This oxide is dimorphic with a rapid phase transition from semiconductor to metal occuring at roughly 120°C.
Anosovite (type II) [12065-65-5]	β-Ti_3O_5 $M = 223.0070$ 64.1 wt.% Ti 35.9 wt.% O (Oxides and hydroxides)	Orthorhombic Distorded pseudobrookite TiO 191–210 pm mC32 ($Z = 4$) S.G. C2/m	Biaxial (?)	n.a.	4900	**Habit:** acicular crystals. **Color:** blue-dark. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** black. Type II can be prepared by the hydrogen reduction of solid TiO_2 at temperature around 1500°C with magnesia as a catalyst. Anosovite type II is similar to that found in artificial titania slags and it is stabilized at room temperature with small amount of iron. This oxide is dimorphic with a rapid phase transition from semiconductor to metal occuring at roughly 120°C.
Antigorite ($2M_1$) (fibrous chrysotile) [Named after its locality Antigorio, Italy] (ICSD 654 and PDF 41-1486)	$Mg_6(OH)_2Si_4O_{10}$ $M = 300.77$ 18.18 wt.% Mg 13.93 wt.% Fe 18.68 wt.% Si 1.34 wt.% H 47.88 wt.% O Coordinence Mg(6), Si(4) (Phyllosilicates, layered)	Monoclinic $a = 532$ pm $b = 950$ pm $c = 1490$ pm 101.9° ($Z = 2$) P.G.2/m S.G. C2/m	Biaxial (–) $\alpha = 1.560$ $\beta = 1.570$ $\gamma = 1.570$ $\delta = 0.007$ $2V = 20–60°$ Dispersion weak	3–4	2600	**Habit:** platy, massive. **Color:** green yellow. **Diaphaneity:** transparent to translucent. **Luster:** resinous, silky. **Cleavage:** (001) perfect. **Fracture:** uneven, flexible. **Streak:** white.
Anthophyllite [Named from Latin *anthophyllum*, clove for its brown color, and Greek *lithos* for stone] (ICSD 30254 and PDF 42-544)	$Mg_7[Si_8O_{22}](OH)_2$ $MM = 780.82$ 21.79 wt.% Mg 28.78 wt.% Si 0.26 wt.% H 49.18 wt.% O Inosilicates	Orthorhombic $a = 1855.40$ pm $b = 1802.26$ pm $c = 528.2$ pm ($Z = 4$) P.G. 2/m2/m2/m S.G. Pnma Amphibole group	Biaxial (+) $\alpha = 1.598–1.674$ $\beta = 1.605–1.685$ $\gamma = 1.615–1.697$ $\delta = 0.017–0.0230$ $2V = 57–90°$	5.5–6	2850–3570 (3090)	**Habit:** prismatic crystals, columnar to fibrous even asbestiform. **Color:** clove-brown to dark brown. **Diaphaneity:** translucent to nearly opaque. **Luster:** vitreous to silky. **Fracture:** subconchoidal. **Cleavage:** perfect [210]. **Streak:** colorless. **Others:** infusible and insoluble in HCl. **Occurrence:** metamorphic rocks.

***Note:** Where the optical sign is listed as "(?)" it is not known or has not been determined.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Antimony (syn., stibium) [from the Arabic, *aluthmud*, the medieval Latin, *antimonium*, originally applied to stibnite] (ICSD 64695 and PDF 35-732)	Sb $M = 121.75$ Coordinence Sb(3) (Native elements)	Trigonal (Rhombohedral) $a = 429.96$ pm $c = 1125.16$ pm A7, *hR2* ($Z = 6$) P.G. 3m S.G. R3m α-Arsenic type	Uniaxial (n.a.) $n_D = 1.70–1.80$ $R = 72.0–77.1\%$	3–3.5 (HV 83–99)	6660	**Habit:** massive, lamellar, massive, reticulate. **Color:** tin white. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** lead gray. **Cleavage:** (0001) perfect. **Fracture:** brittle.
Antlerite [Named after the Antler mine, Mojave Company, Arizona USA] (ICSD 203067 and PDF 7-407)	$Cu_3SO_4(OH)_4$ $M = 354.73108$ 53.74 wt.% Cu 9.04 wt.% S 36.08 wt.% O 1.14 wt.% H Coordinence Cu(6), S(4) (Sulfates, chromates, molybdates, and tungstates)	Orthorhombic $a = 824$ pm $b = 1199$ pm $c = 603$ pm ($Z = 4$) P.G. mmm S.G. $P2_1/aam$	Biaxial(+) $\alpha = 1.726$ $\beta = 1.738$ $\gamma = 1.789$ $\delta = 0.063$ $2V = 53°$	3.5–4	3900	**Habit:** prismatic, tabular. **Color:** white, gray. **Streak:** green, gray. **Diaphaneity:** transparent to translucent. **Luster:** vitreous. **Fracture:** uneven. **Cleavage:** perfect (010).
Apatite [Named from the Greek, *apatos*, misleading, owing to the confusion with beryl, tourmaline, and olivine owing to its wide variety of forms and colors)	$Ca_5(PO_4)_3(OH,F,Cl)$ $M = 504.30248$ 39.74 wt.% Ca 18.43 wt.% P 38.07 wt.% O 3.77 wt.% F Coordinence Ca(6), P(4) (Phosphates, arsenates, and vanadates)	Hexagonal $a = 938$ pm $c = 686$ pm ($Z = 2$) P.G. 6/m S.G. $P6_3/m$ Apatite type	Uniaxial (–) $\varepsilon = 1.624–1.666$ $\omega = 1.629–1.667$ $\delta = 0.001–0.007$ Dispersion moderate	5	3100–3350	**Habit:** prismatic, colloform, massive, granular, earthy. **Color:** white, yellow, green, red, or blue (the color is often due to the presence of rare earths). **Diaphaneity:** transparent to translucent. **Luster:** subresinous. **Streak:** white. **Cleavage:** (0001) indistinct, (1010) indistinct. **Fracture:** conchoidal. **Chemical:** soluble in HCl, and HNO_3. **Occurrence:** found in all type of rocks (igneous, sedimentary, and metamorphic).
Aphthitalite (syn., glaserite) [Named from Greek *aphthitos*, indestructible, *halos*, salt, and *lithos* for stone since the mineral is very stable in air] (ICSD 26014 and PDF 20-928)	$(K,Na)_3Na(SO_4)_2$ $M = 320.33$ 27.46 wt.% K 12.56 wt.% Na 20.02 wt.% S 39.96 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Trigonal (Rhombohedral) $a = 565$ pm $c = 729$ pm ($Z = 1$) P.G. 32/m S.G. P3m1	Uniaxial (+) $\varepsilon = 1.490$ $\omega = 1.496$ $\delta = 0.006$	3	2700	**Habit:** massive, encrustations. **Color:** blue, colorless. **Luster:** vitreous to resinous. **Diaphaneity:** translucent. **Cleavage:** (1011) fair. **Fracture:** conchoidal. **Streak:** white. **Occurrence:** encrustation in volcanoes and fumaroles, and lacustrine salt deposits (e.g., Searles Lake, California, USA).
Aragonite [471-34-1] [Named after the Spanish locality of Aragon where the mineral was first discovered) (ICSD 15194 and PDF 41-1475)	$CaCO_3$ $M = 100.0872$ 40.04 wt.% Ca 12.00 wt.% C 47.96 wt.% O Traces of Sr (up to 5.6 wt.%), Mg,	Orthorhombic $a = 574.1$ pm $b = 796.8$ pm $c = 495.9$ pm ($Z = 4$) S.G. Pmcn	Biaxial (–) $\alpha = 1.530–1.531$ $\beta = 1.680–1.681$ $\gamma = 1.685–1.686$ $\delta = 0.155–0.156$ $2V = 18–19°$	3.5–4 (HV 280)	2940–2950	**Habit:** pseudo hexagonal, columnar, globular, reniform, fibrous. **Color:** colorless, white, gray, yellowish white, or reddish white. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (010) distinct. **Twinning:** {110}. **Fracture:** subconchoidal. **Chemical:** readily dissolved by cold diluted strong mineral acids (e.g., HCl) with evolution of CO_2. Decomposed at 825°C giving off CO_2 and CaO. Meigen's spot test: it exhibits a pink to violet color after immersion in boiling $Co(NO_3)_2$ solution.

	Fe and Zn Coordinence Ca(6), C(3) (Carbonates, aragonite group)	P.G. mmm Aragonite type	Dispersion weak			**Other:** dielectric constant 7.4. **Occurrence:** fossil skeletons, with gypsum and celestine in marl and clays, near geysers and stalactites in caverns.
Armalcolite [64476-39-7] (syn., Kennedyite) [Named after the three astronauts Neil Alden **Arm**strong, Edwin Eugene **Al**drin, and Michael **Col**lins] (ICSD 15845 and PDF 41-1444)	$Mg_{0.75}Fe_{0.25}Ti_2O_5$ $M = 207.95$ 8.77 wt.% Mg 46.05 wt.% Ti 6.71 wt.% Fe 38.47 wt.% O (Oxides and hydroxides)	Orthorhombic $a = 977.62$ pm $b = 1002.14$ pm $c = 374.85$ pm ($Z = 4$) P.G. 2/m 2/m 2/m S.G. Bbmm Karrooite type	Biaxal (?) $R = 13–14\%$	4	3904	**Habit:** granular anhedral to subhedral crystals. **Color:** gray to tan. **Diaphaneity:** opaque. **Luster:** metallic. **Occurrence:** extraterrestrial materials such as in the lunar regolith (Tranquility base, Moon), in Ti-rich basalts (Ovifalk, Disco Islang, Greenlan) and in artificial titania rich slags resulting from the EAF smelting of hemo-ilmenite or ilmenite with anthracite coal. **Melting point:** 1550°C.
Arsenic (syn., arsenicum) [from the Greek, *arsenikon*, a name originally applied to the mineral orpiment] (ICSD 16516 and PDF 5-632)	As $M = 74.9216$ Coordinence As(3) (Native elements)	Trigonal (Rhombohedral) $a = 413.19$ pm 54.12° A7, *hR2* ($Z = 2$) P.G. 3m S.G. R3m α-Arsenic type	Uniaxial (n.a.) $R = 48–51\%$	3.5 (HV 57–69)	5700	**Habit:** nodular, reniform, lamellar. **Color:** tin white or gray. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** black. **Cleavage:** (0001) perfect. **Fracture:** uneven. **Occurrence:** In ore veins in igneous crystalline rocks.
Arsenopyrite (syn., arsenical pyrite, mispickel) [Named after the minerals chemical composition] (ICSD 62400 and PDF 42-1320)	FeAsS $M = 162.8346$ 34.30 wt.% Fe 46.01 wt.% As 19.69 wt.% S (Sulfides and sulfosalts) Coordinence Fe(6)	Monoclinic $a = 576.0$ pm $b = 569.0$ pm $c = 578.5$ pm 112.23° $E0_1$, mP24 ($Z = 8$) S.G. $B2_1/d$ P.G. 2/m Arsenopyrite type	Biaxial $R = 53.7\%$	5.5–6 (HV 1048– 1127)	6100	**Habit:** faces striated, euhedral crystals, prismatic. **Color:** tin white or light steel gray. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** black. **Cleavage:** {110} distinct. **Twinning:** {100}, {101}, {012}. **Fracture:** uneven, brittle. Electrical resistivity 20 to 300 μΩ.cm.
Atacamite [Named after the Atacama desert province in Northern Chile] (ICSD 61252 and PDF 25-269)	$Cu_2Cl(OH)_3$ $M = 213.56672$ 59.51 wt.% Cu 1.42 wt.% H 16.60 wt.% Cl 22.47 wt.% O (Halides)	Orthorhombic $a = 602$ pm $b = 915$ pm $c = 685$ pm P.G. 222 S.G. $P2_1/nam$ ($Z = 4$)	Biaxial (–) $\alpha = 1.831$ $\beta = 1.861$ $\gamma = 1.880$ $\delta = 0.049$ $2V = 75°$ Dispersion strong	3–3.5	3760– 3780	**Habit:** acicular, striated prisms, euhedral crystals, fibrous, granular. **Color:** green, dark green, or blackish green. **Luster:** adamantine. **Diaphaneity:** transparent to translucent. **Streak:** apple green. **Cleavage:** {010} perfect. **Fracture:** conchoidal. **Occurrence:** arid climates with oxidizable copper minerals.
Augelite [Named after the Greek for luster, for its pearly luster on the cleavage] (ICSD 24430 and PDF 34-151)	$Al_2PO_4(OH)_3$ $M = 199.956547$ 26.99 wt.% Al 15.49 wt.% P 56.01 wt.% O 1.51 wt.% H Coordinence Al(5, and 6), P(4) (Phosphates, arsenates, and vanadates)	Monoclinic $a = 1312$ pm $b = 799$ pm $c = 507$ pm $\beta = 112.25°$ ($Z = 4$) P.G. 2/m S.G. C2/m	Biaxial(+) $\alpha = 1.574$ $\beta = 1.588$ $\gamma = 1.576$ $\delta = 0.014$ $2V = 51°$	5	2700	**Habit:** tabular, massive. **Color:** colorless, white. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous. **Fracture:** uneven. **Cleavage:** (101) good.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Augite (syn., fassaite) [Named from the Greek, *auge*, luster] (ICSD 9257and PDF 24-203)	$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$ M = 236.35 0.97 wt.% Na 15.26 wt.% Ca 9.26 wt.% Mg 2.03 wt.% Ti 4.57 wt.% Al 4.73 wt.% Fe 22.58 wt.% S 40.62 wt.% O (Inosilicates, double chains)	Orthorhombic a = 980 pm b = 900 pm c = 525 pm (Z = 4) P.G. 2/m S.G. C2/c	Biaxial (+) α = 1.68–1.703 β = 1.684–1.711 γ = 1.706–1.729 δ = 0.026 $2V$ = 40–52° Dispersion weak	5–6.5	3400	**Habit:** massive, fibrous, columnar. **Color:** white, green, or black. **Diaphaneity:** translucent to opaque. **Luster:** vitreous, resinous. **Cleavage:** (110) perfect, (010) indistinct. **Fracture:** brittle, conchoidal. **Streak:** greenish gray. **Occurrence:** basic igneous and metamorphic rocks.
Autunite [Named in 1852 after Autun, Saône-et-Loire (France) locality where the mineral was first discovered]	$Ca(UO_2)_2(PO_4)_2.10H_2O$ M = 986.26 4.06 wt.% Ca 48.27 wt.% U 6.28 wt.% P 2.45 wt.% H 38.93 wt.% O Coordinence Ca(6), U(2), P(4) (Urano-phosphates)	Tetragonal a = 700.9 pm c = 2073.6 pm (Z = 4) P.G. 422 S.G. I4/mmm	Biaxial (–) ε = 1.553 ω = 1.577 δ = 0.024	2–2.5	3150 (3100)	**Habit:** thin tabular crystals according to {001}, scaly foliated aggregates. **Color:** lemon yellow to greenish yellow to pale green. **Diaphaneity:** transparent to translucent. **Luster:** vitreous to pearly on {001}. **Streak:** yellowish. **Cleavage:** (001) perfect, (100) good, (010) good. **Fracture:** uneven. **Other:** radioactive, strongly fluorescent yellow-green.
Azurite (syn., chessylite) [from the Persian, *lazhward*, blue] (ICSD 2934 and PDF 11-682)	$Cu_3(CO_3)_2(OH)_2$ M = 344.67108 55.31 wt.% Cu 0.58 wt.% H 6.97 wt.% C 37.14 wt.% O Coordinence Cu(5), C(3) (Nitrates, carbonates, and borates)	Monoclinic a = 500.8 pm b = 584.4 pm c = 1033.6 pm β = 92.45° (Z = 2)	Biaxial (+) α = 1.730 α = 1.756 γ = 1.836 δ = 0.108 $2V$ = 68° Dispersion weak	3.5–4	3770	**Habit:** tabular, massive, prismatic, stalactitic. **Color:** azure blue or very dark blue. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Streak:** light blue. **Cleavage:** (011) perfect, (100) good. **Fracture:** conchoidal, brittle. **Occurrence:** secondary mineral in the oxidized zone of copper ore deposits in association with malachite.
Baddeleyite [1314-23-4] [after J. Baddeley who first brought the original specimens from Ceylon (Sri Lanka)] (ICSD 18190 and PDF 37-1484)	ZrO_2 M = 123.2228 74.03 wt.% Zr 25.97 wt.% O (Oxides, and Hydroxides)	Monoclinic a = 514. 54 pm b = 520. 75 pm c = 531. 07 pm 99.23° (Z = 4) Baddeleyite type	Biaxal (–) α = 2.13 β = 2.19 γ = 2.2 δ = 0.070 $2V$ = 30°	6.5	5500–6000	**Habit:** tabular, crystalline. **Color:** brown, colorless, black. **Diaphaneity:** transparent, translucent, opaque. **Luster:** adamantine. **Streak:** white. **Fracture:** uneven. **Cleavage:** (001). Slightly sol. HCl, HNO3, and dil. H_2SO_4, sol. hot conc. H_2SO_4, and HF. Attacked by molten $KHSO_4$, NaOH, and Na_2CO_3. **Melting point:** 2710°C.
Barite [7727-43-7] (syn., heavy spar, barytine, baryte) [Named from the Greek, *baryos*, meaning heavy] (ICSD 16904 and PDF 24-1035)	$BaSO_4$ M = 233.3906 58.84 wt.% Ba 13.74 wt.% S 27.42 wt.% O Coordinence Ba(6), S(4) (Sulfates, chromates, molybdates, and tungstates)	Orthorhombic a = 887.8 pm b = 545.0 pm c = 715.2 pm (Z = 4) P.G. mmm S.G. $P2_1nma$ Barite type	Biaxial (+) α = 1.634–1.637 β = 1.636–1.639 γ = 1.647–1.649 δ = 0.011–0.012 $2V$ = 37–40° Dispersion weak	3–3.5	4490	**Habit:** tabular, prismatic, lamellar, massive, fibrous, cockscomb aggregates. **Color:** white, yellowish white, grayish white, brownish white, or dark brown. **Luster:** vitreous (i.e., glassy), pearly. **Diaphaneity:** transparent, translucent, opaque. **Fracture:** uneven. **Streak:** white. **Cleavage:** (001) perfect, (210) perfect. **Twinning:** {011}. **Luminescence:** phosphorescent. **Chemical:** Insoluble in hot HCl. Decomposes at 1580°C into BaO and SO_3. Can be reduced by carbon at 1000°C yielding BaS and CO_2. **Occurrence:** sedimentary rocks and late gangue mineral in ore veins.

Bastnaesite (syn., hamartite) [Named after the Swedish locality Bastnas Mine, Riddarhyttan, Vastmanland] Ce-rich (ICSD 81673 and PDF 11-340) La-rich (ICSD 36180 and PDF 41-595)	$Ce(CO_3)F$ $M = 219.12$ 63.94 wt.% Ce 5.48 wt.% C 21.90 wt.% O 8.67 wt.% F $La(CO_3)F$ $M = 217.91$ 63.74 wt.% La 5.51 wt.% C 22.03 wt.% O 8.72 wt.% F Both contain Th (Carbonates, nitrates and borates)	Hexagonal $a = 712$ pm $c = 976$ pm $(Z = 6)$ S.G. 6m2 P.G. 6m2 (Ditrigonal dipyramidal)	Uniaxial (+) $\varepsilon = 1.717$ $\omega = 1.818$ $\delta = 0.1010$	4–5	4970	**Habit:** prismatic, granular. **Color:** yellow or reddish brown. **Luster:** vitreous, greasy. **Cleavage:** (1011) imperfect, (0001) poor. **Fracture:** uneven. **Streak:** white.
Bayerite [Named after the German metallurgist Karl J. Bayer()] (ICSD 200413 and PDF 20-11)	α-$Al(OH)_3$ $M = 78.00$ 34.59 wt.% Al 3.88 wt.% H 61.53 wt.% O Coordinence Al(6) (Oxides and hydroxides)	Monoclinic $a = 506.26$ pm $b = 867.19$ pm $c = 471.3$ pm $\beta = 90.45°$, $(Z = 4)$ P.G. 2/m S.G. $P2_1/a$	Biaxial (+) $\alpha = 1.565–1.574$ $\beta = 1.583$ $\gamma = 1.580–1.584$ $\delta = 0.023$ $2V$ = small	n.a.	2540–3050 (3060)	**Habit:** fine fibers. **Color:** colorless. **Luster:** silky. **Diaphaneity:** translucent to transparent. **Streak:** white. **Occurrence:** precipitates of aluminum hydroxide gels onto carbonates at pH > 5.8.
Berdesinskiite [85270-10-6] [Named after the German mineralogist,Waldemar Berdesinski (1911–1990), University of Heidelberg]	V_2TiO_5 $M = 229.747$ 44.35 wt.% V 20.83 wt.% Ti 34.82 wt.% O Coordinence Ti(6)	Monoclinic $a = 1011$ pm $b = 508.4$ pm $c = 703$ pm $\beta = 111.6°$, $(Z = 4)$ P.G. 2/m 2/m 2/m S.G. Bbmm Pseudobrookite type	Biaxial (?) $R = 20.6–21.6\%$	6.5–7	4540	**Habit:** tiny grains. **Color:** black. **Luster:** metallic. **Diaphaneity:** opaque. **Occurrence:** weathered gneiss associated with schreyerite, tourmaline and kornerupine. Melts at 1750°C.
Bertrandite [Named after the French mineralogist, M.A. Bertrand (1847–1907)] (ICSD 202360 and PDF 24-509)	$Be_4[Si_2O_7(OH)_2]$ $M = 238.2302$ 15.13 wt.% Be 23.58 wt.% Si 0.85 wt.% H 60.44 wt.% O (Sorosilicates, pair)	Orthorhombic $a = 1522$ pm $b = 869$ pm $c = 454$ pm $(Z = 4)$ P.G. mm2 S.G. Ccm21	Biaxial (–) $\alpha = 1.589$ $\beta = 1.602$ $\gamma = 1.614$ $\delta = 0.023$ $2V = 76°$ Dispersion none	6	2590	**Habit:** well formed prismatic or tabular hexagonal crystals, with pinacoidal {1010}, {0001}, or prism {1120} or pyramidal terminations. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** translucent to transparent. **Color:** colorless or pale yellow. **Streak:** white. **Cleavage:** [001] perfect, [110] distinct, [101] distinct. **Fracture:** brittle. **Occurrence:** commonly found in Be-bearing pegmatites and may be derived from the alteration of beryl.
Beryl [1302-52-9] (syn., emerald: green, aquamarine: blue, morganite: pink, goshenite: colorless, heliodor: yellow) [Named from the Greek, *beryllos*, signifying a blue-green color of a gemstone] (ICSD 2791 and PDF 9-430)	$Be_3Al_2[Si_6O_{18}]$ $M = 537.50182$ 5.03 wt.% Be 10.04 wt.% Al 31.35 wt.% Si 53.58 wt.% O Coordinence Al(6), Si(4), and Be(4) Traces of Fe, Cr, Mg, Li, Na, K, Cs. (Cyclosilicates, ring)	Hexagonal $a = 921.5$ pm $c = 919.2$ pm $(Z = 2)$ P.G. 6/mmm S.G. P6/mcc Beryl type	Uniaxial (–) $\varepsilon = 1.564–1.598$ $\omega = 1.565–1.602$ $\delta = 0.003–0.008$	7.5–8.0	2640	**Habit:** crystalline, prismatic, columnar. **Color:** green, blue, yellow, colorless, or pink. **Luster:** vitreous, resinous. **Diaphaneity:** transparent to subtranslucent. **Streak:** white. **Cleavage:** [0001] imperfect. **Twinning:** {311}, {110}. **Fracture:** brittle, conchoidal. **Chemical:** insoluble in strong mineral acids. **Other:** dielectric constant 3.9 to 7.7. **Occurrence:** occurs exclusively in high-temperature hydrothermal veins, in granitic pegmatites, at the contacts zone of intrusive mafic igneous rocks with aluminous schists, shales or limestones and to a lesser extent in vugs inside rhyolites.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Bindheimite [Named after the German chemist, J.J. Bindheim] (ICSD 27120 and PDF 42-1355)	$Pb_2Sb_2O_6(O,OH)$ $M = 770.15$ 3.81 wt.% Pb 31.62 wt.% Sb 514.54 wt.% O 0.03 wt.% H (Oxides and hydroxides)	Cubic $a = 1041$ pm ($Z = 6$) P.G. 432 S.G. Fd3m	Isotropic $n_D = 1.84–1.87.$	4–5	4600–7300	**Habit:** encrustations, earthy, encrustations. **Color:** yellow, greenish yellow, green, brownish white, or grayish white. **Luster:** greasy. **Streak:** light greenish brown. **Fracture:** conchoidal.
Biotite (1M) (syn., manganophyllite: Mn, lepidomelane: Fe) [Named after the French physicist, J.B. Biot] (ICSD 68928 and PDF 42-1437)	$K(Mg,Fe)_3Si_3(Al,Fe)O_{10}(OH,F)_2$ Coordinence K(6), Fe(6), Mg(6), Si(4), Al(4) (Phyllosilicates, layered)	Monoclinic $a = 533$ pm $b = 931$ pm $c = 1016$ pm $\beta = 99.3°$ ($Z = 2$) P.G. 2/m S.G. C2/m	Biaxial (–) $\alpha = 1.565–1.625$ $\beta = 1.605–1.696$ $\gamma = 1.605–1.696$ $\delta = 0.040–0.080$ $2V = 0–32°$ Dispersion weak	2.5–3	2700–3300	**Habit:** micaceous, foliated, lamellar, pseudo hexagonal. **Color:** dark brown, greenish brown, blackish brown, yellow, or white. **Diaphaneity:** transparent to opaque. **Luster:** vitreous, pearly. **Streak:** white gray. **Cleavage:** (001) perfect. **Twinning:** [310]. **Fracture:** uneven, elastic. **Occurrence:** granitic rocks. Forms a series with phlogopite.
Bischofite [7791-18-6] [Named after the German chemist and geologist G. Bischof (1792–1870)] (ICSD 47161 and PDF 25-515)	$MgCl_2{\cdot}6H2O$ $M = 203.301$ 11.96 wt.% Mg 34.88 wt.% Cl 5.95 wt.% H (Halides)	Monoclinic $a = 990$ pm $b = 715$ pm $c = 610$ pm $\beta = 93.7°$ ($Z = 2$) P.G. 2/m S.G. C2/m	Biaxial (+) $\alpha = 1.498$ $\beta = 1.505$ $\gamma = 1.525$ $2V = 79°$	1–2	1604 (1585)	**Habit:** fibrous, deliquescent, massive, granular **Color:** colorless or white. **Luster:** vitreous, greasy. **Diaphaneity:** translucent to transparent. **Streak:** white. **Occurrence:** marine evaporites. Dehydratation occurs at 120°C. Soluble in water.
Bismuth [Named from the Arabic, *biismid*, having the properties of antimony] (ICSD 64703 and PDF 5-519)	Bi $M = 208.9804$ Coordinence Bi(3) (Native elements)	Trigonal (Rhombohedral) $a = 474.60$ pm 57.23° A7, *hR2* ($Z = 2$) P.G. 3m S.G. R3m α-Arsenic type	Uniaxial (n.a.) $n_D = 2.26$ $R = 67.9\%$	2–2.5 (HV 16–19)	9750	**Habit:** platy, lamellar, granular, reticulated. **Color:** silver white, pinkish white, or red. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** lead gray. **Cleavage:** [0001] perfect. **Fracture:** uneven.
Bloedite (syn., blödite) (ICSD 48017 and PDF 19-1215)	$Na_2Mg(SO_4)_2{\cdot}4H_2O$ $M = 334.47$ 13.75 wt.% Na 7.27 wt.% Mg 2.41 wt.% H 19.17 wt.% S 57.40 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Monoclinic $a = 1113$ pm $b = 824$ pm $c = 554$ pm $\beta = 100.84°$ ($Z = 2$) P.G. 2/m S.G. $P2_1/a$	Biaxial (–) $\alpha = 1.48$ $\beta = 1.48$ $\gamma = 1.48$ $\delta = 0.00$ $2V = 71°$ Dispersion strong	3	2230	**Habit:** massive, granular. **Color:** colorless, green, yellow, or red. **Diaphaneity:** transparent to translucent.

Boehmite [14457-84-2] [Named after the German geologist and paleontologist J. Böhm (1857–1938)] (ICSD 200599 and PDF 21-1307)	γ-AlO(OH) M = 59.98828 44.98 wt.% Al 1.68 wt.% H 53.34 wt.% O Coordinence Al(6) (Oxides and hydroxides)	Orthorhombic a = 286.8 pm b = 1222.7 pm c = 370 pm (Z = 4) P.G. mmm S.G. A2/mam Lepidocrite type	Biaxial (+) α = 1.646–1.650 β = 1.652–1.660 γ = 1.650–1.670 δ = 0.015 2V = 80°	3.5–4	3440	**Habit:** flaky, nodular, pistolitic, massive. **Color:** white, light yellow, or yellowish green. **Diaphaneity:** transparent to translucent. **Luster:** vitreous, pearly. **Streak:** white. **Cleavage:** perfect (010). **Fracture:** brittle. **Occurrence:** subtropical areas, lateritic soils develop on Al-bearing igneous rocks, major constituent of most bauxite ore.
Boracite [Named after its chemical composition containing boron] (ICSD 9290 and PDF 5-710)	$Mg_6B_{14}O_{26}Cl_2$ M = 768.0744 18.99 wt.% Mg 19.71 wt.% B 9.22 wt.% Cl 52.08 wt.% O Coordinence Mg(6), B(3 and 4) (Nitrates, carbonates, and borates)	Orthorhombic a = 854 pm b = 854 pm c = 1270 pm (Z = 2) P.G. m2m S.G. Pc2a	Biaxial (+) α = 1.662 β = 1.647 γ = 1.673 δ = 0.011 2V = 82°	7	2950	**Habit:** pseudocubic. **Color:** white, yellow. **Diaphaneity:** transparent to translucent. **Luster:** vitreous. **Streak:** white. **Cleavage:** (111). **Fracture:** conchoidal. pyroelectric.
Borax [1303-96-4] (syn., tincal) [from the Arabic, *buraq*, white] (ICSD 30506 and PDF 33-1215)	$Na_2B_4O_5(OH)_4{\cdot}10H_2O$ M = 381.36813 12.06 wt.% Na 11.34 wt.% B 5.29 wt.% H 71.32 wt.% O Coordinence Na(6), B(3 and 4) (Nitrates, carbonates, and borates)	Monoclinic a = 1185.8 pm b = 1067.4 pm c = 1267.4 pm 106.58° (Z = 4) P.G. 2/m S.G. C2/c	Biaxial (–) α = 1.447 β = 1.469 γ = 1.472 δ = 0.025 2V = 39–40°	2–2.5	1730–1900	**Habit:** prismatic, tabular, massive. **Color:** colorless, white, gray, or greenish white. **Diaphaneity:** translucent to opaque. **Luster:** resinous, greasy. **Streak:** white. **Cleavage:** (100) perfect, (110) perfect. **Fracture:** conchoidal, brittle. Sweet alkaline taste. Easy fusible acting as flux for several metal oxides (*m.p.* 75°C).
Bornite [Named after the Austrian mineralogist I. von Born (1742–1791)] (ICSD 1963 and PDF 42-1405)	Cu_5FeS_4 M = 501.823 63.31 wt.% Cu 11.13 wt.% Fe 25.56 wt.% S (Sulfides ans sulfosalts) Coordinence Cu(4), Fe(4)	Cubic a = 1094 pm (Z = 8) S.G. Fm-3m P.G. 4-32	Isotropic R = 21.9%	3 (HV 97–105)	6000	**Habit:** cubic euhedral crystals, tarnishes to purple. **Color:** bronze. **Luster:** metallic. **Diaphaneity:** opaque. **Cleavage:** {111}. **Twinning:** {111}. **Fracture:** conchoidal. **Others:** p-type semconductor with ΔE_g = 0.1 eV due to covellite or digenite inclusions; electrical resistivity 3 to 570 Ω.m.
Boulangerite (syn., mullanite) [Named after the French mining engineer, C.L. Boulanger (1810–1849)] (ICSD 300107 and PDF 42-1407)	$Pb_5CuSb_4S_{11}$ M = 1887.90 26.44 wt.% Sb 54.88 wt.% Pb 18.68 wt.% S (Sulfides and sulfosalts) Coordinence Pb(7), Sb(3)	Monoclinic a = 215.6 pm b = 235.1 pm c = 80.9 pm 100.8° (Z = 8) S.G. P2/a P.G. 2/m	Biaxial (?) R = 37.0–44.1%	2.5–3 (HV 157–183)	6000–6200	**Habit:** prismatic, tabular. **Color:** purple gray. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** gray. **Fracture:** conchoidal. **Cleavage:** {100}. Electrical resistivity 2000 to 40,000 Ω.m.
Bournonite (syn., wheel ore endellionite) [Named after the French mineralogist, J.L. de Bournon] (ICSD 14303 and PDF 42-1407)	$PbCuSbS_3$ M = 974.348 13.04 wt.% Cu 12.18 wt.% Sn 12.50 wt.% Sb 42.53 wt.% Pb 19.75 wt.% S (Sulfides and sulfosalts)	Orthorhombic a = 816 pm b = 870 pm c = 780 pm (Z = 4)	Biaxial R = 36.0–38.2% α = 1.487 β = 1.546 γ = 1.560 2V = 49°	3 (HV 185–199)	5800	**Habit:** tabular, pseudo cubic, cog-wheel. **Color:** lead gray or black. **Diaphaneity:** opaque. **Luster:** metallic. **Cleavage:** (010) imperfect. **Fracture:** subconchoidal. **Streak:** gray.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Bradleyite [Named after American geologist Wilmot Hyde Bradley (1899–1979)]	$Na_3Mg(PO_4)(CO_3)$ $M = 248.25$ 27.78 wt.% Na 9.79 wt.% Mg 12.48 wt.% P 4.84 wt.% C 45.11 wt.% O (Nitrates, carbonates, and borates)	Monoclinic $a = 885$ pm $b = 663$ pm $c = 516$ pm 90.15° ($Z = 2$) S.G. $P2_1/m$ P.G. 2/m	Biaxial	3.5	2720–2734 (2720)	**Habit:** rare minute crystals, extremely fined grained masses. **Color:** light gray. **Diaphaneity:** translucent. **Luster:** vitreous. Soluble in water and in sodium phosphate. **Occurrence:** oil shales.
Brannerite (syn., orthobrannerite) [Named after the American geologist, G. Branner (1850–1922)] (ICSD 201342 and PDF 12-477)	$(U, Ca, Ce)(Ti, Fe)_2O_6$ $M = 354.80$ 33.54 wt.% U 3.39 wt.% Ca 7.90 wt.% Ce 20.24 wt.% Ti 7.87 wt.% Fe 27.06 wt.% O Coordinence Ti(6)	Monoclinic $a = 981$pm $b = 377$ pm $c = 693$ pm $\beta = 118.97°$ ($Z = 2$) S.G. C2/m Brannerite-Thorutite series	Isotropic when metamict $n_D = 2.33$ $R = 14.8\%$	4.5–5.5 (HV 710–730)	4500–6350 (6370)	**Habit:** prismatic crystals, metamict. **Color:** brown, brown green, olive green, black. **Diaphaneity:** opaque to translucent. **Luster:** adamantine, resinous. **Fracture:** conchoidal. **Streak:** dark greenish brown. Insoluble in cold H_2SO_4 or HCl but dissolves in mixture of H_2SO_4 and H_3PO_4. Strongly radioactive.
Braunite [Named in 1831 after K.W. Braun (1790–1872)] (ICSD 4347 and PDF 41-1367)	$Mn^{II}Mn^{III}_6SiO_{12} = Mn_7SiO_{12}$ $M = 604.645$ 63.60 wt.% Mn 4.63 wt.% Si 31.77 wt.% O (Silicates)	Tetragonal $a = 940.8$ pm $c = 1866.8$ pm S.G. $I4_1/acd$ P.G. 422 ($Z = 8$)	Uniaxial () $R = 18.4–19.7$	6–6.5 (HV 920–1196)	4800 (4860)	**Habit:** pyramidal crystals also dense granular. **Color:** brownish black to steel-gray. **Diaphaneity:** opaque. **Luster:** submetallic. **Streak:** brownish black to steel gray. **Fracture:** uneven to conchoidal. **Cleavage:** (112) perfect. **Twinning:** (112). **Other:** weakly ferromagnetic. **Chemical:** soluble in HCl with evolution of nascent chlorine gas leaving a gelatinous silica residue. **Occurrence:** product of weathering occuring along with pyrolusite and psilomelane (romanechite) in manganese ore deposits.
Brochantite (syn., Blanchardite) [Named after the French geologist and mineralogist, A.J.M. Brochant de Villiers) (ICSD 64688 and PDF 43-1488)	$Cu_4(SO_4)(OH)_6$ $M = 452.29164$ 56.20 wt.% Cu 1.34 wt.% H 7.09 wt.% S 35.37 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Monoclinic Prismatic (2/m) $a = 1306.7$ pm $b = 985.0$ pm $c = 602.2$ pm ($Z = 4$)	Biaxial (–) $\alpha = 1.728$ $\beta = 1.771$ $\gamma = 1.8$ $\delta = 0.072$ $2V = 72°$ Dispersion weak	3.5–4	3970	**Habit:** acicular, prismatic, druse. **Color:** emerald green or blackish green. **Luster:** vitreous, pearly. **Diaphaneity:** transparent to translucent. **Streak:** pale green. **Cleavage:** [100] perfect. **Fracture:** conchoidal, brittle. **Occurrence:** secondary, formed in arid climates or in rapidly oxidizing copper sulfide deposits.
Bromargyrite [7785-23-1] (syn., Bromyrite) [from Greek, *bromos*, stench and *argyros*, silver] (ICSD 65061 and PDF 6-438)	AgBr $M = 187.7722$ 57.45 wt.% Ag 42.55 wt.% Br (Halides)	Cubic $a = 577.45$ pm ($Z = 4$) Rock salt type	Isotropic $n_D = 2.25$	1.5–2	5800	**Color:** bright yellow or amber yellow. **Luster:** adamantine-greasy. **Diaphaneity:** transparent to translucent. **Occurrence:** oxidized portions of silver deposits.
Bromellite [1304-56-9] [Named after the Swedish physician	BeO $M = 25.011582$ 36.03 wt.% Be	Hexagonal $a = 269.83$ pm $c = 436.76$ pm	Uniaxial (+) $\varepsilon = 1.733$ $\omega = 1.705–1.719$	9	3017 (3044)	**Habit:** prismatic, pyramidal hemimorphic crystals. **Color:** white to cream. **Diaphaneity:** transparent. **Luster:** vitreous. **Streak:** n.a. **Fracture:** n.a. **Cleavage:**{1010}. **Others:** pyroelectric, fluorescence. **Occurrence:** in calcite veins and skarns.

and mineralogist Magnus von Bromell (1679–1731)] (ICSD 62726 and PDF 35-818)	63.97 wt.% O Coordinence Be(4)	B4, hP4 ($Z = 2$) S.G. $P6_3mc$ P.G. 6mm Wurtzite type	$\delta = 0.014$			
Brookite [12188-41-9] [Named after the English mineralogist, Henry James Brooke (1771–1857)] (ICSD 36408 and PDF 29-1360)	TiO_2 $M = 79.8788$ 59.94 wt.% Ti 40.06 wt.% O Coordinence Ti(6) (Oxides and hydroxides)	Orthorhombic $a = 545.6$ pm $b = 918.2$ pm $c = 514.3$ pm $C2_1$, oP24 ($Z = 8$) P.G. mmm S.G. Pbca Brookite type	Biaxial (+) $\alpha = 2.5831–2.584$ $\beta = 2.5843–2.586$ $\gamma = 2.7004–2.741$ $\delta = 0.117–0.158$ $2V = 0–30°$ Dispersion strong	5.5–6.0	4100–4140 (4130)	**Habit:** tabular. **Color:** reddish brown, yellowish brown, dark brown, black. **Diaphaneity:** transparent, translucent, opaque. **Luster:** submetallic, adamantine. **Streak:** yellowish white. **Fracture:** subconchoidal. **Cleavage:** (120). **Chemical:** insoluble in water, slightly soluble in HCl, HNO_3, soluble in HF and in hot H_2SO_4 or $KHSO_4$. Attacked by molten Na_2CO_3. **Other properties:** dielectric constant of 78.
Brucite [1309-42-8] [Named after the American mineralogist, Archibald Bruce (1777–1818)] (ICSD 64722 and PDF 7-239)	$Mg(OH)_2$ $M = 58.31974$ Coordinence Mg(6) (Oxides and hydroxides)	Trigonal (Hexagonal) $a = 314.7$ pm $c = 476.9$ pm C6, *hP3* ($Z = 1$) P.G. 32 S.G. P-3m1 CdI_2 type	Uniaxial (+) $\varepsilon = 1.560–1.590$ $\omega = 1.580–1.600$ $\delta = 0.012–0.020$ Dispersion strong	2.5	2390	**Habit:** tabulated, foliated. **Color:** white, green. **Diaphaneity:** transparent to translucent. **Luster:** pearly, vitreous. **Streak:** white. **Fracture:** sectile. **Cleavage:** (001). **Melting point:** 350°C.
Bunsenite [1313-99-1] [Named after the German chemist and spectroscopist Robert Wilhelm Bunsen (1811–1899)] (ICSD 9866 and PDF 4-835)	NiO $M = 74.6928$ 78.58 wt.% Ni 21.42 wt.% O (Oxides and hydroxides) Coordinence Ni(6)	Cubic $a = 417.69$ pm B1, cF8 ($Z = 4$) S.G. Fm3m P.G. 432 Rock salt type Periclase group	Isotropic $n_D = 2.37$	5.5	6898 (6806)	**Habit:** octahedral crystals. **Color:** dark pistachio green. **Luster:** vitreous. **Diaphaneity:** transparent. **Streak:** brownish black. **Clivage:** unknown. **Fracture:** uneven. **Chemical:** soluble with difficulty in strong mineral acids. **Occurrence:** found in the oxidized zone of hydrothermal nickel–uranium veins along with nickel and cobalt arsenates.
Bytownite [Named after Bytown, ancient name of Ottawa, Ontario, Canada] (ICSD 34791 and PDF 41-1481)	$(Ca,Na)(Si,Al)_4O_8$ An80-Ab20 $M = 275.01042$ 1.67 wt.% Na 11.66 wt.% Ca 17.66 wt.% Al 22.47 wt.% Si 46.54 wt.% O (Tectosilicates, framework)	Triclinic $a = 817$ pm $b = 1285$ pm $c = 1316$ pm ($Z = 7$) P.G. 1	Biaxial (+/–) $\alpha = 1.563–1.572$ $\beta = 1.568–1.5784$ $\gamma = 1.573–1.583$ $\delta = 0.010–0.011$ $2V = 80–88$	7	2710	**Habit:** granular, euhedral, striated. **Color:** white or gray. **Diaphaneity:** translucent to transparent. **Luster:** vitreous (i.e., glassy). **Cleavage:** (001) perfect, (010) good. **Fracture:** uneven. **Streak:** white. **Occurrence:** magmatic and metamorphic rocks.
Calaverite [Named after Staislaus mine, Carson Hill, Calaveras Co. California) (ICSD 64681 and PDF 7-344)	$AuTe_2$ $M = 452.17$ 56.44 wt.% Te 43.56 wt.% Au (Sulfides and sulfosalts)	Monoclinic $a = 718$ pm $b = 440$ pm $c = 507$ pm 90°13' C34, mC6 ($Z = 2$) P.G. 2/m S.G. C2/m	Biaxial $R = 63.2\%$	2.5	9040	**Habit:** striated, massive, crystalline, fine. **Color:** white. **Luster:** metallic. **Diaphaneity:** opaque.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Calcite [471-34-1] (syn., travertine, nicols, calcareous spar) [Named from the Latin, *calx*, meaning quicklime) (ICSD 73446 and PDF 5-586)	$CaCO_3$ $M = 100.0872$ 40.04 wt.% Ca 12.00 wt.% C 47.96 wt.% O Traces of Mg, Fe, Mn, and Zn Coordinence Ca(6), C(3) (Nitrates, carbonates, and borates)	Trigonal (Rhombohedral) $a = 498.9$ pm $c = 1706.2$ pm $(Z = 6)$ P.G. -32/m S.G. R-3c Calcite type	Uniaxial (–) $\varepsilon = 1.486–1.550$ $\omega = 1.658–1.740$ $\delta = 0.172–0.190$ Dispersion strong	3.0 (HV 110)	2715–2940	**Habit:** crystalline, coarse, stalactitic, massive. **Color:** colorless, white, pink, yellow, or brown. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent, translucent, to opaque. **Streak:** white. **Cleavage:** (1011) perfect. **Twinning:** {0001}, {1014}, {0118}. **Fracture:** brittle, conchoidal. **Luminescence:** fluorescent. **Chemical:** decomposed at 1330°C giving CaO and readily dissolved in diluted acids with evolution of carbon dioxide. Alizarine's spot test: a soln. of 0.5 wt.% Alizarine S in dil. HCl colors the calcite crystal in deep pink, while dolomite, ankerite and magnesite remain colorless. **Occurrence:** sedimentary rocks.
Calomel [10112-91-1] (syn., horn quicksilver) [from the Greek, *kalos*, beautiful, and *melas*, black] (ICSD 64683 and PDF 26-312)	Hg_2Cl_2 $M = 472.0854$ 84.98 wt.% Hg 15.02 wt.% Cl Coordinence Hg(5) (Halides)	Tetragonal $a = 447.8$ pm $c = 1091.0$ pm $(Z = 4)$ S.G. I4/mmm P.G. 4/mmm	Uniaxial (+) $\omega = 1.973$ $\varepsilon = 2.656$ $\delta = 0.683$	1.5–2	6480	**Habit:** tabular, pyramidal, prismatic, earthy. **Color:** white, yellowish gray, gray, yellowish white, or brown. **Luster:** adamantine, resinous. **Luminescence:** fluorescent. **Diaphaneity:** translucent to subtranslucent. **Streak:** pale yellowish white. **Cleavage:** [100], [011]. **Twinning:** [110]. **Fracture:** conchoidal, sectile. **Occurrence:** oxidized mercury deposits. Easy fusible (*m.p.* 525°C). Insoluble in water.
Carnallite [Named after the German mining engineer, Rudolph von Carnall (1804–1874)] (ICSD 64691 and PDF 24-869)	$KMgCl_3{\cdot}6H_2O$ $M = 277.85308$ 14.07 wt.% K 8.75 wt.% Mg 4.35 wt.% H 38.28 wt.% Cl 34.55 wt.% O (Halides) Coordinence K(6), Mg(6)	Orthorhombic $a = 956$ pm $b = 1605$ pm $c = 2256$ pm $(Z = 12)$ P.G. mmm S.G. Pban	Biaxial (+) $\alpha = 1.467$ $\beta = 1.474$ $\gamma = 1.496$ $\delta = 0.029$ $2V = 70°$	2.5	1602	**Habit:** massive, granular, pseudo hexagonal, fibrous. **Color:** colorless, milky white, reddish white, or yellowish white. **Luster:** greasy (i.e., oily), vitreous. **Luminescence:** fluorescent. **Streak:** white, red. **Cleavage:** none. **Fracture:** conchoidal. **Occurrence:** marine evaporites.
Carnotite [Named after the French chemist, M.A. Carnot] (ICSD 15839 and PDF 11-338)	$K_2(UO_2)_2(VO_4)_2{\cdot}3H_2O$ $M = 902.17604$ 8.67 wt.% K 52.77 wt.% U 11.29 wt.% V 0.67 wt.% H 26.60 wt.% O Coordinence V(5), V(4), K(9), U(2) (Uranylphosphates and uranylvanadates)	Orthorhombic $a = 1047$ pm $b = 841$ pm $c = 691$ pm $(Z = 1)$ P.G. 2/m S.G. $P2_1/a$	Biaxial (–) $\alpha = 1.75$ $\beta = 1.92$ $\gamma = 1.95$ $\delta = 0.20$ $2V = 38–44°$	1.5–2	4200	**Habit:** earthy, encrustations, platy. **Color:** canary yellow or greenish yellow. **Luster:** dull, earthy. **Diaphaneity:** translucent. **Streak:** light yellow. **Cleavage:** (001) perfect. **Fracture:** uneven. Radioactive.
Cassiterite [18282-10-5] (syn., tin ore, wood tin) [from the Greek *kassiteros*, tin] (ICSD 39173 and PDF 41-1445)	SnO_2 $M = 150.7088$ 78.77 wt.% Sn 21.23 wt.% O Coordinence Sn(6) (Oxides and hydroxides)	Tetragonal $a = 473.8$ pm $c = 318.8$ pm C4, *tP6* $(Z = 2)$ P.G. 422 S.G. P4/mnm Rutile type	Uniaxial (+) $\varepsilon = 1.990–2.010$ $\omega = 2.093–2.100$ $\delta = 0.096–0.098$ Dispersion strong $R = 12.0\%$	6–7 (HV 1027–1075)	6994	**Habit:** acicular, prismatic, massive, botryroidal, fibrous 'wood tin'. **Color:** yellow, reddish brown, brownish black, or white. **Diaphaneity:** transparent to opaque. **Luster:** adamantine. **Streak:** brownish white. **Fracture:** subconchoidal, irregular. **Cleavage:** [100] perfect, [110] indistinct. **Twinning:** {101}. **Occurrence:** granite, pegmatites and alluvial placer deposits. **Melting point:** 1630°C.

Celestite [7759-02-6] (syn., celestine) [from the Latin, *caelestis*, meaning celestial] (ICSD 28055 and PDF 5-593)	$SrSO_4$ $M = 183.6836$ 47.70 wt.% Sr 17.46 wt.% S 34.84 wt.% O Coordinence Sr(6), S(4) (Sulfates, chromates, molybdates, and tungstates)	Orthorhombic $a = 835.9$ pm $b = 535.2$ pm $c = 686.6$ pm $(Z = 4)$ P.G. mmm S.G. $P2_1nma$ Barite type	Biaxial (+) $\alpha = 1.622$ $\beta = 1.624$ $\gamma = 1.631$ $\delta = 0.009$ $2V = 51°$ Dispersion moderate	3–3.5	3970	**Habit:** tabular, radiated fibrous, crystalline, massive, granular. **Color:** colorless, bluish white, yellowish white, or reddish white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (001) perfect, (210) good. **Fracture:** uneven to conchoidal, brittle. **Chemical:** decomposed at 1607°C. **Occurrence:** sedimentary rocks.
Celsian [Named after the Swedish astronomer and natural scientist, A. Celsius] (ICSD 25836 and PDF 38-1450)	$Ba[Si_2Al_2O_8]$ $M = 375.46$ 36.58 wt.% Ba 14.37 wt.% A 14.96 wt.% Si 34.09 wt.% O (Tectosilicates, framework)	Monoclinic $a = 863$pm $b = 1305$ pm $c = 1441$ pm $\beta = 115.2°$ $(Z = 8)$ P.G. 2/m S.G. 12/c Feldspars group	Biaxial (+) $\alpha = 1.58–1.584$ $\beta = 1.585–1.587$ $\gamma = 1.594–1.596$ $\delta = 0.012–0.014$ $2V = 86–90°$	6–6.5	3250	**Habit:** massive, granular, euhedral. **Color:** white or yellow. **Diaphaneity:** transparent. **Luster:** vitreous (i.e., glassy). **Cleavage:** [001] perfect, [010] good. **Fracture:** brittle, uneven. **Streak:** white. **Occurrence:** contact metamorphic rocks with significant barium.
Cerussite [598-63-0] (syn., white lead ore) [from the Latin, *cerussa*, meaning white lead] (ICSD 36558 and PDF 47-1734)	$PbCO_3$ $M = 267.2092$ 77.54 wt.% Pb 4.49 wt.% C 17.96 wt.% O Coordinence Pb(6), C(3) (Nitrates, carbonates, and borates)	Orthorhombic $a = 615.2$ pm $b = 843.6$ pm $c = 519.5$ pm $(Z = 4)$ P.G. mmm S.G. Pmcn Aragonite type	Biaxial (–) $\alpha = 1.804$ $\beta = 2.076$ $\gamma = 2.079$ $\delta = 0.274$ $2V = 8–14°$ Dispersion strong	3–3.5	6580	**Habit:** reticulate, tabular, massive, granular, crystalline, clustered. **Color:** colorless, gray, smoky gray, or grayish white. **Diaphaneity:** transparent to translucent. **Luster:** adamantine. **Streak:** white. **Cleavage:** (110) distinct, (021) distinct. **Twinning:** {110}, {130}. **Fracture:** conchoidal, brittle. **Chemical:** decomposed at 315°C giving off PbO and CO_2. Soluble in strong mineral acids with evolution of CO_2
Cervantite [Named after the locality Cervantes, Spain] (ICSD 63271 and PDF 11-6945)	Sb_2O_4 $M = 307.4976$ 79.19 wt.% Sb 20.81 wt.% O (Oxides and hydroxides)	Orthorhombic $a = 543$pm $b = 481$ pm $c = 1176$ pm $(Z = 4)$ P.G. mm2 S.G. Pbn21	Biaxial $\alpha = 2.0$ $\beta = 2.076$ $\gamma = 2.1$ $\delta = 0.274$	4–5	4000–6600 (6641)	**Habit:** reniform, earthy, acicular. **Color:** yellow, yellowish orange, white, or cream. **Luster:** vitreous-pearly. **Diaphaneity:** transparent to translucent. **Streak:** light yellow. **Cleavage:** [001] perfect. **Fracture:** conchoidal. **Occurrence:** alteration product of stibnite.
Chabasite [Named after the Greek, *chabazios*, an ancient name of a stone celebrated in a poem ascribed to Orpheus] (ICSD 31263 and PDF 34-137)	$CaSi_4Al_2O_{12}.6H_2O$ Coordinence Ca(7), Si(4), and Al(4) (Tectosilicates, framework)	Trigonal (Rhombohedral) $a = 1317$ pm $c = 1506$ pm $(Z = 6)$ P.G. 32/m S.G. R32/m Zeolite group	Uniaxial (–) $\varepsilon = 1.481$ $\omega = 1.484$ $\delta = 0.003$	4–5	2100	**Habit:** euhedral. **Luster:** vitreous. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (101) perfect. **Twinning:** {100}, and {001}. **Fracture:** uneven.
Chalcanthite [7758-99-8] (syn., copper vitriol, blue vitriol) [Named from the Greek, *chalkos*, copper, and, *anthos*, flower] (ICSD 20657 and PDF 11-646)	$CuSO_4{\cdot}5H_2O$ $M = 249.686$ 25.45 wt.% Cu 4.04 wt.% H 12.84 wt.% S 57.67 wt.% O Coordinence Cu(6), S(4) (Sulfates, chromates, molybdates, and tungstates)	Triclinic $a = 610.45$ pm $b = 1072.0$ pm $c = 594.9$ pm $\alpha = 97.57°$ $\beta = 107.28°$ $\gamma = 77.43°$ $(Z = 2)$ P.G. 1 S.G. P1	Biaxial (–) $\alpha = 1.514$ $\beta = 1.537$ $\gamma = 1.543$ $\delta = 0.029$ $2V = 56°$ Dispersion none	2.5	2120–2300	**Habit:** tabular, encrustations, stalactitic, reniform. **Color:** berlin blue, sky blue, or greenish blue. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Streak:** white. **Fracture:** conchoidal. **Cleavage:** (110) good, (111) indistinct. **Others:** loss two water molecules at 27°C giving $CuSO_4.3H_2O$, that loss two additional water molecules at 93°C yielding the pale blue $CuSO_4.H_2O$, that finally yields the anhydrous white $CuSO_4$ at 110°C. Finally, it decomposes into black CuO and SO_3 fumes at 702°C. **Occurrence:** secondary, formed in arid climates or in rapidly oxidizing copper deposits.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Chalcocite [22205-45-4] [Named from the Greek, *chalkos*, copper] (ICSD 100333 and PDF 33-490)	Cu_2S $M = 159.158$ 79.85 wt.% Cu 20.15 wt.% S (Sulfides and sulfosalts)	Orthorhombic $a = 1188.1$ pm $b = 273.23$ pm $c = 1349.1$ pm ($Z = 96$) Cuprite type	Biaxial $R = 32.2\%$	2.5–3 (HV 68–98)	5800	**Habit:** massive, granular, euhedral crystals. **Color:** black or iron black. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** grayish black. **Cleavage:** {110} indistinct. **Twinning:** {110}, {032}, {112}. **Fracture:** Conchoidal. **Occurrence:** secondary mineral in/near the oxidized zone of copper sulfide ore deposits. **Others:** p-type semiconductor with $\Delta E_g = 0.06$ eV–0.13 eV. Electrical resistivity 80 to 100 μΩ.cm., melting point of 1100°C.
Chalcopyrite [1308-56-1] [Named from the Greek, *chalkos*, copper, hence copper pyrite] (ICSD 2518 and PDF 35-752)	$CuFeS_2$ $M = 183.525$ 30.43 wt.% Fe 34.63 wt.% Cu 34.94 wt.% S Traces of Ag, Au, Pt, Co, Ni, Pb, Sn, Zn, As, and Se (Sulfides and sulfosalts) Coordinence Cu(4), Fe(4)	Tetragonal $a = 529.88$ pm $c = 1043.4$ pm E1$_1$, tI16 ($Z = 4$) S.G. I42d P.G. 42m Chalcopyrite type	Uniaxial $R = 42.0–46.1\%$	3.5–4 (HV 186–219)	4190	**Habit:** rare tetrahedral disphenoidal crystals, botryoidal, striated, druse, usually zoned. **Color:** brass yellow or honey yellow. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** greenish black. **Cleavage:** {011}, {111}. **Fracture:** uneven, brittle. **Twinning:** {112}. **Chemical:** attacked by HNO_3, corroded by a mixture of KOH + $KMnO_4$. **Occurrence:** veins and disseminated in metamorphic and igneous rocks (e.g., gabbros, norites). **Others:** n-type semiconductor with $\Delta E_g = 0.01$ eV–0.03 eV. Electrical resistivity 150 to 9000 μΩ.cm., melting point 950°C.
Chloanthite (syn., white nickel) [Named from Greek, *chloantos*, greenish] (ICSD 2518 and PDF 35-752)	$(Ni,Co)As_3$	Cubic 432	Isotropic	5.5	6400–6600	**Habit:** massive, granular, euhedral crystals. **Color:** tin white or dark gray. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** grayish black. **Fracture:** uneven.
Chlorargyrite [7783-90-6] [Named after Greek, *chloros*, pale green, and Latin, *argentum*, silver] (ICSD 64734 and PDF 31-1238)	AgCl $M = 143.321$ 75.26 wt.% Ag 24.74 wt.% Cl Coordinence Ag(6) (Halides)	Cubic $a = 554.91$ pm B1, cF8 ($Z = 4$) S.G. Fm3m P.G. 4-32 Rock salt type	Isotropic $n_D = 2.071$	2.5	5550	**Habit:** massive, cubic euhedral crystals. **Color:** colorless gray, violet tarnish. **Luster:** resinous. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** [100]. **Fracture:** subconchoidal, sectile.
Chlorite (1M) (syn., alushite, tosudite) [from the Greek, *chloros*, green]	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$ Coordinence Mg(6), Fe(6), Si(4), Al(4) (Phyllosilicates, layered)	Monoclinic $a = 537$ pm $b = 930$ pm $c = 1425$ pm $\beta = 101.77°$ ($Z = 2$)	Biaxial (–) $\alpha = 1.56–1.60$ $\beta = 1.57–1.61$ $\gamma = 1.58–1.61$ $2V = 0–40°$ $\delta = 0.006–0.020$ Dispersion strong	2–3	3000	**Habit:** foliated, scaly, lamellar. **Color:** green. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Twinning:** (001) simple, lamellar, common. **Fracture:** uneven in steps, brittle. **Cleavage:** (001) perfect. **Twinning:** [310]. **Deposits:** metamorphic rocks, weathering of Al-rich sedimentary rocks.
Chloritoid (2M) (syn., ottrelite: contains MnO) [from its similarity with chlorite] (ICSD 1850 and PDF 14-62)	$FeAl_2O[SiO_4]_2(OH)_4$ 26–28 wt.% FeO 2–4 wt.% MgO 39–41 wt.% Al_2O_3 24–26 wt.% SiO_2 2–7 wt.% H_2O Coordinence Fe(6), Mg(6), Al(6), Si(4) (Phyllosilicates, layered)	Monoclinic $a = 948$ pm $b = 548$ pm $c = 1818$ pm $\beta = 101.77°$ ($Z = 8$) P.G. 2/m S.G. C2/c	Biaxial (+) $\alpha = 1.713–1.730$ $\beta = 1.719–1.734$ $\gamma = 1.723–1.740$ $2V = 45–68°$ O.A.P. ⊥ (010) Dispersion strong	6.5 (HV 178–218)	3510–3800	**Habit:** similar to that of micas, lamellar. **Color:** dark green, colorless to green in thin section. **Luster:** vitreous (i.e., glassy) and submetallic for dark varieties. **Diaphaneity:** transparent to translucent. **Twinning:** {001} simple, lamellar {221}, common. **Fracture:** uneven in steps, brittle. **Cleavage:** (001) perfect. **Chemical:** insol. In HCl but attacked by H_2SO_4. Slightly fusible on thin edges. **Dielectric constant:** 6.9. **Deposits:** metamorphic rocks, weathering of Al-rich sedimentary rocks.

Chondrodite [Named from the Greek, *chondros*, grain] (ICSD 15180 and PDF 12-527)	$Mg(OH,F)_2.2Mg_2[SiO_4]$ M = 382.12 23.85 wt.% Mg 18.27 wt.% Fe 14.70 wt.% Si 0.13 wt.% H 35.59 wt.% O 7.46 wt.% F Coordinence Mg(6), Si(4) (Nesosilicates)	Monoclinic a = 789 pm b = 474.3 pm c = 1029 pm 109.03° (Z = 2) P.G. 2/m S.G. $P2_1/b$ (Humite group)	Biaxial α = 1.592–1.615 β = 1.602–1.627 γ = 1.621–1.646 δ = 0.028–0.038 $2V$ = 71–85° O.A.P (010)	6.5	3150–3180	**Habit:** massive. **Color:** brown, yellow, orange, red, colorless. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** translucent to transparent. **Cleavage:** (100) poor. **Twinning:** {001}. **Fracture:** uneven, brittle. **Chemical:** attacked by strong mineral acids giving a silica gel. **Occurrence:** dolomites, limestones, skarns.
Chromite [1308-31-2] (syn., chromic iron, chrome iron ore) [Named from the Greek, *chroma*, color for the brilliant hues of its compounds] (ICSD 20819 and PDF 34-140)	$FeCr_2O_4$ M = 223.8348 46.46 wt.% Cr 24.95 wt.% Fe 28.59 wt.% O Coordinence Fe(4), Cr(6) (Oxides and hydroxides)	Cubic a = 839.40 pm $H1_1$, cF56 (Z = 8) P.G. m3m S.G. Fd3m Spinel type (Chromite Series)	Isotropic n_D = 2.16 R = 14.1%	5.5 (HV 1195–1210)	5090	**Habit:** massive, granular, nuggets. **Color:** black or brownish black. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** brown. **Cleavage:** none. **Twinning:** {111}. **Fracture:** uneven to conchoidal. **Others:** weakly magnetic. Thermal conductivity of 1.73–2 $W.m^{-1}K^{-1}$
Chrysoberyl [12004-06-7] (syn., alexandrite: green) [from the Greek, *chrysos*, golden and the mineral beryl and Czar Alexander II (1818–1881) of Russia] (ICSD 62501 and PDF 11-448)	$BeAl_2O_4$ M = 126.97286 7.10 wt.% Be 42.50 wt.% Al 50.40 wt.% O Coordinence Al(6), Be(4) (Oxides and hydroxides)	Orthorhombic a = 547.56 pm b = 940.41 pm c = 442.67 pm (Z = 4) P.G. mmm S.G. $P2_1/bnm$ Olivine type	Biaxial (+) α = 1.747 β = 1.748 γ = 1.757 δ = 0.010 $2V$ = 45° Dispersion none	8.5	3699	**Habit:** twinning, prismatic, tabular, striated (001). **Color:** green, white, brown, or yellow. **Streak:** white. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Cleavage:** (110) distinct, (010) imperfect. **Twinning:** {031}. **Fracture:** brittle. **Occurrence:** granitic pegmatite dikes.
Chrysocolla (syn., bisbeeite) [Named from the Greek, *chrysos*, gold, and *kolla*, glue in allusion to the name of the material used to solder gold)	$(Cu,Al)_2H_2Si_2O_5(OH)_4{\cdot}nH_2O$ M = 328.42 (n = 0.25) 2.05 wt.% Al 33.86 wt.% Cu 17.10 wt.% S 1.92 wt.% H 45.06 wt.% O (Cyclosilicates, ring)	Monoclinic a = 570 pm b = 890 pm c = 670 pm β = 93.167° (Z = 1)	Biaxial (–) α = 1.575 β = 1.587 γ = 1.600 δ = 0.025	2.5–3.5	2200–2400	**Habit:** botryoidal, earthy, stalactitic. **Color:** green, bluish green, blue, blackish blue, or brown. **Diaphaneity:** translucent to opaque. **Luster:** vitreous, dull. **Cleavage:** none. **Fracture:** sectile. **Streak:** light green. **Occurrence:** mineral of secondary origin commonly associated with other secondary copper minerals.
Chrysotile [Named from Greek, *chrysotos*, guilded in reference to its color and nature]	$Mg_3Si_2O_{10}(OH)_8$ M = 554.22 26.31 wt.% Mg 20.27 wt.% Si 1.45 wt.% H 51.96 wt.% O Phyllosilicates	Monoclinic a = 531.3 pm b = 912 pm c = 1464 pm β = 93.167° (Z = 4) P.G. 2/m S.G. A2/m Kaolinite-serpentinite group	Biaxial (–) α = 1.545–1.569 β = 1.546–1.569 γ = 1.553–1.570 δ = 0.0010 $2V$ = 50°	2.5	2530–2550 (2600)	**Habit:** acicular crystals making fibrous aggragates. **Color:** green to pale green. **Diaphaneity:** translucent. **Luster:** silky. **Streak:** white. **Others:** infusible and insoluble in HCl. **Occurrence:** metamorphic rocks.
Cinnabar [1344-48-5] [from the Latin, *cinnabaris*] (ICSD 70054 and PDF 42-1408)	HgS M = 232.656 86.22 wt.% Hg 13.78 wt.% S (Sulfides and sulfosalts) Coordinence Hg(6)	Trigonal (Hexagonal) a = 414.9 pm c = 949.5 pm B9, hP6 (Z = 3) S.G. $P3_121$ P.G. 32 Cinnabar type	Uniaxial (+) ω = 2.814 ε = 3.143 δ = 0.351 R = 26.3%	2–2.5	8170	**Habit:** druse, disseminated, tabular, massive. **Color:** intense red, brownish red, or gray. **Diaphaneity:** transparent, translucent to opaque. **Luster:** adamantine. **Streak:** scarlet, bright red. **Cleavage:** {1010} perfect. **Twinning:** {0001}. **Fracture:** subconchoidal, brittle, sectile. Decomposed at 386°C in HgO.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Clinohumite [Named after the British mineralogist Sir Abraham Hume, and *clinos*, for its monoclinic crystal system] (ICSD 70054 and PDF 42-1408)	$Mg(OH,F)_2.2Mg_2[SiO_4]$ Coordinence Mg(6), Si(4) (Nesosilicates)	Monoclinic $a = 475$ pm $b = 1027$ pm $c = 1368$ pm 100.83° ($Z = 2$) P.G. 2/m S.G. $P2_1/b$ (Humite group)	Biaxial () $\alpha = 1.629–1.638$ $\beta = 1.641–1.643$ $\gamma = 1.662–1.674$ $\delta = 0.028–0.041$ $2V = 65–84°$ O.A.P (100)	6	3210–3350	**Habit:** massive. **Color:** brown, yellow, orange, red, colorless. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** translucent to transparent. **Cleavage:** (100) poor. **Twinning:** {010}. **Fracture:** uneven, brittle. **Chemical:** attacked by strong mineral acids giving a silica gel. **Deposits:** dolomites, limestones, skarns.
Clinozoïsite [Named after the Austrian natural scientist, S. Von Zoïs, and *clinos* for its monoclinic lattice structure] (ICSD 66923 and PDF 44-1400)	$Ca_2Al.Al_2O(OH)[SiO_4][Si_2O_7]$ $M = 427.37572$ 18.76 wt.% Ca 12.63 wt.% Al 19.71 wt.% Si 0.24 wt.% H 48.67 wt.% O Traces of Fe(III) Coordinence Ca(7), Al(6), Si(4) (Sorosilicates and nesosilicates)	Monoclinic $a = 888.7$ pm $b = 558.1$ pm $c = 1014.0$ pm 115°93 ($Z = 2$) P.G. 2/m S.G. $P2_1/m$ (Epidote group)	Biaxial (+) $\alpha = 1.670–1.715$ $\beta = 1.674–1.725$ $\gamma = 1.690–1.734$ $\delta = 0.005–0.015$ $2V = 14–90°$ Dispersion strong	6–6.5 (HV 680)	3120–3380	**Habit:** prismatic according to b, striated, columnar. **Color:** pale-yellow, cream yellow, pink, greenish, colorless. **Diaphaneity:** transparent to opaque. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (001) perfect. **Twinning:** {100}. **Fracture:** uneven. **Chemical:** insoluble in HCl. **Other:** dielectric constant 8.51. **Occurrence:** regional metamorphic and pegmatite rocks.
Cobaltite [12254-82-9] [from the German, *Kobold*, underground spirit, or goblin, in allusion to the refusal of cobaltiferous ores to smelt properly, hence bewitched] (ICSD 31189 and PDF 42-1345)	CoAsS $M = 197.9868$ 29.77 wt.% Co 37.84 wt.% As 32.39 wt.% S (Sulfides and sulfosalts) Coordinence Co(6)	Cubic $a = 557$ pm F01, cP12 ($Z = 4$) S.G. P213 P.G. 23 NiSbS type	Isotropic $R = 52.7\%$	5.5 (HV 1176–1226)	6330	**Habit:** massive, granular, faces striated. **Color:** reddish silver white, violet steel gray, or black. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** grayish black **Cleavage:** {100} good, {010} good, {001} good. **Fracture:** uneven, brittle. Electrical resistivity 6.5 to 130 mΩ.m.
Coesite [Named after the American chemist, Loring Coes, Jr. (1915–1973), from Norton Company, who first synthesized the mineral] (ICSD 18112 and PDF 14-654)	α-SiO_2 $M = 60.0843$ 46.74 wt.% Si 53.26 wt.% O (Tectosilicates, framework) Coordinence Si (4)	Monoclinic $a = 715.2$ pm $b = 1237.9$ pm $c = 717.0$ pm ($Z = 16$) P.G. 2/m S.G. C2/c	Biaxial (+) $\alpha = 1.590$ $\beta = 1.600$ $\gamma = 1.600$ $\delta = 0.010$ $2V = 64°$	7–8	2930	**Habit:** tabular, high pressure. **Color:** colorless. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Fracture:** conchoidal. **Twinning:** {011}, {021}. **Diaphaneity:** transparent to translucent. **Chemical:** resistant to strong mineral acids, attacked by HF and molten alkali-metal hydroxides.
Coffinite [Named after the American mineralogist, Reuben Clare Coffin (1886–1972)] (ICSD 15484 and PDF 11-420)	$U[SiO_4].nH_2O$ (Nesosilicates) Thorium and rare earths can substitute to uranium	Tetragonal $a = 697.9$ pm $c = 625.3$ pm $I4_1/amd$ ($Z = 4$) P.G. 4/mmm S.G. $I4_1/amd$ Zircon type	Uniaxial (+/–) Metamict $R = 9.9\%$	5–6 (HV 236–333)	3500–5100 (6900)	**Habit:** aggregates of micrometric grains and masses rarely prismatic crystals. Usually metamict due its radioctivity. **Color:** black but yellow to brown in thin sections. **Diaphaneity:** opaque to transucent in thin sections. **Luster:** dull to adamantine. **Streak:** brownish-black. Radioactive. **Occurrence:** in sedimentary rocks from the weathering of uraninite in a supergene, reducing and alkaline environment.

Colemanite (syn., neocolmanite) [Named after William Tell Coleman (1824–1893) owner of the Death Valley, California mine where this species was first found] (ICSD 16764 and PDF 33-267)	$Ca_2B_6O_{11}.5H_2O$ $M = 411.09$ 19.50 wt.% Ca 14.78 wt.% B 2.45 wt.% H 62.27 wt.% O Coordinence Ca(7), B(3, and 4) (Nitrates, carbonates and borates)	Monoclinic $a = 874.3$ pm $b = 1126.4$ pm $c = 610.2$ pm $\beta = 110.12°$ ($Z = 4$) P.G. 2/m S.G. $P2_1/a$	Biaxial (–) $\alpha = 1.586$ $\beta = 1.592$ $\gamma = 1.614$ $\delta = 0.028$ $2V = 55–56°$ Dispersion weak	4–4.5	2420 (2430)	**Habit:** blocky, crystalline, coarse, massive, granular. **Color:** white, yellowish white, gray, or yellowish white. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (010) perfect, (001) distinct. **Fracture:** subconchoidal, brittle. **Diaphaneity:** transparent to translucent. Soluble in hot HCl. **Occurrence:** ancient quaternary lacusterine limestone hosted borate deposits, Furnace Creek Death Valley, California.
Coloradoite [Named after its occurrence in Smuggler mine, Boulder, Colorado] (ICSD 31086 and PDF 32-665)	HgTe $M = 328.19$ 61.12 wt.% Hg 38.88 wt.% Te (Sulfides and sulfosalts)	Cubic $a = 646.0$ pm B3, cF8 ($Z = 4$) S.G. F43m P.G. 43m Blende type	Isotropic $R = 35.4$	2.5 (HV 25–28)	8070	**Habit:** massive, granular. **Color:** iron black. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** black. **Fracture:** conchoidal.
Columbite (syn., niobite) [Named after its niobium (columbium) content] (ICSD 31943 and PDF 16-337)	$(Fe,Mn)(Nb,Ta)_2O_6$ Coordinence Fe(6), Mn(6), Nb(6), Ta(6) (Oxides and hydroxides)	Orthorhombic $a = 510$ pm $b = 1427$ pm $c = 574$ pm ($Z = 2$) P.G. mmm S.G. $P2_1bcn$	Biaxial (+) $\alpha = 2.44$ $\beta = 2.32$ $\gamma = 2.38$ $2V = 75°$	5 (HV 724– 882)	6000	**Habit:** prismatic. **Color:** black, brown. **Luster:** submetallic. **Diaphaneity:** translucent to opaque. **Fracture:** subconchoidal. **Cleavage:** {010}.
Copper (syn., cuprum) [from the Greek, *kyprios*, the name of the island of Cyprus, once producing this metal] (ICSD 64699 and PDF 4-836)	Cu $M = 63.546$ Coordinence Cu(12) (Native elements)	Cubic $a = 361.5$ pm A1, *cF4* ($Z = 4$) P.G. m3m S.G. Fm3m Copper type	Isotropic $n_D = 0.641$ $R = 81.2\%$	2.5–3 (HV 120– 143)	8935	**Habit:** nodular, dendritic, arborescent. **Color:** light rose, copper red, or brown. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** rose. **Cleavage:** none. **Fracture:** hackly. **Chemical:** readily dissolved in nitric acid, HNO_3, giving a blue solution of $Cu(NO_3)_2$ which deposits copper onto a pure zinc rods immersed in the solution. **Occurrence:** Cap rock of copper sulfide veins and in some types of volcanic rocks.
Cordierite [Named after the French mining engineer and geologist Pierre Louis A. Cordier (1777–1861)] (ICSD 100250 and PDF 12-303)	$Mg_2Si_5Al_4O_{18}$ $M = 584.95$ 8.31 wt.% Mg 18.45 wt.% Al 24.01 wt.% Si 49.23 wt.% O Coordinence Mg(6), Si(4), Al(4) (Cyclosilicate, ring)	Orthorhombic $a = 1713$ pm $b = 980$ pm $c = 935$ pm ($Z = 4$) P.G. 2/mmm S.G. C2/ccm	Biaxial (+/–) $\alpha = 1.54$ $\beta = 1.55$ $\gamma = 1.56$ $2V = 65–105°$	7	2500– 2800	**Habit:** prismatic. **Color:** white. **Luster:** vitreous. **Diaphaneity:** transparent to translucent. **Fracture:** even. **Cleavage:** (010) good, (100) poor. **Twinning:** {110}, {130}. **Occurrence:** alumina-rich metamorphic rocks.
Corundum [1344-28-1] (syn., alumina, saphirre: blue, ruby: red) [Named from the Hindi, *kurund*, or the Tamil, *kurundam*, name of the mineral] (ICSD 31545 and PDF 43-1484)	α-Al_2O_3 $M = 101.961$ 52.93 wt.% Al 47.07 wt.% O (Oxides, and hydroxides) Coordinence Al(6)	Trigonal (Rhombohedral) $a = 513.29$ pm 55°17' $D5_1$, hR10 ($Z = 2$) S.G. R3c P.G. 32/m Corundum type	Uniaxial (–) $\varepsilon = 1.765–1.776$ $\omega = 1.757–1.767$ $\delta = 0.008$ Dispersion moderate	9 (HV 2000)	3980– 4020 (3987)	**Habit:** prismatic, crystal often barrel-shaped, also tabular or rhombohedral, **Color:** colorless, yellow, red, blue green, violet, black. **Luster:** vitreous to adamantine. **Diaphaneity:** transparent to opaque. **Streak:** white. **Cleavage:** none. **Twinning:** (101). **Parting:** (101). **Fracture:** uneven. **Chemical:** soluble in strong minerals acids only after fusion with $KHSO_4$ or $CaSO_4$. **Melting point:** 2054°C. **Deposits:** metamorphic rocks, sedimentary rocks.
Cotunnite [7758-95-4] (syn., plumbous chloride) [Named after the Italian physicist Domenico Cotugno (1736–1822), University of Naples] (ICSD 27736 and PDF 26-1150)	$PbCl_2$ $M = 278.11$ 74.50 wt.% Pb 25.50 wt.% Cl (Halides)	Orthorhombic $a = 762.2$ pm $b = 904.5$ pm $c = 453.5$ pm ($Z = 4$) P.G. 2/m S.G. A2/m	Biaxial (+) $\alpha = 2.199$ $\beta = 2.217$ $\gamma = 2.260$ $2V = 67°$	1.5–2	5300– 5800 (5908)	**Habit:** acicular, massive, granular. **Color:** white or yellowish white. **Luster:** adamantine. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** [001] perfect. **Fracture:** conchoidal, sectile. Slightly soluble in hot water releasing Pb^{2+} that give a bright yellow precipitate of $PbCrO_4$ with K_2CrO_4. **Occurrence:** oxidized lead deposits.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Coulsonite [12418-94-9] [Named after A.L. Coulson] (ICSD 28962 and PDF 15-122)	FeV_2O_4 $M = 221.73$ 25.19 wt.% Fe 45.95 wt.% V 26.86 wt.% O Coordinence Fe(4), V(6) (Oxides and hydroxides)	Cubic $a = 829.7$ pm $H1_1$, cF56 ($Z = 8$) P.G. m3m S.G. Fd3m Spinel type	Isotropic $n_D =$ $R = 23\%$	4.5–5	5170–5200 (5150)	**Habit:** microscopic subhedral crystals. **Cleavage:** none **Color:** bluish gray. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** dark brown to balck.
Covellite [1317-40-4] (syn., covelline) [Named after the Italian mineralogist, Niccolo Covelli (1790–1829)] (ICSD 63327 and PDF 6-464)	CuS $M = 95.61$ 66.46 wt.% Cu 33.54 wt.% S (Sulfides and sulfosalts) Coordinence Cu(3), Cu(4)	Trigonal (Hexagonal) $a = 380$ pm $c = 1636$ pm B18, hP12 ($Z = 6$) S.G. $P6_3/mmc$ P.G. 622 Covellite type	Uniaxial (+) $\varepsilon = 1.450$ $\omega = 1.600$ $R = 14.5\%$	1.5–2 (HV 69–78)	4600	**Habit:** tabular, tarnishes purple. **Color:** blue. **Luster:** submetallic. **Diaphaneity:** opaque. **Streak:** dark gray. **Fracture:** conchoidal. **Cleavage:** {0001}. Electrical resistivity 3 to 83 μΩ.cm. **Melting point:** 507°C.
Cristobalite (alpha) [14464-46-1] [Named after Cerro San Cristóbal near Pachuca, Mexico] (ICSD 47219 and PDF 39-1425)	SiO_2 $M = 60.0843$ 46.74 wt.% Si 53.26 wt.% O (Tectosilicates, framework) Coordinence Si (4)	Tetragonal $a = 497.1$ pm $c = 691.8$ pm ($Z = 4$) P.G. 422 S.G. $P4_12_12$	Uniaxial (–) $\varepsilon = 1.482$ $\omega = 1.489$ $\delta = 0.007$	6–7	2330	**Habit:** coarse aggregate. **Color:** colorless. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous(i.e., glassy). **Fracture:** conchoidal. **Twinning:** (111). **Chemical:** resistant to strong mineral acids, attacked by HF and molten alkali-metal hydroxides. **Melting point:** 1713°C.
Crocoite [7758-97-6] [Named from the Greek, *krokos*, meaning crocus or saffron] (ICSD 24607 and PDF 8-209)	$PbCrO_4$ $M = 327.1937$ 63.33 wt.% Pb 15.89 wt.% Cr 19.56 wt.% O Coordinence Pb(6), Cr(4) (Sulfates, chromates, molybdates, and tungstates)	Monoclinic $a = 711$ pm $b = 741$ pm $c = 681$ pm $\beta = 102.55°$ ($Z = 4$) P.G. 2/m S.G. $P2_1/n$ Crocoite type	Biaxial(+) $\alpha = 2.31$ $\beta = 2.37$ $\gamma = 2.66$ $\delta = 0.35$ $2V = 54°$	2.5–3	6000	**Habit:** acicular, striated //c. **Color:** red orange. **Streak:** orange. **Diaphaneity:** translucent. **Luster:** adamantine. **Fracture:** subconchoidal. **Cleavage:** (010). **Twinning:** (011). **Melting point:** 844°C.
Cryolite [13775-53-6] [from the Greek, *kryos*, frost, and lithos, stone for its icy appearance] (ICSD 4029 and PDF 23-772)	Na_3AlF_6 $M = 209.94126$ 32.85 wt.% Na 12.85 wt.% Al 54.30 wt.% F (Halides) Coordinence Na(12), Na(6), Al(6)	Monoclinic $a = 546$ pm $b = 560$ pm $c = 778$ pm $90.18°$ ($Z = 2$) S.G. P21/n P.G. 2/m Prismatic	Biaxial (+) $\alpha = 1.3385$ $\beta = 1.3389$ $\gamma = 1.3396$ $\delta = 0.0011$ $2V = 43°$	2.5–3	2970	**Habit:** massive, granular, pseudocubic euhedral crystals. **Color:** snow white, gray, reddish white, or brownish white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous, greasy. **Streak:** white. **Cleavage:** [001], [110], [101]. **Fracture:** uneven. **Occurrence:** large bed in a granitic vein in gray gneiss. **Melting point:** 1009°C.
Cubanite [Named after Barracanao, Cuba] (ICSD 67529 and PDF 47-1749)	$CuFe_2S_3$ $M = 271.44$ 41.15 wt.% Fe 23.41 wt.% Cu 35.44 wt.% S	Orthorhombic $a = 646$ pm $b = 1112$ pm $c = 623$ pm E9e, oP24 ($Z = 4$)	Biaxial $R = 41.2\%$	3.5 (HV 199–228)	4100	**Habit:** lamellar. **Color:** gray, black. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** gray. **Cleavage:** {110}. **Twinning:** {110}. **Fracture:** subconchoidal. Magnetic.

	Coordinence Cu(4), Fe(4) (Sulfides and sulfosalts)	S.G. Pnma P.G. mmm				
Cuprite [1317-39-1] (syn., chalcotrichite) [from the Latin, *cuprum*, copper, while chalcotrichite from the Greek, *khalkos*, hairy copper) (ICSD 63281 and PDF 5-667)	Cu_2O M = 143.0914 88.82 wt.% Cu 11.18 wt.% O Coordinence Cu(2) (Oxides and hydroxides)	Cubic a = 426.96 pm C3, cP6 (Z = 2) P.G. 432 S.G. Pn3m Cuprite type	Isotropic n_D = 2.849 R = 27.1%	3.5–4 (HV 192– 218)	6106	**Habit:** cubic, octahedral, massive, granular, capillary. **Color:** brownish red or dark red. **Diaphaneity:** transparent to translucent. **Luster:** submetallic to adamantine. **Streak:** brownish red. **Cleavage:** (111) imperfect. **Fracture:** brittle, conchoidal. **Other:** Electrical resistivity 10 to 50 Ω.m. **Occurrence:** oxidized zone of copper deposits.
Datolite [Named after the Greek, *datos*, to divide because of granular character of some varieties] (ICSD 22026 and PDF 36-429)	$CaB[SiO_4](OH)]$ M = 159.98 25.05 wt.% Ca 17.56wt.% Si 6.76wt.% B 0.63wt.% H 50.00wt.% O (Nesosilicates)	Monoclinic a = 962 pm b = 760 pm c = 484 pm 90.15° (Z = 4)	Biaxial (–) α = 1.622–1.626 β = 1.649–1.654 γ = 1.666–1.670 δ = 0.044–0.046 2V = 72–75° O.A.P. (010) Dispersion weak	5–5.5	2960– 3000	**Color:** colorless or white, yellow, green, pink. **Cleavage:** none. **Twinning:** none. **Chemical:** insoluble in HCl but gelatinize. Gives intense yellowish color to bunsen flame when moistened with H_2SO_4. **Deposits:** in cavities and veins in hyapbyssal and volcanic igneous rocks. Skarns. Serpentine and hornblende schists. Secondary mineral associated with calcite, prehnite, zeolites and axinite. **Melting point:** 1235°C.
Dawsonite [Named after the Canadian geologist John William Dawson (1820–1899), principal of McGill University, Montreal, Canada] (ICSD 100140 and PDF 42-1346)	$NaAl(CO_3)(OH)_2$ M = 144.00 15.97 wt.% Na 8.34 wt.% C 18.74 wt.% Al 1.40 wt.% H 55.56 wt.% O	Orthorhombic a = 673 pm b = 1036 pm c = 558 pm P.G. 2/m2/m2/m S.G. Imam (Z = 4) Barentsite type	Biaxial (–) α = 1.462 β = 1.542 γ = 1.596 δ = 0.130 2V = 76.75° Dispersion weak	< 3	2420 (2434)	**Habit:** thin encrustations, bladed, needle-like or radial crystals. **Color:** colorless to white. **Diaphaneity:** transparent. **Luster:** vitreous to silky. **Fracture:** uneven. **Cleavage:** [110] Perfect. **Streak:** colorless. **Other:** fluorescent under short-wavelength UV with dull white. **Occurrence:** low-temperature hydrothermal mineral.
Diamond [7782-40-3] (syn., boart, carbonado) [from the Greek, *adamas*, invincible, or hardest first used in Manilius (AD 16)] (ICSD 29325 and PDF 6-675)	C M = 12.0107 Coordinence C(4) (Native elements)	Cubic a = 356.68 pm A4, *cF8* (Z = 8) P.G. m3m S.G. Fd-3m Diamond type	Isotropic n_D = 2.4175– 2.4178	10	3510	**Habit:** euhedral crystals, granular. **Color:** colorless, white, gray, black, or blue. **Diaphaneity:** transparent to translucent. **Luster:** adamantine. **Luminescence:** fluorescent. **Streak:** colorless. **Cleavage:** (111) perfect. **Fracture:** conchoidal. **Occurrence:** gas rich, ultrabasic diatremes from mantle depths (> 30 km) and alluvial placer deposits derived from the Kimberlite rocks. **Melting point:** 4440°C under 12 GPa. Diamond exists in two major varieties, those bearing nitrogen as an impurity (Type I) and those without (Type II). These two subgroups are further subdivided into Types Ia, Ib, IIa, and IIb. Type Ia diamonds are the most common type of naturally occurring diamond (98%) and they contain between 10 to 3000 ppm wt. nitrogen present into small aggregates, including platelets. By contrast, type Ib diamonds are scarce (0.1%) with a low nitrogen content (25–30 ppm wt.) dispersed substitionally. Of the two type II diamond types, Type IIb which is extremely rare is a semiconductor due to minute amounts of boron impurities and with nitrogen below 0.1 ppm wt. N, it exhibits a blue color, whereas Type IIa diamonds are comparatively pure and contain less than 10 ppm wt. N.
Diaspore [14457-84-2] [from the Greek, *dia*, through and *speirein*, to scatter in reference to its characteristic decrepitation on heating n in the bunsen flame] (ICSD 200952 and PDF 5-355)	AlO(OH) M = 59.98828 44.98 wt.% Al 1.68 wt.% H 53.34 wt.% O Coordinence Al(6) (Oxides and hydroxides)	Orthorhombic a = 440.1 pm b = 942.1 pm c = 284.5 pm (Z = 4) P.G. mmm S.G. $P2_1/bnm$ Geothite type structure	Biaxial (+) α = 1.682–1.706 β = 1.705–1.725 γ = 1.730–1.752 δ = 0.047–0.050 2V = 85–88° Dispersion weak	6.5–7	3440	**Habit:** platy, massive, tabular, disseminated. **Color:** white, greenish gray, grayish brown, colorless, or yellow. **Luster:** vitreous, pearly. **Diaphaneity:** transparent to translucent. **Streak:** white yellow. **Cleavage:** perfect (010), poor (210). **Fracture:** brittle, conchoidal. **Occurrence:** metamorphic and sedimentary bauxite ores.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Diopside (syn., diallage) [Named from the Greek, *dis*, two kinds, and *opsis*, opinion] (ICSD 100738 and PDF 41-1370)	$CaMg[Si_2O_6]$ $M = 216.5504$ 18.51 wt.% Ca 11.22 wt.% Mg 25.94 wt.% Si 44.33 wt.% O Coordinence Ca(8), Mg(6), Si(4) (Inosilicates, double chains)	Monoclinic $a = 970$ pm $b = 890$ pm $c = 525$ pm $\beta = 105.83°$ P.G. 2/m S.G. C2/c $(Z = 4)$	Biaxial (+) $\alpha = 1.665$ $\beta = 1.672$ $\gamma = 1.695$ $\delta = 0.030$ $2V = 56–63°$ Dispersion weak	6	3400	**Habit:** Prismatic, Blocky, Granular. **Color:** white, yellowish green, black, or grayish blue. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Streak:** white green. **Cleavage:** (110) good. **Twinning:** {001}, {100}. **Fracture:** brittle, conchoidal. **Occurrence:** basic and ultrabasic igneous and metamorphic rocks.
Dioptase [Named from the Greek, *dia*, through, and *optomai*, vision] (ICSD 100077 and PDF 33-487)	$CuSiO_2(OH)_2$ (Cyclosilicates, ring)	Trigonal	Uniaxial (+) $\varepsilon = 1.644–1.658$ $\omega = 1.697–1.709$ $\delta = 0.051–0.053$	5	3331	**Habit:** massive, cryptocrystalline. **Color:** dark green or emerald green. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Cleavage:** (1011) good. **Fracture:** conchoidal. **Streak:** green. **Occurrence:** secondary mineral in oxidized zones of copper deposits.
Dolomite [Named after the French mineralogist and geologist, Deodat Guy Silvain Tancrède Gratet de Dolomieu] (ICSD 31336 and PDF 36-426)	$CaMg(CO_3)_2$ $M = 184.4014$ 21.73 wt.% Ca 13.18 wt.% Mg 13.03 wt.% C 52.06 wt.% O Coordinence Mg(6), Ca(6), C(3) (Nitrates, carbonates, and borates)	Trigonal (Rhombohedral) $a = 480.79$ pm $c = 1601.00$ pm $a_{Rh} = 601.5$ pm, 47°07' $(Z = 3)$ P.G. 3 S.G. R3 Dolomite type	Uniaxial (–) $\varepsilon = 1.500–1.520$ $\omega = 1.679–1.703$ $\delta = 0.179–0.185$	3.5–4	2860–2930	**Habit:** rhombohedral, crystalline, massive, botryoidal, globular, stalactitic. **Color:** white, gray, reddish white, brownish white, or gray. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (1011) perfect. **Twinning:** {0001}, {1010}, {1110}, {0112}. **Fracture:** brittle, subconchoidal. **Chemical:** readily dissolved by strong mineral acids with evolution of carbon dioxide. **Occurrence:** sedimentary rocks.
Dravite [Named after the Drava River, Austria] (ICSD 72937 and PDF 44-1457)	$NaMg_3Al_6(OH)_4B_3O_3[Si_6O_{18}]$ Coordinence Na(6), Mg(6), Al(6), B(3), Si(4) (Cyclosilicates, ring)	Trigonal $a = 1594$ pm $c = 722$ pm $(Z = 3)$ P.G. 3m S.G. R3m Tourmaline group	Uniaxial (–) $\varepsilon = 1.650$ $\omega = 1.628$ $\delta = 0.022$	7–7.5	3020	**Habit:** prismatic. **Color:** brown, yellow. **Luster:** resinous. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (101) poor, {110} poor. **Twinning:** {101}. **Fracture:** subconchoidal.
Eglestonite [Named after the American mineralogist, Thomas E. Egleston (1832–1900)] (ICSD 12102 and PDF 29-909)	$Hg_6Cl_4O(OH)$ $M = 1342.90$ 89.62 wt.% Hg 0.08 wt.% H 7.92 wt.% Cl (Halides)	Cubic $a = 1603.6$ pm $(Z = 16)$ S.G. Ia3d	Isotropic $n_D = 2.49$	2–3	8300–8450 (8650)	**Color:** yellow or brownish yellow. **Luster:** adamantine, resinous. **Diaphaneity:** transparent to translucent.
Elbaite [Named after the Island of Elba, Italy] (ICSD 9252 and PDF 26-964)	$NaLi_1Al_1(OH)_4B_3O_3[Si_6O_{18}]$ $M = 916.68$ 2.51 wt.% Na 1.89 wt.% Li 19.13 wt.% Al 18.38 wt.% Si 3.54 wt.% B 0.44 wt.% H 54.11 wt.% O	Trigonal $a = 1646$ pm $c = 1625$ pm $(Z = 3)$ P.G. 3m S.G. R3m Tourmaline group	Uniaxial (–) $\varepsilon = 1.650$ $\omega = 1.628$ $\delta = 0.022$	7–7.5	2900	**Habit:** prismatic. **Color:** white. **Luster:** resinous. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (101) poor, {110} poor. **Twinning:** {101}. **Fracture:** subconchoidal.

	Coordinence Na(6), Li(6), Al(6), B(3), Si(4) (Cyclosilicates, ring)					
Electrum	(Au, Ag) (Native elements)	Cubic	Isotropic R = 83%	(HV 34–44)		
Embolite [Named from the Greek for intermediate, alluding to the 1:1 ratio of chloride and bromide] (ICSD 9252 and PDF 26-964)	Ag(Br,Cl) M = 165.55 65.16 wt.% Ag 24.13 wt.% Br 10.71 wt.% Cl (Halides)	Cubic	Isotropic n_D = 2.15			**Habit:** massive. **Color:** yellowish green or grayish yellow. **Luster:** adamantine, greasy. **Diaphaneity:** transparent to translucent. **Streak:** white. **Occurrence:** oxidized portions of silver deposits.
Enargite [Named from the Greek, *enargis*, distinct] (ICSD 75556 and PDF 35-580)	Cu_3AsS_4 M = 398.806 47.80 wt.% Cu 20.04 wt.% As 32.16 wt.% S (Sulfides and sulfosalts) Coordinence Cu(4), As(4)	Orthorhombic a = 642.6 pm b = 742.2 pm c = 614.4 pm (Z = 2) S.G. Pn2m P.G. m2m	Biaxial R = 25–28%	3 (HV 133–185 and 245–346 //)	4500	**Habit:** striated tabular crystals. **Color:** bronze. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** dark gray. **Fracture:** uneven. Electrical resistivity 0.2 to 40 mΩ.m
Enstatite [13776-74-4] (syn., bronzite) [from the Greek, *enstates*, opponent or resistant owing to the unfusibility of the mineral and bronze brown] (ICSD 37313 and PDF 19-768)	$Mg_2[Si_2O_6]$ M = 200.778 60 wt.% SiO_2 40 wt.% MgO Traces of Ca, Fe, Mn, Ni, Cr, Al and Ti Coordinence Mg(6, 8), Si(4) (Inosilicates, single chain)	Orthorhombic a = 1822.0 pm b = 882.9 pm c = 519.2 pm (Z = 4) P.G. mmm S.G. $P2_1bca$ Enstatite type	Biaxial (+) α = 1.650–1.668 β = 1.652–1.673 γ = 1.658–1.680 δ = 0.008–0.011 $2V$ = 54–90° Dispersion weak	5–6	3190–3500	**Habit:** massive, tabular, lamellar, prismatic. **Color:** white, yellowish green, brown, greenish white, or gray. **Luster:** vitreous (i.e., glassy), pearly. **Diaphaneity:** translucent to opaque. **Streak:** gray. **Cleavage:** (100) distinct, (010) distinct. **Twinning:** {101}. **Fracture:** uneven, brittle. **Chemical:** insoluble in HCl but sol. in HF. Decomposed at 1550°C. **Other:** dielectric constant 8.23. **Occurrence:** magmatic mafic rocks.
Epidote [from the Greek, *epidosis*, increase, owing to the high lattice parameter] (ICSD 10268 and PDF 45-1446)	$Ca_2Fe.(Al, Fe)_2O(OH)[SiO_4][Si_2O_7]$ M = 519.30 15.44 wt.% Ca 3.90 wt.% Al 24.20 wt.% Fe 16.22 wt.% Si 0.19 wt.% H 40.05 wt.% O (Sorosilicates and nesosilicates)	Monoclinic a = 889.0 pm b = 563.0 pm c = 1019.0 pm 115°40 (Z = 2) Epidote group	Biaxial (–) α = 1.715–1.751 β = 1.725–1.784 γ = 1.734–1.797 δ = 0.015–0.049 $2V$ = 90–116° Dispersion strong	6–6.5 (HV 680)	3380–3490	**Habit:** prismatic according to b, striated, columnar. **Color:** gray, apple green, brown, blue, or rose red. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy), resinous, pearly. **Streak:** white. **Cleavage:** [001] perfect, [100] imperfect. **Fracture:** uneven. **Chemical:** insoluble in strong mineral acids, but attacked by HCl after calcination giving a gel of silica, fusible giving a dark green globule. **Occurrence:** regional metamorphic and pegmatite rocks.
Epsomite [Named after Epsom, a town near London, England] (ICSD 29384 and PDF 36-419)	$MgSO_4.7H_2O$ M = 246.47598 9.86 wt.% Mg 13.01 wt.% S 71.40 wt.% O 5.73 wt.% H Coordinence Mg(6), S(4) (Sulfates, chromates, molybdates, and tungstates)	Orthorhombic a = 1196 pm b = 1199 pm c = 685.8 pm (Z = 4) P.G. 222 S.G. $P2_12_12_1$ Epsomite type	Biaxial(+) α = 1.433 β = 1.455 γ = 1.461 δ = 0.028 $2V$ = 52	2–2.5	1680	**Habit:** botryoidal, prismatic. **Color:** colorless. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous. **Fracture:** conchoidal.
Erythrite (syn., cobalt bloom) (ICSD 81385 and PDF 33-413)	$Co_3(AsO_4)_2.8H_2O$ M = 598.76072 29.53 wt.% Co 25.03 wt.% As 42.75 wt.% O 2.69 wt.% H Coordinence Co(6), As(4) (Phosphates, arsenates, and vanadates)	Monoclinic a = 1026 pm b = 1337 pm c = 474 pm β = 105.1° (Z = 2) P.G. 2/m S.G. C2/m Vivianite type	Biaxial(–) α = 1.626 β = 1.661 γ = 1.699 δ = 0.073 $2V$ = 90°	1–2	3060	**Habit:** reniform, fibrous. **Color:** purple red. **Streak:** pale purple. **Diaphaneity:** translucent. **Luster:** adamantine. **Fracture:** sectile. **Cleavage:** (010) perfect.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Eskolaite [1308-38-09] [Named after the Finnish geologist, Pentti Eskola (1883–1964)] (ICSD 201102 and PDF 38-1479)	Cr_2O_3 M = 151.9904 68.42 wt.% Cr 31.56 wt.% O (Oxide and hydroxides) Coordinence Cr()	Trigonal (Rhombohedral) a = 497.3 pm c = 1358.4 pm $D5_1$, hR10 (Z = 2) S.G. R3c P.G. 32/m Corundum type	Uniaxial (–) R = 19.6%	9–9 (HV 3200)	5180 (5245)	**Habit:** hexagonal prismatic crystals, rarely platty with (0001) and (1010). **Color:** black to dark green. **Luster:** vitreous. **Diaphaneity:** opaque but transparent on thin edges. **Streak:** light green. **Chemical:** insoluble in mineral acids and alkalis. **Other:** nonmagnetic, infusible. **Occurrence:** occurs in skarn associated with sulfide of igneous origin or as rounded grains in sedimentary detrital deposits such as beach mineral sands.
Eudialyte (syn., eucolite) [from the Greek, *eu*, well, and *dialytos*, decomposable] (ICSD 68157 and PDF 41-1465)	$Na_4(Ca,Ce)_2(Fe,Mn,Y)Zr[Si_8O_{22}](OH,Cl)_2$ M = 992.15 9.27 wt.% Na 6.06 wt.% Ca 7.06 wt.% Ce 0.90 wt.% Y 9.19 wt.% Zr 1.66 wt.% Mn 3.38 wt.% Fe 22.65 wt.% Si 0.15 wt.% H 1.79 wt.% Cl 37.90 wt.% O (Cyclosilicates, ring)	Trigonal (Rhombohedral) a = 1434 pm c = 3021 pm (Z = 12) P.G. 32/m S.G. R3m	Uniaxial (+) ω = 1.593–1.643 ε = 1.597–1.634 δ = 0.001–0.010	5–5.5	2900	**Habit:** Massive-Granular, Tabular. **Cleavage:** [0001] Imperfect. **Fracture:** Uneven. **Luster:** vitreous (i.e., glassy). **Color:** pinkish red, red, yellow, yellowish brown, or violet. **Streak:** white. **Occurrence:** Nepheline–syenite rocks.
Euxenite [Named from the Greek *euxenos*, hospitable, in allusion to the rare earth elements it hosts] (ICSD 100175 and PDF 14-463)	$(Y,Ca,Ce)(Nb,Ta,Ti)_2O_6$ M = 392.28 2.04 wt.% Ca 3.57 wt.% Ce 15.86 wt.% Y 18.45 wt.% Ta 2.44 wt.% Ti 33.16 wt.% Nb 24.47 wt.% O	Orthorhombic a = 1464.3 pm b = 555.3 pm c = 519.5 pm (Z = 4) P.G. 2/m2/m2/m S.G. Pbcn	Biaxial (?) Often metamict but recrystallize after heat treatment at 1000°C n_D = 2.25 R = 15.0%	5.5–6.5 (HV 530–767)	4300–5870 (5130)	**Habit:** rare prismatic or flattened crystals. **Color:** Brownish black, brown, yellow, olive green. **Luster:** submetallic. **Diaphaneity:** opaque. **Cleavage:** (101). **Fracture:** subconchoidal to conchoidal. **Streak:** black to reddish brown. Radioactive. **Occurrence:** granite pegmatites, syenites, yellow and orange weathering products.
Falcondoite (syn., garnierite, genthite) [Named from the contraction of **Falcon**bridge **Do**minica C. Por A., Loma Peruera laterite deposit at Bonao, Dominican Republic]	$(Ni,Mg)_4[Si_4O_{10}](OH)_2{\cdot}6H_2O$ M = 750.99 3.24 wt.% Mg 22.44 wt.% Si 23.45 wt.% Ni 1.88 wt.% H 49.00 wt.% O (Phyllosilicates, layered)	Orthorhombic a = 1350 pm b = 269 pm c = 524 pm (Z = 4) P.G. 2/m2/m2/m S.G. Pncn	Biaxial n ~ 1.55	3–4	2410 (2620)	**Habit:** stalactitic. **Color:** green or yellowish green. **Luster:** resinous.
Faujasite [Named after Barthelemy Faujas de	$(Na_2,Ca,Mg)_{3.5}[Al_7Si_{17}O_{48}]{\cdot}32H_2O$ (Tectosilicates, network)	Cubic a = 247 pm	Isotropic n_D = 1.47–1.48	5	1923–1940	**Habit:** euhedral. **Color:** colorless, white, or pale brown. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (111) perfect, (111)

Saint Fond (1741–1819), French geologist and writer on the origin of volcanoes] (ICSD 4392 and PDF 39-1380)		(Z = 8) P.G. 432 S.G. Fd3m				perfect, (111) perfect. **Fracture:** brittle, uneven. **Occurrence:** usually occurs in basaltic volcanics, metapyroxenite, also with augite in limburgite.
Fayalite [10179-73-4] (syn., hortonolite: Mn,Mg, knebelite: Mn) [Named after the locality, Fayal, one of the island of the Acores archipel] (ICSD 26375 and PDF 31-633)	$Fe_2[SiO_4]$ Fe-pole: Fo10-0 M = 203.7771 54.81 wt.% Fe 13.78 wt.% Si 31.41 wt.% O Traces of Mg, Ca, and Mn Coordinence Fe(6), Si(4) (Nesosilicates)	Orthorhombic a = 481.7 pm b = 1047.7 pm c = 610.5 pm (Z = 4) P.G. mmm S.G. Pbnm Olivine group	Biaxial (–) α = 1.827 β = 1.869 γ = 1.879 δ = 0.052 $2V$ = 47–54° Dispersion weak O.A.P (001)	6.5–7 (HV 820)	4390	**Habit:** massive, granular. **Color:** brown black, or black. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** translucent to transparent. **Streak:** white. **Cleavage:** (010) distinct, (001) poor. **Twinning:** {100}, {011}, {012}. **Fracture:** conchoidal. **Chemical:** attacked by strong mineral acids giving a gel of silica. Fusible giving a magnetic globule. **Occurrence:** ultramafic silica-poor igneous rocks such as gabbros, basalts, peridotites.
Ferberite [13870-24-1] [Named after the German chemist, Moritz Rudolph Ferber (1805–1875)] (ICSD 64733 and PDF 46-1446)	$FeWO_4$ M = 303.6826 18.39 wt.% Fe 60.54 wt.% W 21.07 wt.% O Coordinence Fe(6), W(4) (Sulfates, chromates, molybdates, and tungstates)	Monoclinic a = 473.2 pm b = 570.8 pm c = 496.5 pm β = 90.00° (Z = 2) P.G. 2/m S.G. P2/c Wolframite type	Biaxial (+) α = 2.31 β = 2.40 γ = 2.46 δ = 0.15 $2V$ = 79°	4–4.5	7600	**Habit:** short prismatic. **Color:** brown, black. **Luster:** submetallic. **Diaphaneity:** opaque. **Streak:** black. **Cleavage:** (010) poor. **Twinning:** {100}, {023}. **Fracture:** uneven.
Fergusonite [Named after the Scottish physician Robert Ferguson (1799–1865)] (ICSD 100836 and PDF 32-680)	$YNbO_4$ M = 245.80983 36.17 wt.% Y 37.80 wt.% Nb 26.04 wt.% O (Oxides and hydroxides)	Tetragonal a = 517 pm c = 530 pm (Z = 2) S.G. I4$_1$/a	Isotropic n_D = 2.190	5.5–6	5050	**Color:** brown or brownish black. **Diaphaneity:** translucent to opaque. **Luster:** submetallic. **Cleavage:** indistinct. **Fracture:** subconchoidal. **Streak:** brown.
Ferroaxinite [Named from Greek *axine*, ax in reference to its wedge-shaped crystals] (ICSD 4343 and PDF 27-76)	$Ca_2FeAl_2[Si_4BO_{15}](OH)$ M = 570.12 14.06 wt.% Ca 9.80 wt.% Fe 9.47 wt.% Al 19.71 wt.% Si 1.90 wt.% B 0.18 wt. H 44.90 wt.% O	Triclinic a = 896 pm b = 922 pm c = 716 pm α = 102.7° β = 98.03° γ = 88.03° S.G. P1 (Z = 2) Axinite group	Biaxial (–) α = 1.674–1.683 β = 1.682–1.691 γ = 1.685–1.694 δ = 0.00090–0.0110 $2V$ = 67–73°	6.5–7	3290–3320	**Habit:** thin wedge-shaped axehead crystals. **Color:** gray to bluish gray. **Diaphaneity:** opaque to translucent. **Luster:** vitrous. **Cleavage:** good (100). **Fracture:** uneven to conchoidal. **Streak:** colorless.
Ferropseudobrookite [12449-79-5]	$FeTi_2O_5$ M = 231.576 24.12 wt.% Fe 41.34 wt.% Ti 34.54 wt.% O Coordinence Ti(6)	Monoclinic (Z = 4) P.G. 2/m S.G. A2/m Karrooite type	Biaxial (?)			Melt at 1500°C
Fluorite [7789-75-5] (syn., fluor spar) [Named from Latin, *fluere*, to flow] (ICSD 60559 and PDF 35-816)	CaF_2 M = 78.0748 51.33 wt.% Ca 48.67 wt.% F Traces of Y and Ce (Halides) Coordinence Ca(8)	Cubic a = 546.36 pm C1, cF12 (Z = 4) S.G. Fm3m P.G. 4-32 Fluorite type	Isotropic n_D = 1.434	4	3180	**Habit:** crystalline, massive, granular, octahedral crystals. **Color:** white, yellow, green, red, or blue. **Luster:** vitreous (i.e., glassy). **Luminescence:** fluorescent blue under short and long UV light. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** [111]. **Fracture:** conchoidal, splintery. Insoluble in water, dissolved in hot conc. H_2SO_4 evolving gaseous HF, slightly soluble in HCl and HNO_3. Decrepitation when fired. Fusible ($m.p.$ 1418°C) giving a white enamel. Sometimes radioactive owing to traces of Th. **Occurrence:** low-temperature vein deposits, guangue materials, sedimentary rocks.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Forsterite [26686-77-1] (syn., olivine, chrysolite, peridot) [Named after the English mineralogist Adolarius Jacob Forster (1739–1806)] (ICSD 9334 and PDF 34-189)	$Mg_2[SiO_4]$ Mg-pole: Fo90-100 57.1 wt.% MgO 42.9 wt.% SiO_2 Traces Fe, Mn Coordinence Mg(6), Si(4) (Nesosilicates)	Orthorhombic $a = 475.8$ pm $b = 1021.4$ pm $c = 598.4$ pm ($Z = 4$) P.G. mmm S.G. Pbnm Olivine group	Biaxial (+) $\alpha = 1.635$ $\beta = 1.651$ $\gamma = 1.670$ $\delta = 0.035$ $2V = 82°$ Dispersion weak O.A.P. (001)	6.5–7 (HV 820)	3220	**Habit:** prismatic, tabular. **Color:** white, yellow, or greenish yellow. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (010) good, (001) poor. **Fracture:** conchoidal. **Chemical:** attacked by concentrated HCl with formation of a gel of silica. **Melting point:** 1898°C.
Franklinite [1317-55-1] [Named after the American scientist, Benjamin Franklin (1706–1790)] (ICSD 81205 and PDF 22-1012)	$ZnFe_2O_4$ $M = 241.0776$ Coordinence Zn(4), Fe(6) (Oxides and hydroxides)	Cubic $a = 842.0$ pm $H1_1$, cF56 ($Z = 8$) P.G. m3m S.G. Fd3m Spinel type	Isotropic $n_D = 2.36$ $R = 18.9\%$	5.5	5320	**Habit:** octahedral. **Color:** black, red brown. **Diaphaneity:** opaque. **Luster:** metallic. **Cleavage:** none. **Parting:** {111}.
Gahnite [Named after the Swedish chemist and mineralogist, J.G. Gahn (1745–1818)] (ICSD 9559 and PDF 5-669)	$ZnAl_2O_4$ $M = 183.35$ 29.43 wt.% Al 35.66 wt.% Zn 34.90 wt.% O Coordinence Zn(4), Al(6) (Oxides and hydroxides)	Cubic $a = 808$ pm $H1_1$, cF56 ($Z = 8$) P.G. m3m S.G. Fd3m Spinel type	Isotropic $n_D = 1.805$	7.5–8	4570–4620	**Habit:** octahedral crystals or irregular grains. **Color:** dark green, yellow. **Diaphaneity:** translucent. **Luster:** vitreous. **Streak:** brown to yelow. **Fracture:** conchoidal. **Occurrence:** metamorphic rocks (schists) or lithium-rich granite pegmatites.
Galaxite [Named after locality Bald Knob, Sparta near the town of Galax, NC, USA] (ICSD 66855 and PDF 29-880)	$(Mn,Mg)(Al,Fe)_2O_4$ $M = 172.72$ 1.41% Mg 28.63% Mn 29.68% Al 3.23% Fe 37.05% O (Oxides and hydroxides)	Cubic $a = 827.1$ pm $H1_1$, cF56 ($Z = 8$) P.G. m3m S.G. Fd3m Spinel type	Isotropic $n_D = 1.923$	7.5	4230 (4040)	**Habit:** granular, generally occurs as anhedral to subhedral crystals in matrix. **Color:** brown red, black. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** brownish red. **Fracture:** conchoidal, uneven fracture producing small, conchoidal fragments.
Galena [1314-87-0] (syn., lead glance, blue lead) [the Roman naturalist, Pliny, used the Latin name, *galena*, to describe lead ore] (ICSD 38293 and PDF 5-592)	PbS $M = 239.266$ 86.60 wt.% Pb 13.40 wt.% S Traces Ag, Bi, As, Sb, Zn, Cd, Cu. (Sulfides and sulfosalts) Coordinence Pb(6)	Cubic $a = 593.6$ pm B1, cF8 ($Z = 4$) S.G. Fm3m P.G. 4-32 Rock salt type	Isotropic $n_D = 3.921$ $R = 43.2\%$	2.5–3 (HV 71–84)	7597	**Habit:** octahedral crystals, massive, granular. **Color:** light lead gray or dark lead gray. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** grayish black. **Cleavage:** {001}, {010}, {100}. **Twinning:** {111}, {114}. **Fracture:** subconchoidal, brittle. **Chemical:** attacked by HNO_3 with evolution of H_2S, with sulfur and precipitate of $PbSO_4$ soluble in hot HCl. Yellow precipitate of lead iodide with KI. Electrical resistivity 6.8 to 90,000 μΩ.cm. **Melting point:** 1118°C. **Occurrence:** veins, and disseminated in igneous and sedimentary rocks.
Gaylussite (syn., natrocalcite) [Named after the French chemist and physicist, Joseph Louis Gay-Lussac	$Na_2Ca(CO_3)_2.5H_2O$ $M = 296.15233$ 15.53 wt.% Na 13.53 wt.% Ca	Monoclinic $a = 1159$ pm $b = 778$ pm $c = 1121$ pm	Biaxial (–) $\alpha = 1.444$ $\beta = 1.5155$ $\gamma = 1.523$	2.5	1930–1990	**Habit:** disseminated, tabular. **Color:** colorless, white, or yellowish white. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** translucent. **Streak:** white. **Cleavage:** [110] perfect, [001] indistinct. **Fracture:** conchoidal.

(1778–1850)] (ICSD 26969 and PDF 21-343)	3.40 wt.% H 8.11 wt.% C 59.43 wt.% O (Nitrates, carbonates, and borates)	$\beta = 102°$ ($Z = 4$) P.G. 2/m S.G. 12/a	$\delta = 0.0790$ $2V = 34°$ Dispersion strong			
Gehlenite [Named after the German chemist, Adolph F. Gehlen (1775–1815)] (ICSD 39921 and PDF 35-755)	$Ca_2Al[SiAlO_7]$ $M = 274.20$ 29.23 wt.% Ca 19.68 wt.% Al 10.24 wt.% Si 40.84 wt.% O (Sorosilicates, pair)	Tetragonal $a = 769.0$ pm $c = 506.75$ pm ($Z = 2$) Melilite type	Uniaxial (–) $\varepsilon = 1.667$ $\omega = 1.657$ $2V$ = small	5–6	3054	**Habit:** short prismatic to equant crystals. **Color:** colorless to straw-yellow and even brown. **Diaphaneity:** translucent to transparent. **Luster:** vitreous. **Cleavage:** (001) distinct. **Chemical:** gelatinizes in conc. HCl. **Occurrence:** skarns.
Geikielite [9312-99-8] [Named after the Scottish geologist Sir Archibald Geikie (1835–1924)] (ICSD 65794 and PDF 6-494)	$MgTiO_3$ $M = 120.180$ 20.22 wt.% Mg 39.84 wt.% Ti 39.94 wt.% O (Oxides and hydroxides)	Hexagonal $a = 505.478$ pm $c = 1389.92$ pm ($Z = 6$) S.G. R3m P.G. 3 Ilmenite type	Uniaxal (–) $\omega = 1.95–1.98$ $\varepsilon = 2.31–2.35$ $\delta = 0.3600–0.3700$ Dispersion strong Pleochroism moderate to weak	5–6	3790–4200 (3895)	**Habit:** tabullar or small prismatic crystals. **Color:** bluish black, brownish black, ruby-red. **Diaphaneity:** translucent to opaque. **Luster:** metallic to submetallic. **Streak:** purple brown. **Fracture:** conchoidal to subconchoidal. **Cleavage:** [1011] distinct. **Other:** melting point at 1630°C. **Deposits:** metamorphosed magnesian limestones. Also in ultramafic igneous rocks such as carbonatites, kimberlites, and serpentinized ultramafic rocks.
Gersdorffite (syn., gray nickel pyrite, nickel glance) [Named after Herr von Gersdorff, owner of Schladming Mine, Austria) (ICSD 16980 and PDF 42-1343)	NiAsS $M = 165.6776$ 35.42 wt.% Ni 45.22 wt.% As 19.35 wt.% S (Sulfides and sulfosalts)	Cubic $a = 517.9$ pm ($Z = 4$) P.G. 23 S.G. $P2_13$ Cobaltite group	Isotropic $R = 45.0$	5.5	5900–6330	**Habit:** massive, granular, euhedral crystals, tabular. **Color:** tin white or white. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** grayish black. **Cleavage:** (100) good, (010) good, (001) good. **Fracture:** brittle. Antiferromagnetic.
Gibbsite [21645-51-2] [Named after George Gibbs (1776–1833)] (ICSD 36233 and PDF 33-18)	$Al(OH)_3$ $M = 78.991618$ 34.59 wt.% Al 61.53 wt.% O 3.88 wt.% H Coordinence Al(6) (Oxides and hydroxides)	Monoclinic $a = 971.9$ pm $b = 507.05$ pm $c = 864.12$ pm $\beta = 94.57°$ ($Z = 8$) P.G. 2/m S.G. $P2_1/n$	Biaxial (+) $\alpha = 1.560–1.580$ $\beta = 1.560–1.580$ $\gamma = 1.580–1.600$ $\delta = 0.02$ $2V = 0–40°$ Dispersion strong	2.5–3.5	2400	**Habit:** tabular, foliated. **Color:** white, gray. **Luster:** pearly, vitreous. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (001). **Twinning:** {310}, and {001}. **Fracture:** uneven, tough.
Glauberite (syn., Glauber's salt) [Named after Glauber's salt, of alchemist origin itself from the German chemist Johann Wilhelm Glauber (1603–1668)] (ICSD 26773 and PDF 19-1187)	$Na_2Ca(SO_4)_2$ $M = 278.18$ 16.53 wt.% Na 14.41 wt.% Ca 23.05 wt.% S 46.01 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Monoclinic $a = 1013$ pm $b = 831$ pm $c = 853$ pm $\beta = 112.183°$ ($Z = 4$) P.G. 2/m S.G. C2/c	Biaxial (–) $\alpha = 1.507–1.515$ $\beta = 1.527–1.535$ $\gamma = 1.529–1.536$ $\delta = 0.021–0.022$ $2V = 24–34°$ Dispersion strong	2.5–3	2700–2850	**Habit:** tabular, prismatic. **Color:** yellow, reddish gray, or red. **Luster:** vitreous (glassy). **Diaphaneity:** transparent to translucent. **Streak:** white. **Fracture:** brittle–conchoidal. **Cleavage:** [001] perfect. **Occurrence:** dry salt-lake beds in desert climates.
Glaucodot [Named from the Greek, *glaucos*, blue, in reference to its use in the dark blue glass called smalt]	(Co,Fe)AsS $M = 165.15$ 8.45% Fe 26.76% Co 45.37% As 19.42% S (Sulfides and sulfosalts)	Orthorhombic $a = 663$ pm $b = 2833$ pm $c = 563$ pm ($Z = 24$) P.G. 2/m2/m2/m S.G. Cmmm	Biaxial (?) $R = 52.5\%$	5 (HV 1071–1166)	5900–6100 (6220)	**Habit:** prismatic crystals often twinned. **Color:** silver- to gray-white. **Luster:** metallic. **Diaphaneity:** opaque. **Cleavage:** (010) perfect. **Fracture:** brittle, uneven. **Streak:** black. **Occurrence:** high-temperature sulfide vein deposits.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Glauconite [Named from the Greek, *glaucos*, originally gleaming, later bluish green, silvery, or gray]	$(K,Na)(Fe,Al,Mg)_2(Si,Al)_4O_{10}(OH)_2$ (Phyllosilicates, layered)	Monoclinic P.G. 2/m Mica type	Biaxial (–) $\alpha = 1.590–1.612$ $\beta = 1.609–1.643$ $\gamma = 1.610–1.644$ $\delta = 0.020–0.032$ $2V = 0–20°$	2	2400–2950 (2900)	**Habit:** rounded aggregates and pellets. **Color:** yellow-green to blue-green. **Diaphaneity:** translucent to opaque. **Luster:** dull to earthy. **Cleavage:** (001) perfect. **Chemical:** readily decomposed by HCl. **Occurrence:** sedimentary rocks such as limestones, siltstones and sandstones.
Glaucophane [Named from the Greek, *glaukos*, blue, and *fanos*, appearing] (ICSD 24433 and PDF 20-453)	$Na_2(Mg,Fe)_3Al_2Si_8O_{22}(OH)_2$ (Inosilicates, chain, ribbon) Coordinance Na(8), Mg(6), Al(6), and Si(4)	Monoclinic $a = 974.80$ pm $b = 1791.50$ pm $c = 527.70$ pm 102°78 ($Z = 2$) P.G.: 2/m S.G. C2/m Tremolite type	Biaxial (–) $\alpha = 1.606–1.661$ $\beta = 1.622–1.667$ $\gamma = 1.627–1.670$ $\delta = 0.009–0.021$ $2V = 0–50°$ Dispersion strong	6–6.5	3080–3300	**Habit:** massive, fibrous, columnar, granular. **Color:** colorless, grayish blue, bluish black, or lavender blue. **Luster:** vitreous (i.e., glassy), pearly. **Diaphaneity:** translucent. **Streak:** grayish blue. **Cleavage:** [110] good, [110] good. **Fracture:** conchoidal, uneven, brittle. **Chemical:** insoluble in strong mineral acids. Easy fusible giving a green enamel. The powdered mineral colors the bunsen flame in yellow (Na). Slightly attracted by electromagnet. **Occurrence:** metamorphic blue schists.
Goethite [1309-37-1] (syn., needle iron stone, acicular iron ore, limonite, groutite: Mn-varieties) [Named after the German poet, Johann Wolfgang von Goethe (1749–1832), groutite after the American petrologist Frank Fitch Grout (1880–1958)] (ICSD 28247 and PDF 29-713)	α-FeO(OH)=0.5Fe_2O_3 $2H_2O$ $M = 88.85177$ 62.85 wt.% Fe 36.01 wt.% O 1.13 wt.% H Coordinence Fe(6) (Oxides and hydroxides)	Orthorhombic $a = 459.6$ pm $b = 995.7$ pm $c = 302.1$ pm ($Z = 4$) P.G. mmm S.G. $P2_1/bnm$	Biaxial (–) $\alpha = 2.260–2.275$ $\beta = 2.393–2.409$ $\gamma = 2.398–2.515$ $\delta = 0.138–0.140$ $2V = 0–27°$ Dispersion strong $R = 17.3\%$	5–5.5 (HV 525–824)	4269	**Habit:** acicular, reniform, radialor fibrous. **Color:** brown, black, reddish brown, or yellowish brown. **Luster:** subadamantine, silky. **Diaphaneity:** translucent to opaque. **Streak:** yellowish brown. **Cleavage:** (010), (100). **Fracture:** uneven, hackly (looking notched or hacked). **Occurrence:** iron ore deposits.
Gold [7440-57-5] (syn., aurum) (ICSD 64701 and PDF 4-784)	Au $M = 196.96655$ Coordinence Au(12) (Native elements)	Cubic $a = 407.86$ pm A1, *cF4* ($Z = 4$) P.G. m3m S.G. Fm3m Copper type	Isotropic $n_D = 0.368$ $R = 74\%$	2.5–3 (HV 50–52)	19,287	**Habit:** octahedral, dendritic, arborescent, platy, granular. **Color:** yellow, pale yellow, orange, yellow white, or reddish white. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** yellow. **Cleavage:** none. **Twinning:** {111}. **Fracture:** hackly. **Occurrence:** Quartz veins and alluvial placers deposits. **Chemical:** inert to most strong mineral acids (e.g., HCl, H_2SO_4, HF) but readily dissolved by aqua regia (i.e., 3 vol. HCl + 1 vol. HNO_3).
Goslarite [7446-20-0] [Named after the locality of Goslar, Germany]	$ZnSO_4{\cdot}7H_2O$ $M = 287.56056$ 22.74 wt.% Zn 4.91 wt.% H 11.15 wt.% S 61.20 wt.% O (Sulfates, chromates, molybdates and tungstates)	Orthorhombic $a = 1180$ pm $b = 1205$ pm $c = 682$ pm ($Z = 24$) P.G. 222 S.G. $P2_12_12_1$ Epsomite-Goslarite series	Biaxial (–) $\alpha = 1.457$ $\beta = 1.480$ $\gamma = 1.484$ $2V = 46°$	2–2.5	2000	**Habit:** stalactitic, massive, acicular. **Color:** white, yellowish white, or reddish white. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** [010] perfect. **Fracture:** conchoidal.

Graphite [7440-44-0] (syn., plumbago, black lead) [from the Greek, *graphein*, to write due to its use in making pencils] (ICSD 31170 and PDF 42-1487)	C M = 12.0107 Coordinence C(3) (Native elements)	Hexagonal a = 246.4 pm c = 673.6 pm A9, *hP4* (Z = 4) P.G. 6/mmm S.G. $P6_3/mmc$ Graphite type	Uniaxial (n.a.) n_D = 1.93–2.07 R = 12.5%	1.5–2 (HV 12)	2230	**Habit:** foliated, tabular, earthy. **Color:** dark gray, black, or steel gray. **Diaphaneity:** opaque. **Luster:** submetallic. **Streak:** black **Cleavage:** (0001) perfect. **Fracture:** sectile. **Occurrence:** metamorphosed limestones, organic-rich shales, and coal beds. **Melting point:** 4492°C (10MPa).
Greenalite [Named after its green color]	$Fe_2Fe_2Si_2O_5(OH)_4$ M = 354.28 44.14 wt.% Fe 17.44 wt.% Si 0.94 wt.% H 37.48 wt.% O (Phyllosilicates, layered)	Monoclinic a = 554 pm b = 955 pm c = 744 pm β = 104.2° (Z = 2) Sphenoidal 2	Isotropic when fined-grained n_D = 1.65–1.675	3	2850– 3150 (3150)	**Habit:** rounded pellets with fibrous texture ressembling glauconite. **Color:** olive-green to dark-green. **Diaphaneity:** translucent to opaque. **Luster:** weakly ferromagnetic. **Occurrence:** banded iron formations.
Greenockite [Named after Lord Greenock, i.e., Charles Murray Cathcart (1783–1859)] (ICSD 60629 and PDF 41-1049)	CdS M = 144.48 77.81 wt.% Cd 22.19 wt.% S (Sulfides and sulfosalts)	Hexagonal a = 413.6 pm c = 671.3 pm B4, hP4 (Z = 2) S.G. $P6_3mc$ P.G. 6mm Wutzite group	Uniaxial (+) ε = 2.506 ω = 2.529 δ = 0.023 R = 19.6%	3–3.5 (HV 98)	4800– 4900 (4820)	**Habit:** hemimorphic pyramidal crystals. **Color:** yellow to red. **Luster:** resinous to adamantine. **Diaphaneity:** translucent. **Cleavage:** (1122). **Fracture:** brittle, uneven. **Streak:** yellow to orange. **Occurrence:** sulfide ore veins.
Grossular (syn., grossularite, hessonite: brownish orange) [from the Latin, *grossularia*, gooseberry, hessonite is from the Greek, hesson, slight, in reference to the smaller specific gravity] (ICSD 24944 and PDF 39-368)	$Ca_3Al_2(SiO_4)_3$ M = 450.44638 26.69 wt.% Ca 11.98 wt.% Al 18.71 wt.% Si 42.62 wt.% O Coordinence Ca(8), Al(6), Si(4) (Nesosilicates)	Cubic a = 1185.1 pm (Z = 8) P.G. 432 S.G. Ia3d Garnet group (Ugrandite series)	Isotropic n_D = 1.734	6.5–7.5	3420– 3800 (3594)	**Habit:** dodecahedral, massive, granular, euhedral crystals, crystalline. **Color:** colorless, white, green, or yellow. **Streak:** brownish white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy), resinous. **Cleavage:** none. **Fracture:** conchoidal. **Chemical:** soluble in HCl, and HNO_3. **Occurrence:** contact metasomatic deposits.
Grunerite (syn., amosite) [Named after the Swiss-French chemist Louis Emmanuel Gruner (1809–1883)] (ICSD 24590 and PDF 44-1401)	$Fe_7Si_8O_{22}(OH)_2$ M = 1000.61 39.03 wt.% Fe 22.43 wt.% Si 0.20 wt.% H 38.34 wt.% O Inosilicates	Monoclinic a = 957 pm b = 1822 pm c = 533 pm β = 102.1° P.G. 2/m S.G. C2/n	Biaxial (–) α = 1.662–1.687 β = 1.678–1.709 γ = 1.698–1.729 δ = 0.0010 $2V$ = 82–83°	5–6	3100– 3600 (3660)	**Habit:** acicular crystals making fibrous aggragates. **Color:** brown to dark green. **Diaphaneity:** translucent to nearly opaque. **Luster:** vitreous to silky. **Fracture:** subconchoidal. **Cleavage:** perfect [110]. **Streak:** colorless. **Others:** infusible and insoluble in HCl. **Occurrence:** contact metamorphic rocks.
Gummite [12326-21-5]	$UO_3.nH_2O$ M = 304.043	Amorphous	Isotropic	n.a.	n.a.	Generic name for a mixture of uranium and lead oxides of intense yellow color resulting from the weathering of uraninites.
Gypsum [10101-41-4] (syn., selenite, alabaster, satin spar) [from the Greek, *gypsos*, meaning burned mineral. Selenite from the Greek, *selenos*, in allusion to its pearly luster (moon light) on cleavage fragments] (ICSD 2057 and PDF 33-311)	$CaSO_4.2H_2O$ M = 172.17216 23.28 wt.% Ca 2.34 wt.% H 18.62 wt.% S 55.76 wt.% O Coordinence Ca(8), S(4) (Sulfates, chromates, molybdates, and tungstates)	Monoclinic a = 568.0 pm b = 1551.8 pm c = 629.0 pm β = 113°83' (Z = 4) P.G. 2/m S.G. A2/n	Biaxial (+) α = 1.510 β = 1.523 γ = 1.529 δ = 0.009 $2V$ = 58° Dispersion strong	2.0	2320	**Habit:** tabular, crystalline, massive,reniform, fibrouscockscomb aggregates: 'desert roses'. **Color:** white, colorless, yellowish white, greenish white, or brown. **Luster:** vitreous, pearly. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (010), (100). **Twinning:** {100}. **Fracture:** conchoidal, fibrous. **Chemical:** start to decomposes at 38°C yielding $CaSO_4.H_2O$ that decomposes at 80°C into $CaSO_4.0.5H_2O$ that finally decomposes at 150°C giving off water and yielding $CaSO_4$. **Occurrence:** sedimentary evaporites.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Hafnon [13870-13-8] (hafnium orthosilicate) [Named after its hafnium content] (ICSD 59111 and PDF 20-467)	$HfSiO_4$ $M = 270.5731$ 65.97 wt.% Hf 10. 38 wt.% Si 23.65 wt.% O (Nesosilicates)	Tetragonal $a = 657.25$ pm $c = 596.32$ pm $c/a = 1.102$ $(Z = 4)$ P.G. 4/mmm S.G. $I4_1/amd$ Zircon type	Uniaxal (+) $\varepsilon = ?$ $\omega = ?$ $\delta = ?$ Dispersion very strong	6.5–7	6970	**Habit:** tiny millimeter prismatic, tabular, crystals. **Color:** amber, brown, reddish brown, colorless. **Diaphaneity:** transparent to translucent or opaque (metamict). **Luster:** adamantine. **Streak:** white. **Fracture:** uneven. **Cleavage:** (110). **Twinning:** {111}. **Other:** radioactive due to U isomorphic substitution. **Chemical:** insoluble in HCl and HNO_3, slightly soluble in conc. H_2SO_4, readily dissolved by conc. HF. Radioactive owing to the isomorphic substitution of Zr(IV) cations by U(IV) and Th(IV) can contain some Pb from decaying. at high pressure and temperature adopt a scheelite type structure. **Occurrence:** in tantalum-bearing granite pegmatites.
Halite [7647-14-5] (syn., rock salt) [from the Greek, *halos*, salt, and *lithos*, rock] (ICSD 18189 and PDF 5-628)	NaCl $M = 58.44246$ 39.34 wt.% Na 60.66 wt.% Cl (Halides) Coordinence Na(6)	Cubic $a = 564.02$ pm B1, cF8 $(Z = 4)$ S.G. Fm3m P.G. 4-32 Rock salt type	Isotropic $n_D = 1.5446$	2.5	2160–2170	**Habit:** euhedral crystals, granular, crystalline. **Color:** white, clear, light blue, dark blue, or pink. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent. **Streak:** white. **Cleavage:** [100], [010], [001]. **Fracture:** conchoidal, brittle. **Occurrence:** marine or continental evaporite. Soluble in water, the soln. Color the flame of a bunsen in yellow. Fusible (*m.p.* 801°C).
Halloysite [Named after the Belgian geologist, Baron Omalius d'Halloy (1707–1789)] (ICSD 26716 and PDF 29-1489)	$Al_2[Si_2O_5(OH)_4].2H_2O$ $M = 258.16$ 20.90 wt.% Al 21.76 wt.% Si 1.56 wt.% H 55.78 wt.% O Phyllosilicates	Monoclinic $a = 514$ pm $b = 892$ pm $c = 725$ pm $\beta = 99.7°$ $(Z = 2)$ S.G. Cc	Biaxial (–) $\alpha = 1.559$ $\beta = 1.564$ $\gamma = 1.565$ $2V = 37°$	1–2	2580–2620	**Habit:** earthy to waxy mineral. **Color:** white to tan. **Diaphaneity:** opaque but becomes translucent when immersed in water. **Luster:** dull. **Fracture:** conchoidal. **Cleavage:** {001} probable. **Occurrence:** alteration of basaltic rocks or hydrothermally altered monzonites.
Hanksite [Named after the American mineral collector, Elwood P. Hancock (1836–1916)] (ICSD 2852 and PDF 25-1348)	$KNa_{22}(SO_4)_9(CO_3)_2Cl$ $M = 1564.92$ 2.50 wt.% K 32.32 wt.% Na 1.54 wt.% C 18.44 wt.% S 2.27 wt.% Cl 42.94 wt.% O (Sulfates, chromates, chromates, molybdates, and tungstates)	Hexagonal $a = 1047$pm $c = 2120$ pm $(Z = 2)$ P.G. 6/m S.G. $P6_3/m$	Uniaxial (–) $\varepsilon = 1.46$ $\omega = 1.48$ $\delta = 0.02$	3	2500	**Habit:** crystalline, coarse. **Color:** white or yellow. **Diaphaneity:** transparent. **Luster:** vitreous, or greasy. **Streak:** white. **Fracture:** conchoidal. **Occurrence:** continental evaporitic deposits under desert climates.
Hausmannite [Named after the German mineralogist, Johann Friedrich Ludwig Hausmann (1782–1859)] (ICSD 68174 and PDF 24-734)	$Mn_3O_4 = Mn^{II}Mn^{III}_2O_4$ $M = 228.81175$ 72.03 wt.% Mn 27.97 wt.% O Coordinence Mn(4, and 6) (Oxides and hydroxides)	Tetragonal $a = 813.6$ pm $c = 944.2$ pm $(Z = 8)$ P.G. 4/mmm S.G. $I4_1/amd$ Distorded spinel type	Uniaxial (–) $\varepsilon = 2.15$ $\omega = 2.46$ $\delta = 0.31$ $R = 17.5\%$	5–5.5 (HV 541–613)	4863	**Habit:** pseudo-octahedral. **Color:** brown, black. **Diaphaneity:** translucent to opaque. **Luster:** submetallic. **Streak:** light brown. **Fracture:** uneven. **Cleavage:** perfect (001). **Twinning:** {112}, {101}.
Haüyne (syn., hauynite) [Named after the French crystallographer, R.J. Hauy]	$(Na,Ca)_{4-8}[Al_6Si_6O_{24}](SO_4,S,Cl)_{1-2}$ $M = 1032.43$ 8.91 wt.% Na 7.76 wt.% Ca	Cubic $a = 913$ pm $(Z = 1)$ Sodalite type	Isotropic $n_D = 1.496–1.505$	5.5–6	2440–2500	**Habit:** euhedral crystals. **Color:** white, gray, blue, green, red, yellow. **Luster:** vitreous (i.e., glassy), greasy. **Diaphaneity:** transparent to translucent. **Streak:** bluish white. **Cleavage:** (110) perfect, (011) perfect, (101) perfect. **Twinning:** {111} common. **Fracture:** conchoidal. **Occurrence:** igneous rocks low in silica and rich in alkalis.

(ICSD 39952 and PDF 37-473)	15.68 wt.% Al 16.32 wt.% Si 9.32 wt.% S 1.72 wt.% Cl 40.29 wt.% O (Tectosilicates, network)					
Hedenbergite [Named after the Swedish mineralogist, M.A.L. Hedenberg] (ICSD 10226 and PDF 41-1372)	$CaFe[Si_2O_6]$ $M = 248.09$ 16.15 wt.% Ca 22.51 wt.% Fe 22.64 wt.% Si 38.69 wt.% O Coordinence Ca(8), Fe(6), Si(4) Traces Al, Mn, Ti (Inosilicates, simple chain)	Monoclinic $a = 985.4$ pm $b = 902.4$ pm $c = 526.3$ pm 104.33° ($Z = 4$) P.G. 2/m S.G. C2/c Diopside type	Biaxial (+) $\alpha = 1.699–1.739$ $\beta = 1.705–1.745$ $\gamma = 1.728–1.757$ $\delta = 0.018–0.029$ $2V = 52–63°$ Dispersion strong	5.5–6.5	3550	**Habit:** granular, crystalline, lamellar. **Color:** grayish green, brownish green, dark green, black. **Luster:** vitreous (i.e., glassy), pearly. **Diaphaneity:** translucent to opaque. **Streak:** white green. **Cleavage:** (110) perfect, (110) indistinct. **Twinning:** {100}, {001} simple, multiple, common. **Fracture:** conchoidal, brittle. **Chemical:** insoluble in strong mineral acids, fusible giving a magnetic globule. **Other:** dielectric constant 8.99, attracted by a strong permanent magnet. **Occurrence:** contact metamorphic rocks.
Hematite [1309-37-1] (syn., Kidney ore, specularite, martite) [from the Greek, *haematites*, bloodlike, in allusion to vivid red color of the powder] (ICSD 64599 and PDF 33-664)	α-Fe_2O_3 $M = 159.6922$ 69.94 wt.% Fe 30.06 wt.% O (Oxides, and Hydroxides) Traces Ti, Mg. Coordinence Fe(6)	Trigonal (Rhombohedral) $a = 503.29$ pm 13.749° $D5_1$, hR10 ($Z = 2$) S.G. R-3c P.G. -32/m Corundum type	Uniaxis (–) $\varepsilon = 2.96$ $\omega = 3.22$ $\delta = 0.28$ Dispersion strong $R = 28\%$	5.5–6.5 (HV 739–1062)	5256	**Habit:** tabular, blocky, earthy, botryoidal. **Color:** reddish gray, black, or blackish red. **Luster:** metallic, greasy. **Diaphaneity:** translucent to opaque. **Streak:** reddish brown. **Cleavage:** none. **Twinning:** (001),(101). **Fracture:** subconchoidal. **Chemical:** soluble in hot HCl.Becomes magnetic after firing in reducing flamme. Antiferromagnetic. **Occurrence:** magmatic, hydrothermal, metamorphic and sedimentary rocks.
Hercynite [from Latin, *Hercynia Silva*, Forested Mountains] (ICSD 74611 and PDF 34-192)	$FeAl_2O_4$ $M = 173.80768$ 31.05 wt.% Al 32.13 wt.% Fe 36.82 wt.% O (Oxides and hydroxides)	Cubic $a = 813.5$ pm $H1_1$, cF56 ($Z = 8$) S.G. Fd3m Spinel type (Spinel Series)	Isotropic $n_D = 1.835$	7.5	3950–4400	**Habit:** euhedral crystals, massive, granular. **Color:** black. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** opaque. **Streak:** dark green. **Cleavage:** [111]. **Fracture:** uneven. **Occurrence:** magmatic rocks.
Hessite (syn., telluric silver) [Named after the Swiss chemist, G.H. Hesse) (ICSD 73230 and PDF 34-142)	Ag_2Te $M = 235.4682$ 45.81 wt.% Ag 54.19 wt.% Te (Sulfides and sulfosalts)	Monoclinic $a = 813$ pm $b = 448$ pm $c = 809$ pm $\beta = 112.9°$ ($Z = 2$) S.G. $P2_1/c$ P.G. 2	Biaxial $R = 38.5\%$	1.5–2 (HV 28–41)	7200–7900	**Habit:** euhedral crystals, granular. **Color:** lead gray or steel gray. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** light gray. **Cleavage:** [100] indistinct. **Fracture:** uneven.
Heulandite [Named after the English mineralogist, John Henry Heuland (1778–1856)] (ICSD 31278 and PDF 41-1357)	$(Ca,Na)Si_7Al_2O_{15}.6H_2O$ Coordinence Ca(6), Na(6), Si(4), Al(4) (Tectosilicates, framework)	Monoclinic $a = 1773$ pm $b = 1782$ pm $c = 743$ pm $\beta = 116.3°$ ($Z = 4$) P.G. m S.G. Cm Zeolite group	Biaxial (+) $\alpha = 1.490$ $\beta = 1.500$ $\gamma = 1.500$ $\delta = 0.005$ $2V = 35°$	3.5–4	2150	**Habit:** platy. **Color:** white. **Luster:** vitreous. **Diaphaneity:** transparent to translucent. **Cleavage:** (010) perfect. **Fracture:** subconchoidal. **Occurrence:** volcanic tuffs and volcano-clastic sediments.
Hongquiite [100100-26-3] [Named after locality of first discovery in 1976 Tao district, Hongqui, China] (ICSD 28955 and PDF 43-1296)	TiO $M = 63.8664$ 74.95 wt.% Ti 25.05 wt.% O (Oxides and hydroxides)	Cubic $a = 429.3$ pm B1, cF8 ($Z = 4$) S.G. Fm3m P.G. 432 Rock salt type	Isotropic $R = 32.6\%$	HV 710	4950 (4888)	**Habit:** cuboctahedral crystals. **Color:** gold. **Diaphaneity:** opaque. **Luster:** metallic. **Cleavage:** none. **Other:** paramagnetic with $\chi_m = +88 \times 10^{-6}$ emu, melting point of 1750°C; specific heat capacity of 628 $J.kg^{-1}.K^{-1}$, coefficient of linear thermal expansion of $9.19 \times 10^{-6}\ K^{-1}$. **Occurrence:** high-temperature metamorphic rocks of the garnet-hornblende-pyroxenite facies along with platinum group metals ores.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Hubnerite (syn., huebnerite) [Named after the German mineralogist, Adolph Huebner] (ICSD 15850 and PDF 13-434)	$MnWO_4$ $M = 302.775649$ 18.14 wt.% Mn 60.72 wt.% W 21.14 wt.% O Coordinence Mn(6), W(4) (Sulfates, chromates, molybdates, and tungstates)	Monoclinic $a = 483.4$ pm $b = 575.8$ pm $c = 499.9$ pm $\beta = 91.18°$ ($Z = 2$) P.G. 2/m S.G. P2/c Wolframite type	Biaxial (+) $\alpha = 2.17$ $\beta = 2.22$ $\gamma = 2.30$ $\delta = 0.13$ $2V = 73°$	4–4.5	7250	**Habit:** long prismatic. **Color:** red brown. **Luster:** submetallic. **Diaphaneity:** opaque. **Cleavage:** (010) perfect. **Fracture:** uneven, brittle.
Humite [Named after the British mineralogist Sir Abraham Hume (1749–1838)] (ICSD 34847 and PDF 12-755)	$Mg(OH,F)_2.3Mg_2[SiO_4]$ (Nesosilicates)	Orthorhombic $a = 1024$ pm $b = 2072$ $c = 473.5$ ($Z = 4$) P.G. 2/m2/m2/m S.G. Pnma (Humite group)	Biaxial $\alpha = 1.607–1.643$ $\beta = 1.619–1.653$ $\gamma = 1.639–1.675$ $\delta = 0.029–0.031$ $2V = 65–84°$ O.A.P (001)	6	3200–3420	**Habit:** massive. **Color:** brown, yellow, orange, red, colorless. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** translucent to transparent. **Cleavage:** (100) poor. **Fracture:** uneven, brittle. **Chemical:** attacked by strong mineral acids giving a silica gel. **Deposits:** dolomites, limestones, skarns.
Illite (syn., hydromuscovite, hydromica, gumbelite) [Named after Illinois, USA]	$(K,H)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,H_2O]$ (Phyllosilicates, layered)	Monoclinic $a = 518$ pm $b = 898$ pm $c = 1032$ pm $\beta = 101.83°$ ($Z = 2$) S.G. C2/m P.G. 2/m	Biaxial (–) $\alpha = 1.535–1.57$ $\beta = 1.555–1.6$ $\gamma = 1.565–1.605$ $\delta = 0.030–0.035$ $2V = 5–25°$ Dispersion none	1–2	2820–2610	**Habit:** fined grained clay sometimes indurated. **Color:** gray-white to graish-green. **Diaphaneity:** translucent to opaque. **Luster:** waxy. **Streak:** white. **Cleavage:** (001) perfect. Decomposed by conc. HCl. **Occurrence:** weathering of orthoclase associated with other clay minerals such as kaolinite.
Ilmenite [12168-52-4] (syn., mannacanite) [after the lake Ilmen, Russia] (ICSD 30664 and PDF 29-733)	$FeTiO_3$ $M = 151.7252$ 31.56 wt.% Ti 36.81 wt.% Fe 31.63 wt.% O (Oxides and hydroxides) Coordinence Fe(6), Ti(6)	Trigonal (Rhombohedral) $a = 508.84$ pm $c = 1408.85$ pm ($Z = 6$) S.G. R3m P.G. 3 Ilmenite type	Uniaxal (–) $\omega = 2.700$ $\varepsilon = 2.700$ Dispersion strong $R = 19.4\%$	5.0–5.5 (HV 519–703)	4720–4780	**Habit:** tabullar, lamellar, massive. **Color:** iron black. **Diaphaneity:** opaque. **Luster:** submetallic. **Streak:** brownish black. **Fracture:** subconchoidal. **Cleavage:** none. **Chemical:** insol. in HCl, or HNO_3 but attacked by boiling H_2SO_4. Slightly antiferromagnetic with a specific magnetic susceptibility of $+10^{-6}$ m^3.kg^{-1}. Nonfusible with a melting point of 1365–1470°C. Semiconductive with an electrical resistivity ranging from 0.001 to 4 Ω.m. **Deposits:** massive hard rock hemo-ilmenite deposits in ultramafic igneous rocks (e.g., anorthosites, peridotites, gabbros, diorites, syenites) such as the large deposits of Allard lake (Québec, Canada) or Tellnes (Norway). Sedimentary deposits as heavy mineral sands in South Africa (Richards Bay), Australia, India and Brazil.
Iodargyrite [7783-96-2] (syn., Iodyrite) [Named after Greek, *iodos*, violet, and Latin, *argentum*, silver) (ICSD 65063 and PDF 9-374)	AgI $M = 234.77267$ 45.95 wt.% Ag 54.05 wt.% I (Halides)	Hexagonal $a = 459$ pm $c = 751$ pm ($Z = 2$) P.G. 6mm S.G. P 6$_3$mc	Uniaxial (+)	1.5–2	5500–5700	**Habit:** platy. **Color:** pale yellow or green. **Luster:** adamantine-greasy. **Diaphaneity:** transparent to translucent.
Iron (native telluric and meteoritic) [7439-89-6] (syn., ferrum, ferrite)	α-Fe $M = 55.845$ (Native elements)	Cubic $a = 286.645$ pm A2, cI2 ($Z = 2$)	Isotropic $R = 60\%$	4 (HV 160)	7300–7870 (7890)	**Habit:** tiny magnetic globules. **Color:** steel gray for freshly exposed surfaces to iron black. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** gray. **Fracture:** hackly. Ferromagnetic with a Curie temperature of 770°C. **Occurrence:** in basalts in the Disko Island, Greeland.

(ICSD 64795 and PDF 6-696)		S.G. Im3m P.G. 432				
Iridium [Named from the Latin, *iris*, rainbow, in allusion to the colored salts derived from its compounds] (ICSD 64992 and PDF 6-598)	(Ir,Os,Ru) (Native elements)	Cubic a = 383.92 pm A1, cF4 (Z = 4) Fm3m Copper type	Isotropic R = 68%	6–7	22,600–22,800	**Color:** white. **Diaphaneity:** opaque. **Luster:** metallic. **Cleavage:** none. **Streak:** white.
Iridosmine (syn., siserskite, nevyanskite)	$Ir_xOs_yRu_z$ Native elements (Platinum group metals, PGMs)	Hexagonal a = 273 pm c = 432 pm (Z = 2) S.G. $P6_3/mmc$	Uniaxial R = 55%	6–7 (HV 1206–1246)	17,600–22,400	**Habit:** hexagonal tabular crystals to flattened grains. **Color:** tin white to iron black. **Luster:** metallic. **Diaphaneity:** opaque. **Cleavage:** [0001] perfect. **Fracture:** subconchoidal to uneven. **Streak:** white. Does not dissolve into aqua regia (3 vol.HCl + 1 vl. HNO_3). **Occurrence:** mafic and ultramafic igneous rocks (e.g., gabbros, peridotites, pyroxenolites) along with magnetite and ilmenite and placer deposits.
Jacobsite [1310-36-7] [Named after Jacobsberg, Wermland, Sweden] (ICSD 66851 and PDF 10-319)	$MnFe_2O_4$ (Oxides, and hydroxides)	Cubic a = 851 pm H1$_1$, cF56 (Z = 8) Fd3m Spinel type	Isotropic n_D = 2.30 R = 18.5%	5.5 (HV 724–745)	4870	**Habit:** massive. **Color:** black. **Diaphaneity:** opaque. **Luster:** metallic to submetallic. **Streak:** brownish-black. **Cleavage:** none. Ferromagnetic.
Jadeite [from the Spanish, *piedra de ijada*, stone of the side, because its supposed to cure kidney ailments if applied to the side of the body] (ICSD 10232 and PDF 22-1338)	$Na(Al,Fe)[Si_2O_6]$ M = 202.1387 11.37 wt.% Na 13.35 wt.% Al 27.79 wt.% Si 47.49 wt.% O Coordinence Na(8), Al(6), Si(4) Traces of Mg, Ca, and Fe (Inosilicates, chain, ribbon)	Monoclinic a = 940.9 pm b = 856.4 pm c = 522.0 pm 107.43° (Z = 4) P.G. 2/m S.G. C2/c Diopside type	Biaxial (+) α = 1.640–1.658 β = 1.645–1.663 γ = 1.652–1.673 δ = 0.012–0.013 $2V$ = 67–75° Dispersion moderate	6–6.5	3240–3430	**Habit:** granular, fibrous, massive. **Color:** green, white, pale bluish gray, grayish green, or pale purple. **Luster:** vitreous (i.e., glassy), pearly. **Diaphaneity:** translucent. **Streak:** white. **Cleavage:** (110) good. **Twinning:** {100}, {001}. **Fracture:** tough. **Chemical:** insoluble in strong mineral acids. **Occurrence:** strongly metamorphosed sodium-rich serpentinous rocks.
Jarosite [Named in 1852 after the Barranco del Jaroso Ravine in the Sierra Almagrera, Spain] (ICSD 12107 and PDF 36-427)	$K[Fe_3(SO_4)_2(OH)_6]$ M = 692.9319 5.642 wt.% K 24.178 wt.% Fe 18.510 wt.% S 50.797 wt.% O 0.873 wt.% H Coordinence K(12), Fe(6), S(4) (Sulfates, chromates, molybdates, and tungstates) and tungstates); Al can substitute to Fe (Alunite-Jarosite solid solution)	Trigonal (Rhombohedral) a = 730.4 pm c = 1726.8 pm (Z = 3) P.G. 32/m S.G. R3m Alunite group	Uniaxial (–) ε = 1.705–1.715 ω = 1.791–1.820 δ = 0.660	2.5–3.5	2910–3260 (3250)	**Habit:** minute pseudocubic crystals or tabular, also granular, massive, earthy cryptocristalline crust and coatings. **Color:** ocherous, amber-yellow or dark brown. **Diaphaneity:** opaque. **Luster:** subadamantine to vitreous or resinous. **Streak:** pale yellow. **Fracture:** uneven to conchoidal. **Cleavage:** distinct (0001). **Other:** Pyroelectric. **Chemical:** insoluble in water but dissolves in HCl. **Occurrence:** widespread secondary mineral as encrustation and coating in the oxidizing zone of sulfidic ore deposits along with limonite and goethite. Forms from the aerobic alteration of pyrite.
Kainite [from the Greek, *kainos*, contemporary] (ICSD 26003 and PDF 25-660)	$MgSO_4.KCl.3H_2O$ M = 248.96544 15.70 wt.% K 9.76 wt.% Mg 2.43 wt.% H 12.88 wt.% S 14.24 wt.% Cl 44.98 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Monoclinic a = 1972 pm b = 1623 pm c = 953 pm β = 94.92° (Z = 4) S.G. C2/m P.G. 2/m	Biaxial (–) α = 1.494 β = 1.505 γ = 1.516 δ = 0.022 $2V$ = 88°	3	2100	**Habit:** massive, granular, encrustations. **Color:** white, yellow, reddish gray, or dark flesh red. **Luster:** vitreous, greasy. **Streak:** white. **Fracture:** conchoidal. **Cleavage:** [001] good.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Kaolinite (1Tc) [Named after the locality, Kao-Ling, China, where clay was extracted, from the Chniese, *kao* high, *ling*, mountain] (ICSD 63315 and PDF 14-164)	$Al_4[Si_4O_{10}(OH)_8]$ M = 516.32088 20.90 wt.% Al 21.76 wt.% Si 1.56 wt.% H 55.78 wt.% O Coordinence Al(6), Si(4) (Phyllosilicates, layered)	Triclinic a = 515 pm b = 892 pm c = 738 pm α = 91.8° β = 104.8° γ = 90.0°, (Z = 1) P.G. 1 S.G. P1	Biaxial (–) α = 1.553–1.563 β = 1.559–1.569 γ = 1.565–1.570 δ = 0.007 $2V$ = 40–44° Dispersion none	2–2.5	2600	**Habit:** platy, massive. **Color:** white, brownish white, grayish white, yellowish white, or grayish green. **Diaphaneity:** transparent to translucent. **Luster:** earthy (i.e., dull). **Streak:** white. **Cleavage:** (001) perfect. **Fracture:** flexible.
Karelianite [1314-24-7] [Named after Karelia, Finland] (ICSD 201106 and PDF 34-187)	V_2O_3 M = 149.880 67.98 wt.% V 32.02 wt.% O (Oxides and hydroxides)	Trigonal (Rhombohedral) a = 499 pm c = 1398 pm $D5_1$, hR10 (Z = 2) S.G. R3c P.G. 32/m Corundum type	Uniaxial (–)	8–9	4870 (4950)	**Habit:** granular anhedral crystal or prismatic crystals. **Color:** black. **Diaphaneity:** opaque. **Luster:** metallic. **Cleavage:** none. **Fracture:** conchoidal. **Streak:** black. **Occurrence:** found in sulfide-rich glacial boulders derived from high-grade metamorphic rocks (schists and quartzites).
Karrooite [12032-35-8] [Named after the South African Karroo desert]	$MgTi_2O_5$ M = 200.036 12.15 wt.% Mg 47.85 wt.% Ti 40.00 wt.% O Coordinence Ti(6)	Orthorhombic a = 975 pm b = 1000 pm c = 375 pm P.G. 2/m 2/m 2/m S.G. A2/m Karrooite type	Biaxial (?)	n.a.	3630	Melts at 1630°C
Kernite (syn., rasorite) [Named after locality of Kern County, California, the location of the borate deposits at Kramer] (ICSD 10378 and PDF 25-1322)	$Na_2B_4O_6(OH)_2.3H_2O$ M = 290.28379 15.84 wt.% Na 14.90 wt.% B 3.13 wt.% H 66.14 wt.% O Coordinence Na(5), B(3, and 4) (Carbonates and borates)	Monoclinic a = 702.2 pm b = 915.1 pm c = 1567.6 pm β = 108.88° (Z = 4) P.G. 2/m S.G. $P2_1/c$	Biaxial (–) α = 1.454 β = 1.472 γ = 1.488 δ = 0.034 $2V$ = 80° Dispersion distinct	2.5–3	1900– 1920 (1905)	**Habit:** crystalline, coarse, acicular, massive. **Color:** colorless or white. **Luster:** vitreous, pearly. **Diaphaneity:** transparent to translucent. **Cleavage:** (100) perfect, (001) perfect, (201) good. **Fracture:** uneven, brittle. **Streak:** white. **Occurrence:** Weathered buried salty lake deposits.
Krennerite [Named after the Hungarian mineralogist Joseph A. Krenner (1839–1920)] (ICSD 30902 and PDF 8-20)	$AuTe_2$ M = 452.17 43.56 wt.% Au 56.44 wt.%Te (Sulfides and sulfosalts)	Orthorhombic a = 1654 pm b = 882 pm c = 446 pm C46, oP24 (Z = 8) S.G. Pma	Biaxial R = 60.9%	2.5	8530	**Habit:** striated. **Color:** white or blackish yellow. **Luster:** metallic. **Diaphaneity:** opaque.
Kyanite (syn., cyanite, disthene) [from the Greek, *kyanos*, blue, and *dis*,	$Al_2O[SiO_4] = Al_2SiO_5$ M = 162.04558 33.30 wt.% Al	Triclinic a = 712.3 pm b = 784.8 pm	Biaxial (–) α = 1.712–1.718 β = 1.721–1.723	5.5 (100) 7.0	3530– 3650	**Habit:** blady, columnar, tabular, fibrous. **Color:** blue, white, yellowish, gray, green, or black. **Luster:** vitreous (i.e., glassy), pearly. **Diaphaneity:** translucent to transparent. **Streak:** white. **Fracture:** uneven, brittle. **Luminescence:** pink to red. **Cleavage:** (100)

two-fold, and *sthenos*, force, owing to the variation of hardness according to crystal planes] (ICSD 27771 and PDF 11-46)	17.33 wt.% Si 49.37 wt.% O Traces of Fe, Ca, Cr Coordinence Al(6), Si(4) (Nesosubsilicates)	c = 556.4 pm α = 90°5.5 β = 101°25 γ = 105°44.5 (Z = 4) P.G. 1 S.G. P1	γ = 1.727–1.734 δ = 0.012–0.016 2V = 82–83° Dispersion weak	(010)		perfect, (010) imperfect. **Twinning:** {100}. **Chemical:** insoluble in strong mineral acids. **Other properties:** Unfusible but when heated above 1200°C transforms to a mixture of silica and mullite ($Al_6Si_2O_{13}$). Dielectric constant of 5.7 to 7.18. Diamagnetic with a specific magnetic susceptibility of -10^{-10} $m^3.kg^{-1}$. **Occurrence:** metamorphosed peri-aluminous sedimentary rocks.
Kyzylkumite [80940-68-7] [Named after Kyzyl-Kum, Uzbekistan]	$V_2Ti_3O_9$ M = 389.4786 26.16 wt.% V 36.87 wt.% Ti 36.97 wt.% O Coordinence Ti(6) (Oxides, and hydroxides)	Monoclinic a = 3380 pm b = 457.8 pm c = 1999 pm β = 93.40° (Z = 4) Pseudorutile type	Biaxial (?)	n.a.	3750 (3770)	**Habit:** prismatic crystals. **Color:** black. **Luster:** vitreous to resinous.
Labradorite (syn., spectrolite) [Named after the Isle of Paul, Labrador, Canada where the mineral was first discovered about 1770]	$(Ca,Na)(Si_3Al)_4O_8$ An60 Ab40 M = 271.81357 3.38 wt.% Na 8.85 wt.% Ca 15.88 wt.% Al 24.80 wt.% Si 47.09 wt.% O (Tectosilicates, framework)	Triclinic a = 815.5 pm b = 1284 pm c = 1016 pm Z = 6	Biaxial (+) α = 1.554–1.563 β = 1.559–1.568 γ = 1.562–1.573 α = 0.008–0.010 2V = 78–86°	7	2690	**Habit:** euhedral crystals, striated. **Color:** white or gray. **Diaphaneity:** translucent to transparent. **Luster:** vitreous (i.e., glassy). **Cleavage:** (001) perfect, (010) good, (110) distinct. **Fracture:** uneven. **Streak:** white. **Occurrence:** magmatic and metamorphic rocks.
Langbeinite [Named after the German chemist of Leopoldshall A. Langbein] (ICSD 100420 and PDF 19-975)	$K_2Mg_2(SO_4)_3$ M = 1291.77 0.93 wt.% Ca 47.63 wt.% Mn 6.05 wt.% Fe 4.35 wt.% Si 11.31 wt.% Sb 29.73 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Cubic a = 992 pm (Z = 4) P.G. 2/m S.G. $P2_13$	Isotropic n_D = 1.533–1.535	3.5–4	2824	**Habit:** nodules or grains. **Color:** colorless. **Diaphaneity:** translucent to transparent. **Luster:** vitreous. **Cleavage:** none. **Fracture:** conchoidal. Phosphorescent. **Occurrence:** marine evaporite deposits.
Larnite [Named after Scawt Hill, near Larne, Co., Antrim, Ireland] (ICSD 39006 and PDF 33-302)	$Ca_2[SiO_4]$ M = 172.24 46.54 wt.% Ca 16.31 wt.% Si 37.16 wt.% O (Nesosilicates)	Monoclinic a = 548 pm b = 676 pm c = 928 pm 94.55° (Z = 4)	Biaxial (+) α = 1.707 β = 1.715 γ = 1.730 δ = 0.023 2V = 13–14° Dispersion strong	6	3280	**Habit:** tabullar crystals, granular or massive aggregates. **Color:** colorless to white. **Diaphaneity:** translucent to transparent. **Luster:** vitreous. **Streak:** white. **Cleavage:** (100). **Fracture:** conchoidal to uneven. **Twinning:** polysynthetic (100). **Chemical:** gelatinizes by dil. HCl. **Occurrence:** metamorphic and ingneous rocks.
Laumontite [Named after the French mineralogist, François Pierre Nicolas Giller de Laumont (1747–1834)] (ICSD 72914 and PDF 45-1325)	$CaSi_4Al_2O_{12}.4H_2O$ M = 470.44 8.52 wt.% Ca 11.47 wt.% Al 23.88 wt.% Si 1.71 wt.% H 54.42 wt.% O Coordinence Ca(6), Si(4), Al(4) (Tectosilicates, zeolite group)	Monoclinic a = 1475 pm b = 1310 pm c = 755 pm β = 111.5° (Z = 4) P.G. m S.G. Cm	Biaxial (–) α = 1.510 β = 1.520 γ = 1.520 δ = 0.010 2V = 25–45°	3–4	2300	**Habit:** prismatic. **Color:** white. **Diaphaneity:** translucent to transparent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (010) perfect, (110) perfect. **Fracture:** uneven. Pyroelectric. **Deposits:** volcanic tuffs.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Lawsonite [Named after the American mineralogist Prof. A.C. Lawson] (ICSD 80835 and PDF 13-533)	$CaAl_2[Si_2O_7(OH)_2]\cdot H_2O$ $M = 314.24$ 12.75 wt.% Ca 7.17 wt.% Al 17.88 wt.% Si 1.28 wt.% H 50.91 wt.% O Coordinence Ca(8), Al(6), Si(4) (Sorosilicates, pair)	Orthorhombic $a = 878.7$ pm $b = 1312.3$ pm $c = 583.6$ pm $(Z = 4)$ P.G. mmm S.G. Ccmm	Biaxial (+) $\alpha = 1.665$ $\beta = 1.674$ $\gamma = 1.685$ $\delta = 0.020$ $2V = 76–87°$ O.A.P. (100) Dispersion strong	7–8	3050–3120	**Habit:** prismatic, tabular. **Color:** colorless, pale blue, or grayish blue. **Diaphaneity:** translucent to transparent. **Luster:** vitreous (i.e., glassy), greasy. **Streak:** white. **Cleavage:** (010) perfect, [100] perfect. **Twinning:** {110}. **Fracture:** uneven brittle. **Deposits:** originally described from a crystalline schist associated with serpentine. Also found as a secondary mineral in altered gabbros and diorites.
Lazulite (syn., scorzalite: Fe, Ni) [Named from the Arabic, *azul*, meaning sky and the Greek, *lithos*, stone] (ICSD 31259 and PDF 34-136)	$MgAl_2(PO_4)_2(OH)_2$ $M = 302.23$ 8.04 wt.% Mg 17.86 wt.% Al 20.50 wt.% P 0.67 wt.% H 52.94 wt.% O Coordinence Fe(6), Mg(6), Al(6), P(4) (Phosphates, arsenates, and vanadates)	Monoclinic $a = 716$ pm $b = 726$ pm $c = 724$ pm $\beta = 120.67°$ $(Z = 2)$ P.G. 2/m S.G. $P2_1/c$	Biaxial(–) $\alpha = 1.612$ $\beta = 1.634$ $\gamma = 1.643$ $\delta = 0.031$ $2V = 70°$	6	3000	**Habit:** massive, prismatic. **Color:** azure blue. **Streak:** white. **Diaphaneity:** translucent. **Luster:** vitreous. **Fracture:** uneven. **Cleavage:** (011) perfect.
Lazurite (syn., lapis lazuli, lasurite, ultamarine) [Named from the Persian *lazward*, blue] (ICSD 49760 and PDF 42-1312)	$(Na,Ca)_{7.8}(Al,Si)_{12}(O,S)_{24}[(SO_4),Cl_2,(OH)_2]$ (Tectosilicates, network)	Cubic $a = 891$ pm $(Z = 1)$ Sodalite type	Isotropic $n_D = 1.5$	5.5	2380–2420	**Habit:** massive, granular. **Color:** dark blue or greenish blue. **Diaphaneity:** translucent. **Luster:** greasy. **Luminescence:** fluorescent. **Cleavage:** (110) imperfect. **Fracture:** conchoidal. **Streak:** light blue.
Lepidocrocite [20344-49-4] [from the Greek, *lipis*, scale, and *krokis*, fibre] (ICSD 27846 and PDF 8-98)	FeO(OH) $M = 88.8517$ 62.85 wt.% Fe 36.01 wt.% O 1.13 wt.% H Coordinence Fe(6) (Oxides and hydroxides)	Orthorhombic $a = 386.8$ pm $b = 1252.5$ pm $c = 306.6$ pm $(Z = 4)$ P.G. mmm S.G. A2/mam Lepidocrite type	Biaxial (–) $\alpha = 1.94$ $\beta = 2.20$ $\gamma = 2.51$ $\delta = 0.57$ $2V = 83°$ Dispersion weak $R = 20.4\%$	5 (HV 690–782)	4090	**Habit:** scaly, fibrous, blady, tabular, pulverulent. **Color:** red, yellowish brown, or blackish brown. **Luster:** submetallic. **Diaphaneity:** opaque. **Streak:** dark yellow brown, or orange. **Cleavage:** perfect (010), good (001). **Fracture:** uneven. **Occurrence:** iron ore deposits.
Lepidolite M1 [Named from the Greek *lepidion*, scale, and *lithos*, stone] (ICSD 30785 and PDF 38-425)	$K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$ $M = 386.31252$ 10.12 wt.% K 3.59 wt.% Li 6.98 wt.% Al 29.08 wt.% Si 0.52 wt.% H 49.70 wt.% O (Phyllosilicates, layered)	Monoclinic $a = 521$ pm $b = 897$ pm $c = 2016$ pm $\beta = 100.8°$ $(Z = 4)$ P.G. 2/m S.G. C2/m Mica group	Biaxial (–) $\alpha = 1.525–1.548$ $\beta = 1.551–1.58$ $\gamma = 1.554–1.586$ $\delta = 0.029–0.038$ $2V = 25–58°$ Dispersion weak	2.5–3	2800–2900 (2830)	**Habit:** massive, tabular, lamellar. **Color:** pale lilac blue, light red, colorless, or gray. **Cleavage:** (001) perfect. **Diaphaneity:** translucent. **Luster:** vitreous, pearly. **Fracture:** uneven. **Streak:** white. **Occurrence:** lithia-bearing pegmatites.

Leucite (syn., amphigene) [from the Greek, *leukos*, white] (ICSD 9826 and PDF 38-1423)	$K[Si_2AlO_6]$ M = 218.24724 17.91 wt.% K 12.36 wt.% Al 25.74 wt.% Si 43.99 wt.% O Coordinence K(12), Si(4), Al(4) (Tectosilicates, framework)	Tetragonal (pseudo-Cubic) a = 1343 pm c = 1370 pm (Z = 16) P.G. 4/m S.G. $I4_1a$	Isotropic n_D = 1.508–1.511	5.5–6	2470	**Habit:** crystalline, coarse. **Color:** colorless, white, or gray. **Diaphaneity:** translucent to transparent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (110) indistinct. **Twinning:** {100}, {112}. **Fracture:** brittle, conchoidal. **Occurrence:** acid volcanic rocks.
Limonite [Named from the Greek *leimon*, meadow since it often occurs in bogs and swamps]	$FeO.OH.nH_2O$ (Oxides and hydroxides)	Amorphous or cryptocrystalline	Isotropic n_D = 2.0–2.1	4–5.5	2700–4300	
Linnaeite (syn., Linneite) [Named in 1845 after the Swedish botanist, C. Linnaeus (1707–1778)] (ICSD 24212 and PDF 42-1448)	Co_3S_4 M = 305.0636 57.95 wt.% Co 42.05 wt.% S (Sulfides and sulfosalts)	Cubic a = 943 pm (Z = 8) P.G. 23 S.G. Fd3m Lannaeite group	Isotropic R = 43.6–47.4%	4.5–5.5 HV 492	4500–4850 (4830)	**Habit:** octahedral crystals crystalline, fine, encrustations, granular. **Color:** white or pinkish white. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** grayish black. **Cleavage:** {001} imperfect. **Fracture:** uneven to subconchoidal. **Other:** fuse on the charcoal giving a magnetic globule of Co_3O_4. Soluble in hot concentrated HNO_3 giving sulfur. **Occurrence:** hydrothermal veins and with other sulfidic Co and Ni ores.
Litharge [1317-36-8] [Named in 1917 after Greek word meaning a pyrometallurgical process to separate lead from silver] (ICSD 62842 and PDF 5-561)	α-PbO M = 223.1994 92.83 wt.% Pb 7.17 wt.% O (Oxides and hydroxides)	Tetragonal a = 397.6 nm c = 502.3 nm (Z = 2) P.G. S.G. P4/nmm Litharge type	Uniaxial (–) α = 2.535 β = 2.665	2	9140 (9355)	**Habit:** massive, scaly, earthy. **Color:** red. **Luster:** greasy to dull. **Cleavage:** (110). Dimorphous with massicot. **Other properties:** insoluble in water (ca. 17 mg/L at 20°C) but soluble in acetic acid, dilute HNO_3 and in warm solutions of alkali-metal hydroxides. Heated at 300–450°C in air, it convert slowly to minium (Pb_3O_4) but at higher temperatures it reverts to PbO finally it melts at 888°C and finally decomposes at 1472°C. **Occurrence:** rare mineral of secondary origin associated with galena.
Livingstonite [Named after the missionary, David Livingstone (1813–1873)] (ICSD 60144 and PDF 36–416)	$HgSb_2S_4$ M = 944.118 21.25 wt.% Hg 51.58 wt.% Sb 27.17 wt.% S (Sulfides and sulfosalts)	Monoclinic a = 3025 pm b = 398 pm c = 2160 pm β = 104.17° (Z = 8) P.G. 2/m S.G. A2/a	Biaxial (–)	2	4810–4900	**Habit:** radial, fibrous, columnar. **Color:** steel gray or lead gray. **Luster:** sub metallic. **Diaphaneity:** opaque to subtranslucent. **Streak:** red. **Cleavage:** [010] perfect, [100] perfect. **Fracture:** uneven.
Loparite [Named after the Russian name of inhabitants of the Kola Peninsula] (ICSD 24444 and PDF 35-618)	$(Ce,Na,Ca)(Ti,Nb)O_3$ M = 164.60 8.38 wt.% Na 2.43 wt.% Ca 8.44 wt.% La 17.03 wt.% Ce 23.27 wt.% Ti 11.29 wt.% Nb 29.16 wt.% O (Oxides and hydroxides)	Cubic a = 389 pm S.G. Pm3m Perovskite type	Isotropic n_D = 2.33	5.5	4860 (5250)	**Habit:** tiny cubes. **Color:** black. **Luster:** metallic. **Streak:** brownish. **Fracture:** conchoidal. **Diaphaneity:** translucent in this section. **Occurrence:** greisens and granites.
Maghemite [Named from the fisrt syllables of magnetite and hematite referring to the magnetism and and composition] (ICSD 70048 and PDF 25-1402)	γ-Fe_2O_3 M = 159.69 69.94 wt.% Fe 30.06 wt.% O (Oxides and hydroxides)	Cubic a = 834 pm H11, cF56 (Z = 8) S.G. Fd3m Spinel type	Isotropic n_D = 2.52–2.74 R = 25.0%	5.5–6 (HV 894–988)	5170	**Habit:** massive, granular, crystalline. **Color:** black. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** black. **Cleavage:** none. **Fracture:** conchoidal. Ferromagnetic materials.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Magnesiochromite (syn., picotite) (ICSD 20819 and PDF 10-351)	$MgCr_2O_4$ M = 192.29480 12.6395 wt.% Mg 33.2809 wt.% O 54.0796 wt.% Cr Coordinence Mg(4), Cr(6) (Oxides and hydroxides)	Cubic a = 827.7pm H11, cF56 (Z = 8) P.G. m3m S.G. Fd3m Spinel type (Chromite series)	Isotropic n_D = 2.00–2.22	5.5	4200–4430	**Habit:** massive granular. **Cleavage:** none. **Color:** black. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** dark red. **Fracture:** uneven.
Magnesioferrite (syn., ceylonite) (ICSD 49551 and PDF 36-398)	$MgFe_2O_4$ M = 200.00 12.15 wt.% Mg 55.85 wt.% Fe 32.00 wt.% O (Oxides and hydroxides)	Cubic a = 838.3 pm $H1_1$, cF56 (Z = 8) S.G. Fd3m Spinel type (Magnetite series)	Isotropic n_D = 2.380	7.5	4520	**Habit:** octahedron or massive. **Color:** black. **Diaphaneity:** opaque. **Luster:** submetallic to metallic luster. **Streak:** black. **Cleavage:** none. **Fracture:** uneven. Ferromagnetic. **Occurrence:** metamorphic rocks.
Magnesite [546-93-0] (syn., giobertite, bitter spar) [Named after the Greek city of *Magnesia*] (ICSD 80870 and PDF 8-479)	$MgCO_3$ M = 84.3142 28.83 wt.% Mg 14.25 wt.% C 56.93 wt.% O Coordinence Mg(6), C(3) (Nitrates, carbonates, and borates)	Trigonal a = 463.30 pm c = 1501.60 pm $R\bar{3}c$ (Z = 6) P.G. -32/m S.G. R-3c Calcite type	Uniaxial (–) ε = 1.509–1.563 ω = 1.700–1.782 δ = 0.190–0.218 Dispersion strong	3.5–4.5	2980–3500	**Habit:** rhombohedral, massive, granular, earthy, fibrous. **Color:** colorless, white, grayish white, yellowish white, or brownish white. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent, translucent, to opaque. **Streak:** white, gray. **Cleavage:** (1011) perfect. **Fracture:** brittle, conchoidal. **Chemical:** decomposed at 990°C giving MgO and readily soluble in diluted acids with evolution of carbon dioxide.
Magnetite [1309-37-1] (syn., lodestone, magnetic iron ore) [Named from Middle Latin *magnes* meaning magnet in reference to its magnetic properties; or after Magnes, a shepherd who from discovered the mineral on Mount Ida when the rock was attracted to the nails in his shoes] (ICSD 24830 and PDF 19-629)	$Fe_3O_4 = Fe^{II}Fe^{III}_2O_4$ M = 231.5386 72.36 wt.% Fe 27.64 wt.% O Coordinence Fe(4 and 6) (Oxides and hydroxides)	Cubic a = 839.4 pm $H1_1$, *cF56* (Z = 8) P.G. m3m S.G. Fd3m Spinel type	Isotropic n_D = 2.42 R = 21.1%	5.5–6.5 (HV 530–599)	5201	**Habit:** octahedral, massive, granular, crystalline. **Color:** black. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** black. **Cleavage:** none. **Twinning:** {111}. **Fracture:** subconchoidal. **Other:** highly ferromagnetic, electrical resistivity 56 μΩ.cm.
Malachite [Named from the Greek, *malachis*, mallow in reference to green leaf color] (ICSD 100150 and PDF 41-1390)	$Cu_2(CO_3)(OH)_2$ M = 221.11588 57.48 wt.% Cu 0.91 wt.% H 5.43 wt.% C 36.18 wt.% O Coordinence Cu(4), C(3) (Nitrates, carbonates, and borates)	Monoclinic a = 950.2 pm b = 1197.4 pm c = 324.0 pm β = 98.75° (Z = 4) P.G. 2/m S.G. $P2_1/a$	Biaxial (–) α = 1.655 β = 1.875 γ = 1.909 δ = 0.254 $2V$ = 43° Dispersion strong.	3.5–4	3700–4000 (4050)	**Habit:** botryoidal, stalactitic, massive, fibrous. **Color:** bright green or blackish green. **Luster:** vitreous, silky, earthy or adamantine. **Diaphaneity:** translucent to subtranslucent to opaque. **Streak:** pale green. **Cleavage:** [201] perfect, [010] fair. **Fracture:** uneven or subconchoidal. **Chemistry:** readily dissolved by HCl, and HNO_3 evolving carbon dioxide (i.e., effervescence). **Other:** dielectric constant 6.23 to 4.4. **Occurrence:** secondary mineral in the oxidized zones of copper ore deposits, in sandstones. Weathering gives cuprite or azurite.
Manganite (syn., brown manganese) [Named after its chemical	MnO(OH) M = 87.94482 62.47 wt.% Mn	Monoclinic a = 884 pm b = 523 pm	Biaxial (+) α = 2.24 β = 2.24	4 (HV 367–459)	4200–4400	**Habit:** prismatic. **Color:** black, gray. **Luster:** submetallic. **Diaphaneity:** opaque. **Streak:** red brown. **Cleavage:** perfect (010), good (110). **Twinning:** {011}. **Fracture:** conchoidal.

composition] (ICSD 27456 and PDF 41-1379)	36.39 wt.% O 1.15 wt.% H Coordinence Mn(6) (Oxides and hydroxides)	c = 574 pm β = 90.0° P.G. 2/m S.G. $B2_1/d$, (Z = 8)	γ = 2.24 δ = 0.29 R = 19.0–31.4%			
Manganosite [1344-43-0] [Named in 1874 after its manganese content] (ICSD 9864 and PDF 7-230)	MnO M = 70.93745 77.45 wt.% Mn 22.55 wt.% O Coordinence Mn(6) (Oxides, and hydroxides)	Cubic a = 444.5 pm B1, cF8 (Z = 4) S.G. Fm3m P.G. 432 Rock salt type Periclase group	Isotropic n_D = 2.19 R = 13.6	5.5	5364 (5370) (HV 317– 328)	**Habit:** octahedral crystals, irregular grains or masses. **Color:** emerald green to brown upon exposure to sunlight. **Luster:** vitreous to adamantine becomes dull on exposure to air and sunlight. **Diaphaneity:** translucent. **Streak:** brown. **Fracture:** fibrous. **Cleavage:** fair {001}. **Chemical:** poorly attacked by HCl or HNO3 giving a colorless solution. Melting point at 1840°C. **Occurrence:** alteration product of other manganese minerals and ores under reducing conditions.
Marcasite [Named after Arabic or Moorish for pyrite and similar substances] (ICSD 26756 and PDF 37-475)	FeS_2 M = 119.979 46.55 wt.% Fe 53.45 wt.% S (Sulfides and sulfosalts) Coordinence Fe(6)	Orthorhombic a = 444.3 pm b = 542.3 pm c = 338.76 pm C18, oP6 (Z = 2) S.G. Pnnm P.G. 222 Marcasite type	Isotropic R = 48.9–55.5%	6–6.5 (HV 941– 1288)	4900	**Habit:** tabular, cickscomb aggregate, faces curved. **Color:** white green. **Luster:** metallic. **Diaphaneity:** opaque. **Fracture:** conchoidal. **Cleavage:** {101}. **Twinning:** {101}. **Streak:** black. Pyroelectric. **Occurrence:** sedimentary, magmatic, metamorphic, and hydrothermal.
Margarite ($2M_1$) [Named from the Greek, *margaritos*, meaning pearl] (ICSD 31365 and PDF 18-276)	$CaAl_2(OH)_2Si_2Al_2O_{10}$ M = 398.18 10.07 wt.% Ca 27.10 wt.% Al 14.11 wt.% Si 0.51 wt.% H 48.22 wt.% O Coordinence Ca(6), Al(6), Al(4), Si(4) (Phyllosilicates, layered)	Monoclinic a = 514 pm b = 900 pm c = 981 pm 100.8° (Z = 4) P.G.2/m S.G. C2/c	Biaxial (–) α = 1.635 β = 1.645 γ = 1.648 δ = 0.013 $2V$ = 45° Dispersion weak	3.5–4.5	3100	**Habit:** foliated. **Color:** gray yellow. **Diaphaneity:** transparent to translucent. **Luster:** vitreous. **Cleavage:** (001) perfect. **Fracture:** uneven, flexible. **Streak:** white.
Marialite [Named by von Rath in honor of his wife, Maria Rosa vom Rath (1830–1888)] (ICSD 39963 and PDF 31-1279)	$Na_4ClSi_3Al_3O_{24}$ M = 845.11 10.88 wt.% Na 9.58 wt.% Al 29.91 wt.% Si 4.20 wt.% Cl 45.44 wt.% O (Tectosilicates, framework) Coordinence Na(6), Si(4), Al(4)	Tetragonal a = 1206.4 pm c = 751.4 pm (Z = 2) S.G. 4/m P.G. I4/m Scapolite type	Uniaxial (–) ε = 1.536 ω = 1.540 δ = 0.004	5–6	2550	**Habit:** prismatic. **Color:** colorless. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Fracture:** conchoidal. **Cleavage:** {110}. **Streak:** white. Fluorescent under UV-light: yellow, orange.
Massicot [1317-36-8] [Named from Spanish *mazacote*] (ICSD 15402 and PDF 38-1477)	β-PbO M = 223.1994 92.83 wt.% Pb 7.17 wt.% O (Oxides and hydroxides)	Orthorhombic a = 589.1 nm b = 548.9 nm c = 475.5 nm (Z = 4) P.G. 222 S.G. Pbcm	Biaxial (+) α = 2.510 β = 2.610 γ = 2.710 $2V$ = 90°	2	9640 (9560)	**Habit:** massive, scaly, earthy. **Color:** sulfur yellow or reddish yellow. **Luster:** greasy to dull. **Cleavage:** (100) and (010). Dimorphous with litharge. **Other properties:** insoluble in water (ca. 17 mg/L at 20°C) but soluble in acetic acid, dilute HNO_3 and in warm solutions of alkali-metal hydroxides. Heated at 300–450°C in air, it convert slowly to minium (Pb_3O_4) but at higher temperatures it reverts to PbO finally it melts at 888°C and finally decomposes at 1472°C. **Occurrence:** rare mineral of secondary origin associated with galena.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Meionite [Named from the Greek, *meios*, less, referring to its less acute pyramidal form compared with vesuvianite] (ICSD 2628 and PDF 44-1399)	$Ca_4CO_3Si_6Al_6O_{24}$ $M = 934.71$ 17.15 wt.% Ca 17.32 wt.% Al 18.03 wt.% S 1.28 wt.% C 46.22 wt.% O (Tectosilicates, framework) Coordinence Ca(6), Si(4), Al(4)	Tetragonal $a = 1217.4$ pm $c = 765.2$ pm $(Z = 2)$ S.G. 4/m P.G. I4/m Scapolite group	Uniaxial (–) $\varepsilon = 1.558$ $\omega = 1.595$ $\delta = 0.037$	5–6	2760	**Habit:** prismatic. **Color:** colorless. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Fracture:** conchoidal. **Cleavage:** {110}. **Streak:** white. Fluorescent under UV-light: yellow, orange.
Melanterite [7782-63-0] (syn., Green Vitriol, Pistanite, copperas, ferrous sulfate heptahydrate) [Named after the Greek and meaning black metallic dye] (ICSD 16589 and PDF 22-633)	$FeSO_4{\cdot}7H_2O$ $M = 278.01756$ 20.09 wt.% Fe 5.08 wt.% H 11.53 wt.% S 63.30 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Monoclinic $a = 1407$ pm $b = 650.9$ pm $c = 1105.4$ pm $\beta = 105.60°$ $(Z = 4)$ P.G. 2/m S.G. $P2_1/c$ Melanterite type	Biaxial (+) $\alpha = 1.470–1.471$ $\beta = 1.477–1.480$ $\gamma = 1.486$ $\delta = 0.015–0.016$ $2V = 85°27'$ Dispersion none.	2	1890 (1893)	**Habit:** rare euhedral short prismatic crystals, equant, sometimes pseudo-octahedral forming fibrous and capillary aggregates in efflorescences and encrustations. **Color:** colorless to green, yellow green, brownish black, bluish green, or greenish white. **Luster:** vitreous (glassy). **Diaphaneity:** subtransparent to translucent. **Streak:** white. **Cleavage:** [001] perfect, [110] distinct. **Fracture:** conchoidal. **Other:** readily soluble in water giving solutions that taste sweetish astringent and iron, insoluble in ethanol. Easily fusible. Loss of three water molecules above 21°C giving pale apple-green $FeSO_4{\cdot}4H_2O$. Then loss of another three water molecules above 80°C, to give the white monohydrate: $FeSO_4{\cdot}H_2O$. The complete dehydratation occurs above 406°C forming the yellowish green crystals of orthorhombic anydrous sulfate: $FeSO_4$. Finally, it decomposes above 480°C on intense heating giving-off Fe_2O_3 with strong evolutions of corrosive white fumes of SO_2/SO_3. **Occurrence:** secondary product formed during weathering of pyrite, marcassite, and other iron sulfides; effloresnce and crusts on mining walls. Large amount of synthetic material by-produced during the industrial manufacture of white pigment titanium dioxide by the sulfate process. The synthetic mineral is extensively used as flocculating agent in waste water treatment, as feedstock in inks and plant fertilizers.
Melilite [Named from the Latin *mel* for honey and *lithos*, stone]	$(Ca,Na)_2(Mg,Fe,Al)[Si_2O_7]$ (Sorosilicates, pair)	Tetragonal $a = 780$ pm $c = 500$ pm $(Z = 2)$ Melilite type	Uniaxial (+/–) $\varepsilon = 1.638–1.657$ $\omega = 1.631–1.667$ $\delta = 0.010$	5–5.5	2950	**Habit:** equant or short prismatic crystals. **Color:** colorless, yellow to light brown. **Diaphaneity:** translucent. **Luster:** vitreous. **Streak:** white. **Cleavage:** (001). **Fracture:** conchoidal. **Chemical:** gelatinizes in cold and dilute HCl. **Occurrence:** ultramafic igneous rocks and skarns.
Mercury (syn., hydrargyrum, quicksilver) [Named from the Arabic]	Hg $M = 200.59$ (Native elements)	Trigonal (Rhombohedral) $a = 300.5$ pm, 70.53° A10, hR1 $(Z = 1)$ S.G. R3m Mercury type	Isotropic	liquid	13,596	**Occurrence:** Secondary mineral resulting from oxidation of cinnabar deposits.
Merwinite [Named after the American mineralogist Herbert Eugene Merwin (1878–1963)] (ICSD 26002 and PDF 35-591)	$Ca_3Mg(SiO_4)_2$ $M = 328.71$ 36.58 wt.% Ca 7.39 wt.% Mg 17.09 wt.% Si 38.94 wt.% O	Monoclinic $a = 1325.4$ pm $b = 529.3$ pm $c = 932.8$ pm $\beta = 91.9° (Z = 4)$ P.G. 2/m S.G.: $P\ 2_1/a$	Biaxial (+) $\alpha = 1.702–1.710$ $\beta = 1.710–1.718$ $\gamma = 1.718–1.726$ $\delta = 0.008–0.023$ $2V = 52–76°$	6	3150–3310 (3340)	**Habit:** granular or rarely euhedral tabular or prismatic crystals. **Color:** colorless to light green. **Diaphaneity:** translucent. **Luster:** oily to vitreous. **Streak:** white. **Cleavage:** (100). **Fracture:** uneven. **Chemical:** readily soluble in HCl. **Occurrence:** high-pressure low-temperature metamorphism of carbonated rocks.

Metacinnabar (syn., Onofrite(Se) Guadalcazarite(Zn) Saukovite(Cd)) [Named from Greek, *meta*, and *cinnabar* similar chemical composition and association with cinnabar] (ICSD 24094 and PDF 6-261)	HgS M = 232.656 86.22 wt.% Hg 13.78 wt.% S (Sulfides and sulfosalts)	Cubic a = 585.3 pm (Z = 4)	Isotropic R = 26.8%	3	7700–7800	**Habit:** granular, encrustations. **Color:** black or gray black. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** black. **Fracture:** uneven.
Microcline (syn., amazonite green) [from the Greek, *mikron*, little and *klinein*, to stoop in reference to its characteristic variation of cleavage angle and amazonite after Amazon River, South America] (ICSD 34790 and PDF 19-932)	$K[Si_3AlO_8]$ M = 278.33154 14.05 wt.% K 9.69 wt.% Al 30.27 wt.% Si 45.99 wt.% O Coordinence K(10), Si(4), Al(4) (Tectosilicates, framework)	Triclinic a = 857.7 pm b = 1296.7 pm c = 722.3 pm α = 89.7° β = 115.97° γ = 90.87° (Z = 4) P.G. 1 S.G. P1	Biaxial (–) α = 1.518 β = 1.522 γ = 1.525 δ = 0.007 $2V$ = 77–84° Dispersion weak	6	2560	**Habit:** blocky, crystalline, coarse, prismatic. **Color:** white, cream, bright green, or green. **Diaphaneity:** translucent to transparent. **Luster:** vitreous (i.e., glassy). **Cleavage:** (001) perfect, (010) good. **Twinning:** albite [010], pericline [010]. **Fracture:** uneven. **Streak:** white. **Occurrence:** granitic pegmatites, hydrothermal and metamorphic rocks.
Millerite [Named after the British crystallographer William H. Miller] (ICSD 40054 and PDF 12-41)	NiS M = 114.537 48.76 wt.% Fe 51.24 wt.% Ni (Sulfides and sulfosalts) Coordinence Ni(5)	Trigonal (Rhombohedral) a = 961.6 pm c = 315.2 pm B13, hR6 (Z = 3) S.G. R3m P.G. 3m Millerite type	Uniaxial R = 54–60%	3–3.5 (HV 225–256 and 235–280 //)	5500	**Habit:** acicular, fibrous. **Color:** brass yellow. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** greenish gray. **Fracture:** uneven. Electrical resistivity 20 to 40 μΩ.cm.Antiferromagnetic.
Minium (syn., red lead oxide) [Named after the river Minius located in northwest of Spain] (ICSD 22325 and PDF 41-1494)	Pb_2PbO_4 M = 685.5976 90.67 wt.% Pb 9.33 wt.% O (Oxides and hydroxides)	Tetragonal P.G. –4 Spinel type	Uniaxial n ~ 2.42	2.5–3	8200	**Habit:** scaly, massive, granular, striated. **Color:** light red, brownish red, vivid red, or yellowish red. **Luster:** adamantine. **Diaphaneity:** subtransparent to opaque. **Streak:** yellowish orange. **Cleavage:** [110] perfect, [010] perfect. **Fracture:** earthy. **Occurrence:** Oxidized portions of lead ore deposits.
Molybdenite (2H) [1317-33-5] (syn., molybdic ochre) [Named from the Greek, *molybdos*, lead] (ICSD 49801 and PDF 37-1492)	MoS_2 M = 160.072 59.94 wt.% Mo 40.06 wt.% S (Sulfides and sulfosalts) Coordinence Mo(6)	Hexagonal a = 316.04 pm c = 1229.50 pm C7, hP6 (Z = 2) S.G. $P6_3/mmc$ P.G. 622 Molybdenite type	Uniaxial (–) ω = 4.33 ε = 2.03 δ = 2.3 R = 15.0–37.0%	1–1.5 (HV 16–19 and 21–28 //)	5060	**Habit:** foliated, massive, disseminated. **Luster:** metallic. **Diaphaneity:** opaque. **Color:** bluish lead gray or lead gray. **Streak:** greenish gray. **Cleavage:** {0001} perfect. **Fracture:** sectile and flexible. Sol. conc. Acids. Electrical resistivity 0.12 to 7.5 Ω.m.
Monazite [Named from the Greek, *monazeis*, to be alone in allusion to its isolated crystals and their rarity when first found] (ICSD 79746 and PDF 32-199)	$(Ce0.50La0.25Nd0.20Th0.05)PO_4$ Coordinence Ce(8), P(4) M = 240.21 14.46 wt.% La 29.17 wt.% Ce 4.83 wt.% Th 12.89 wt.% P 12.01 wt.% Nd 26.64 wt.% O (Phosphates, arsenates, and vanadates)	Monoclinic a = 679.0 pm b = 701 pm c = 646 pm β = 104.4° (Z = 4) P.G. 2/m S.G. $P2_1/n$ Crocoite type	Biaxial (+) α = 1.785–1.800 β = 1.786–1.801 γ = 1.838–1.851 δ = 0.045–0.075 $2V$ = 10–19°	5–5.5	5150–5300 (5340)	**Habit:** crystalline, tabular, prismatic. **Color:** black, gray, brown, red, yellow, green, or orange. **Diaphaneity:** transparent to opaque. **Luster:** adamantine, resinous (Th rich). **Streak:** grayish white. **Cleavage:** (001) distinct, (100) indistinct. **Twinning:** {100} common. **Fracture:** uneven, subconchoidal. **Chemical:** slightly soluble in hot conc. H_2SO_4. When wetted by H_2SO_4, color the Bunsen flame in blue-green. Unfusible. **Deposits:** granodiorites, syenites, granitic pegmatites, heavy mineral sands. **Other properties:** slightly paramagnetic with a specific magnetic susceptibility of 10^{-7} $m^3.kg^{-1}$. Owing to its thorium content that can reach 10 wt.% in some cases (e.g., Madagascan monazite), monazite is considered as a radioactive material as defined in 49 CFR 173.403, that is, with a specific activity greater than 70 kBq /kg.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Monteponite [1306-19-0] (syn. cadmium oxide) [Named after the Sardinian locality Monte Poni, Italy] (ICSD 29289 and PDF 5-640)	CdO $M = 128.4104$ 87.54 wt.% Cd 12.46 wt.% O	Cubic $a = 469.53$ pm B1, cF8 ($Z = 4$) S.G. Fm3m P.G. 4–32 Rock salt type Periclase group	Isotropic $n_D = 2.49$	3	8100–8200 (8238)	**Habit:** coating. **Color:** black but orange-red in transmitted light. **Luster:** metallic. **Diaphaneity:** transparent. **Others:** Soluble in strong mineral acids, melting point of 1555°C.
Monticellite [Named after the Italian mineralogist Teodoro Monticelli (1759–1846)] (ICSD 79792 and PDF 35-590)	$CaMg[SiO_4]$ $M = 156.4$ 25.61 wt.% Ca 15.53 wt.% Mg 17.95 wt.% Si 40.90 wt.% O Coordinence Ca(6), Mg(6), Si(4) (Nesosilicates)	Orthorhombic $a = 481.5$ pm $b = 1108.4$ pm $c = 637.6$ pm ($Z = 4$) P.G. mmm S.G. Pbnm (Olivine group)	Biaxial (–) $\alpha = 1.639–1.653$ $\beta = 1.645–1.664$ $\gamma = 1.653–1.674$ $\delta = 0.014–0.017$ $2V = 72–82°$ Dispersion weak	5.5	3080–3270	**Habit:** crystalline, fine, prismatic. **Color:** colorless or gray. **Diaphaneity:** transparent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (010) good, (100) poor. **Twinning:** {031}. **Occurrence:** metamorphosed siliceous dolomitic limestones.
Montmorillonite (syn. bentonite) [Named after Montmorillon, Vienne, France]	$Na_{0.5}Ca_{0.5}Al_2[Si_4O_{10}](OH)_2.10H_2O$ 0.84 wt.% Na 0.73 wt.% Ca 9.83 wt.% Al 20.46 wt.% Si 4.03 wt.% H 64.12 wt.% O Phyllosilicates	Monoclinic $a = 493–520$ pm $b = 894–902$ pm $c = 1240$ pm $\beta = 99.54°$ ($Z = 1$) S.G. C2/m	Biaxial (–) $\alpha = 1.480–1.503$ $\beta = 1.500–1.534$ $\gamma = 1.500–1.534$ $2V = 10–25°$	1–2	2290–2360	**Habit:** tabular crystals. **Color:** pale yellow to olive green. **Diaphaneity:** translucent. **Luster:** waxy to resinous. **Fracture:** conchoidal to fibrous. **Cleavage:** (001) perfect. **Other:** Expands with ethylene glycol but not with water. Decomposed by HCl with formation of a gel. **Occurrence:** found in weathering products of basic igneous rocks along with other phyllosilicates such as kaolinite, glauconite, chlorite and vermiculite. Found in vertisols.
Montroydite [Named after theTexan mine owner Montroyd Sharp] (ICSD 15890 and PDF 34-1469)	HgO $M = 216.5894$ 92.61 wt.% Hg 7.39 wt.% O (Oxides and hydroxides)	Orthorhombic $a = 661$ pm $b = 552$ pm $c = 352$ pm ($Z = 4$) P.G. 222 S.G. Pnma	Biaxial (+) $\alpha = 2.37$ $\beta = 2.50$ $\gamma = 2.65$ $\delta = 0.280$	1.5–2	11,300 (11,209)	**Habit:** crystalline, fine. **Color:** reddish orange. **Luster:** adamantine. **Streak:** reddish orange. **Cleavage:** [010] perfect. **Occurrence:** oxidized mercury deposits.
Mullite (syn., mullite 3:2) [Named from the Island of Mull, Scotland] (ICSD 66444 and PDF 15-776)	$Al_6Si_2O_{13}$ $M = 322.38$ 34.31 wt.% Al 16.55 wt.% Si 49.13 wt.% O (Nesosubsilicates)	Orthorhombic $a = 757.8$ pm $b = 768.76$ pm $c = 288.42$ pm ($Z = 1$) P.G. 2/m2/m2/m S.G. Pbam	Biaxial (+) $\alpha = 1.642–1.653$ $\beta = 1.644–1.655$ $\gamma = 1.654–1.679$ $\delta = 0.012–0.026$ $2V = 20–50°$ O.A.P. (010)	6–7	3150–3260 (3050)	**Habit:** well-formed fine sized crystals, prismatic crystals shaped like slender prisms. **Color:** colorless, violet, yellow, white, light pink. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (glassy). **Streak:** white. **Fracture:** brittle. **Occurrence:** Originally found in melted argillaceous inclusions in lavas from cenozoic on the Island of Mull, Scotland but usually found in artificial melts in porcelain and refractories as a result of the heating of andalusite, kyanite and sillimanite to high temperatures (1400°C) according to reaction: $3\,Al_2SiO_5 = Al_6Si_2O_{13} + SiO_2$.
Muscovite $2M_1$ (syn., isinglass, potash mica, fuchsite: Cr, sericite) [from Latin, *vitrum muscoviticum*, Muscovy glass, alluding to the Russian	$KAl_2(Si_3Al)O_{10}(OH,F)_2$ $M = 398.3081$ 9.82 wt.% K 20.32 wt.% Al 21.15 wt.% Si	Monoclinic $a = 520.3$ pm $b = 899.5$ pm $c = 2003.0$ pm $\beta = 94.47°$	Biaxial (–) $\alpha = 1.552–1.574$ $\beta = 1.582–1.610$ $\gamma = 1.587–1.616$ $\delta = 0.034–0.042$	2.5–3 (HV 85)	2770–2880	**Habit:** massive, lamellar, foliated, micaceous. **Color:** white, gray, silver white, brownish white, or greenish white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (001) perfect. **Fracture:** brittle, sectile. **Chemical:** insoluble in strong mineral acids. Unfusible. **Dielectric properties.** Relative permittivity: 5 to 8, dielectric field strength: 10–20 kV/mm, loss tangent 0.001 to 0.004 , electrical resistivity

province of Muscovy] (ICSD 34406 and PDF 6-263)	0.51 wt.% H 48.20 wt.% O Coordinence K(6), Al(6), Si(4), and Al(4) (Phyllosilicates, layered)	(Z = 4) Type $2M_1$ mica (Micas group)	$2V$ = 30–47° Dispersion weak			10^{11} to 10^{12} ohm.m. **Occurrence:** granites and pegmatites.
Nahcolite [144-55-8] (sodium bicarbonate) [Named in 1929 from an acronym of Na, H, C, O and the Greek, *lithos*, stone] (ICSD 18183 and PDF 15-70)	$NaHCO_3$ M = 84.007 52.39 wt.% CO_2 36.89 wt.% Na_2O 10.72 wt.% H_2O (Carbonates)	Monoclinic a = 752.5 pm b = 972 pm c = 353 pm β = 93°19' (Z = 4) S.G. $P2_1/n$ P.G. 2/m	Biaxial (–) α = 1.375 β = 1.498–1.503 γ = 1.583 δ = 0.208 $2V$ = 75°	2.5	2210–2238 (2160)	**Habit:** elongated crystals, fibrous masses and friable porous aggregates. **Color:** colorless, white, yellow, gray even reddish brown to black due to chromophoric impurities (Fe). **Diaphaneity:** transparent. **Luster:** vitreous to resinous. **Cleavage:** perfect on {101}, good on {111}, fair on {100}. **Twinning:** common on {101}. **Streak:** white. **Fracture:** conchoidal. **Chemical:** soluble in water, ethanol, and glycerol. On heating aqueous solutions decomposes from 20°C and the solid begins to decomposes at 50°C loosing CO_2 and giving Na_2CO_3. Evolves CO_2 on contact with weak acids (e.g., acetic). **Occurrence:** precipitates from hot mineral springs, efflorescences around saline lakes in arid regions.
Natrolite [Named from Latin *natrium* or Greek, *natron*, native soda and lithos, stone] (ICSD 16033 and PDF 15-800)	$Na_2Si_3Al_2O_{10}.2H_2O$ M = 380.22 12.09 wt.% Na 14.19 wt.% Al 22.16 wt.% Si 1.06 wt.% H 50.49 wt.% O Coordinence Na(6), Si(4), and Al(4). (Tectosilicates, framework)	Orthorhombic a = 1830.0 pm b = 1863.0 pm c = 660.0 pm (Z = 8) P.G. m2m S.G. Fd2d (Zeolite group)	Biaxial (+) α = 1.480 β = 1.480 γ = 1.490 δ = 0.012 $2V$ = 38–62°	5–5.5	2230	**Habit:** acicular. **Color:** colorless, gray. **Diaphaneity:** transparent to translucent. **Luster:** vitreous. **Streak:** white. **Cleavage:** (110) perfect. **Fracture:** uneven. **Other:** Cp = 381 to 425 $J.K^{-1}.mol^{-1}$.
Nepheline (syn., nephelite, elaeolite) [from the Greek, *nephele*, cloud, because it becomes clouded when put in strong acid] (ICSD 2937 and PDF 9-338)	$KNa_3Si_4Al_4O_{16}$ M = 146.08 6.69 wt.% K 11.80 wt.% Na 18.47 wt.% Al 19.23 wt.% Si 43.81 wt.% O Coordinence Na(8), K(9), Si(4), Al(4) (Tectosilicates, framework)	Hexagonal a = 1001 pm c = 840.5 pm (Z = 2) P.G. 6 S.G. $P6_3$	Uniaxial (–) ε = 1.528–1.544 ω = 1.531–1.549 δ = 0.003–0.005	6	2600	**Habit:** massive, granular, prismatic. **Color:** white, gray, brown, brownish gray, or reddish white. **Diaphaneity:** transparent to opaque. **Luster:** vitreous, greasy. **Streak:** white. **Cleavage:** (1010) poor. **Twinning:** {100}, {112}, and {335}. **Fracture:** Subconchoidal. **Occurrence:** Silica-poor igneous rocks. **Other:** Cp = 123 $J.K^{-1}.mol^{-1}$.
Niccolite (syn., nickeline) [Named from the old German, *nickel*, meaning an ore which is not usefull] (ICSD 31062 and PDF 47-1737)	NiAs M = 133.61159 43.92 wt.% Ni 56.08 wt.% As Traces of Fe, S, Co, Sb, Bi, and Cu (Sulfides and sulfosalts) Coordinence Ni(6)	Hexagonal a = 360.9 pm c = 501.9 pm $B8_1$, hP4 (Z = 2) S.G. $P6_3/mmc$ P.G. 622 Niccolite type	Uniaxial R = 52.0–58.3%	5–5.5 (HV 308–455)	7780	**Habit:** massive, reniform, columnar. **Color:** dark tarnish red or pale copper red. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** brownish black. **Cleavage:** {1010} imperfect, {0001} imperfect. **Fracture:** uneven, brittle. **Chemical:** dissolved by aqua regia. Electrical resistivity 0.1 to 2 mΩ.cm. **Occurrence:** in ore veins with silver, copper, and nickel arsenides and sulfides.
Niter (syn., salpeter nitre) [Named from Latin, *nitrum*, the Greek, *nitron*, or the Hebrew, *nether*; perhaps originally from Nitria, a city in Upper Egypt] (ICSD 10289 and PDF 5-377)	KNO_3 M = 101.10324 38.67 wt.% K 13.85 wt.% N 47.47 wt.% O Coordinence K(6), N(3) (Nitrates, carbonates, and borates)	Orthorhombic a = 643.1 pm b = 916.4 pm c = 541.4 pm (Z = 4) P.G. mmm S.G. Pmcn Aragonite type	Biaxial (–) α = 1.333 β = 1.505 γ = 1.505 δ = 0.172 $2V$ = 7°	2	2100	**Occurrence:** efflorescence on cavern walls.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Nitratite (syn., nitratine, soda niter, nitronatrite) [Named after its composition of containing nitrates] (ICSD and PDF 11-686)	$NaNO_3$ $M = 84.9947$ 27.05 wt.% Na 16.48 wt.% N 56.47 wt.% O Coordinence Na(6), N(3) (Nitrates, carbonates, and borates)	Trigonal (Rhomboedral) $a = 507$ pm $c = 1682$ pm ($Z = 6$) P.G. 32/m S.G. R3c Calcite type	Uniaxial (–) $\varepsilon = 1.587$ $\omega = 1.336$ $\delta = 0.251$	1.5–2	2240–2290	**Habit:** massive. **Color:** white, reddish brown, gray, or lemon yellow. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Cleavage:** perfect (1014). **Twinning:** {0001}. **Fracture:** uneven, sectile. **Occurrence:** residual water-soluble surface deposits in extremely arid deserts. Nitrates occur in clay rich caliche deposits replenished by occasional desert thunderstorms which fix N_2 from the air.
Norbergite [Named after the Ostanmosoa iron mine, Norberg, Vastmanland, Sweden] (ICSD 15203 and PDF 11-686)	$Mg(OH,F)_2.Mg_3[SiO_4]$ $M = 202.00$ 36.10 wt.% Mg 13.90 wt.% Si 0.25 wt.% H 35.64 wt.% O 14.11 wt.% F Coordinence Mg(6), Si(4) (Nesosilicates)	Orthorhombic $a = 470$ pm $b = 1022$ pm $c = 872$ pm ($Z = 4$) P.G. mmm S.G. Pbnm (Humite group)	Biaxial (+) $\alpha = 1.563–1.567$ $\beta = 1.567–1.579$ $\gamma = 1.590–1.593$ $\delta = 0.026–0.027$ $2V = 44–50°$	6–6.5	3200–3320	**Habit:** massive, tabular. **Color:** white, yellow, colorless. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** translucent to transparent. **Streak:** white. **Cleavage:** (100) poor. **Twinning:** {001}. **Fracture:** uneven, brittle. **Chemical:** attacked by strong mineral acids giving a silica gel. **Deposits:** dolomites, limestones, skarns.
Northupite [Named after the American amateur mineralogist, Charles H. Northup] (ICSD 4237 and PDF 19-1213)	$Na_3Mg(CO_3)_2Cl$ $M = 248.75$ 27.73 wt.% Na 9.77 wt.% Mg 9.66 wt.% C 14.25 wt.% Cl 38.59 wt.% O (Carbonates, nitrates and borates)	Cubic $a = 1401$ pm ($Z = 16$) P.G. 2/m3 S.G. Fd3	Isotropic $n_D = 1.514$	3.5–4	2380	**Habit:** crystalline-coarse, pyramidal. **Color:** white, yellow, or gray. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (glassy). **Occurrence:** continental evaporite deposits.
Nosean (syn., noselite) [Named after the German mineralogist, K.W. Nose] (ICSD 203102 and PDF 17-538)	$Na_8[Al_6Si_6O_{24}](SO_4)$ $M = 1012.38486$ 18.17 wt.% Na 15.99 wt.% Al 16.65 wt.% Si 0.20 wt.% H 3.17 wt.% S 45.83 wt.% O Traces of Ca, Fe (Tectosilicates, framework)	Cubic $a = 905$ pm ($Z = 1$) Sodalite type	Isotropic $n_D = 1.495$	5.5	2300–2400	**Habit:** massive, granular. **Color:** white, gray, blue, green, or brown. **Luster:** vitreous (i.e., glassy), greasy. **Luminescence:** fluorescent. **Streak:** bluish white. **Cleavage:** [110] poor. **Twinning:** {111}. **Fracture:** brittle, conchoidal. **Occurrence:** igneous rocks low in silica and rich in alkalis.
Olkhonskite [165467-07-2] [Named after Olkhon Island, Lake Baikal, Russia]	$Cr_{1.5}V_{0.5}Ti_3O_9$ $M = 391.10$ 19.94 wt.% Cr 6.51 wt.% V 36.73 wt.% Ti 36.82 wt.% O Coordinence Ti(6)	Monoclinic $a = 703$ pm $b = 502$ pm $c = 1883$ pm $\beta = 119.6°$ S.G. Unknown Pseudorutile type	Biaxial (?) $R = 18.6–20\%$	(HK 1412)	(4480)	**Habit:** platy inclusions in rutile. **Color:** black. **Luster:** metallic. **Occurrence:** paragenesis with schreyerite, eskolaite, and karelianite.

Oligoclase (syn., sunstone) [Named from the Greek, *oligos*, and *kasein*, little, cleavage]	$(Na,Ca)(Si,Al)_4O_8$ An20-Ab80 $M = 265.41986$ 6.93 wt.% Na 3.02 wt.% Ca 12.20 wt.% Al 29.63 wt.% Si 48.22 wt.% O (Tectosilicates, framework)	Triclinic $a = 815$ pm $b = 1278$ pm $c = 850$ pm $(Z = 5)$	Biaxial (+) $\alpha = 1.533–1.543$ $\beta = 1.537–1.548$ $\gamma = 1.542–1.552$ $\delta = 0.009$ $2V = 82–86°$	7	2650	**Habit:** euhedral crystals. **Color:** white or gray. **Luster:** vitreous (i.e., glassy). **Luminescence:** fluorescent. **Cleavage:** (001) perfect, (010) good. **Fracture:** uneven. **Streak:** white. **Occurrence:** magmatic and pegmatitic rocks.
Olivine (syn., peridot, chrysolite light yellowish green) [Named after the green color]	$(Mg,Fe)_2[SiO_4]$ (Nesosilicates)	Orthorhombic	Biaxial (+/–) $\alpha = 1.635–1.827$ $\beta = 1.651–1.869$ $\gamma = 1.670–1.879$ $\delta = 0.035–0.052$ $2V = 82–134°$ Dispersion weak	6.5–7	3220–4390	**Habit:** massive. **Color:** yellowish green, olive green, greenish black, or reddish brown. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Cleavage:** (001) good, (010) distinct. **Fracture:** conchoidal, brittle. **Streak:** white. **Occurrence:** basic and ultrabasic igneous rocks
Orpiment [from the Latin, *auri pigmentum*, given by Pliny in allusion to the vivid golden hue] (ICSD 15239 and PDF 24-75)	As_2S_3 $M = 246.0412$ 60.90 wt.% As 39.10 wt.% S Traces of Se, Sb, V, and Ge (Sulfides and sulfosalts)	Monoclinic $a = 1149$ pm $b = 959$ pm $c = 425$ pm $D5_1$, mP20 $(Z = 4)$ S.G. P21/c P.G. 2/m Orpiment type	Biaxial (+) $\alpha = 2.40$ $\beta = 2.81$ $\gamma = 3.02$ $\delta = 0.62$ $2V = 76°$ $R = 22.6\%$	1.5–2 (HV 23–52)	3490–3520	**Habit:** prismatic, massive, fibrous, foliated, flexible crystals. **Color:** lemon yellow, brownish yellow, or orange yellow. **Diaphaneity:** transparent to opaque. **Luster:** resinous. **Streak:** pale yellow. **Cleavage:** [010] perfect. **Fracture:** even, sectile. **Chemical:** dissolved by the aqua regia. **Occurrence:** in hydrothermal veins with realgar, stibine and pyrite. **Other:** dielectric constant
Orthoclase (syn., orthose, adularia) [Named from the Greek, *orthos*, right, and *kalos*, I cleave in allusion to the mineral's right angle of good cleavage] (ICSD 9544 and PDF 31-966)	$K[Si_3AlO_8]$ $M = 278.33154$ 14.05 wt.% K 9.69 wt.% Al 30.27 wt.% Si 45.99 wt.% O Coordinence K(10), Si(4), Al(4) (Tectosilicates, framework)	Monoclinic $a = 862.5$ pm $b = 1299.6$ pm $c = 719.3$ pm $\beta = 116.01°$ $(Z = 4)$ P.G. 2/m S.G. C2/m	Biaxial (–) $\alpha = 1.518–1.521$ $\beta = 1.523–1.525$ $\gamma = 1.526–1.528$ $\delta = 0.005–0.006$ $2V = 65–75°$ Dispersion strong	6	2560	**Habit:** prismatic, massive, granular, blocky. **Color:** white, pink, yellow, or red. **Diaphaneity:** transparent to translucent. **Luster:** pearly, vitreous (i.e., glassy). **Streak:** white. **Cleavage:** (001) perfect, (010) good, (110) poor. **Twinning:** Carlsbad [001], Baveno [021]. **Fracture:** uneven. **Occurrence:** intrusive and extrusive igneous, and metamorphic rocks.
Orthoferrosilite (syn., ferrosilite)	$(Fe,Mg)_2[Si_2O_6]$ Traces of Ca, Fe, Mn, Ni, Cr, Al and Ti (Inosilicates, single chain)	Orthorhombic $a = 908.1$ pm $b = 1843.1$ pm $c = 523.8$ pm $(Z = 16)$ P.G. 222 S.G. Pbca	Biaxial (+)	5–6	3300–3500	**Habit:** phenocrystals. **Color:** brown to black. **Diaphaneity:** translucent. **Luster:** vitreous. **Streak:** brown. **Cleavage:** (210). **Fracture:** uneven. **Occurrence:** basic and ultrabasic rocks.
Palladium [Named after the discovery of the asteroid, Pallas] (ICSD 64922 and PDF 46-1043)	Pd or (Pd,Hg) $M = 106.42$ (Native elements)	Cubic $a = 389.03$ pm A1, cF4 $(Z = 4)$ S.G. Fm3m Copper type	Isotropic $R = 70\%$	4.5–5	11,550	**Habit:** granular. **Color:** gray. **Diaphaneity:** opaque. **Luster:** metallic.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Palygorskite (syn., attapulgite, Fuller's earth) [Named after locality Palygorskaya in the Urals Mountains, Russia and after *Attapulgus*, Georgia, USA] (ICSD 75974 and PDF 21-958)	$Mg_{1.5}Al_{0.5}[(Si_4O_{10})(OH)_4].H_2O$ $M = 411.35$ 8.86 wt.% Mg 3.28 wt.% Al 27.31 wt.% Si 2.21 wt.% H 58.34 wt.% O Phyllosilicates	Monoclinic $a = 1278$ pm $b = 1789$ pm $c = 524$ pm $\beta = 105.2°$ $(Z = 4)$ S.G. C2/m Paligorskite group	Biaxial (–) $\alpha = 1.522–1.528$ $\beta = 1.530–1.546$ $\gamma = 1.533–1.548$ $2V = 36°–61°$	2–2.5	2290–2360	**Habit:** aggregates or masses of lath-shaped crystals. **Color:** white to tan. **Diaphaneity:** opaque but becomes translucent in thin sections. **Luster:** dull. **Fracture:** conchoidal. **Cleavage:** {110 } good. Insoluble in HCl and infusible. **Occurrence:** hydrothermal veins.
Patronite [Named after the Peruvian engineer Antenor Rizo-Patron (1866–1948), who discoverer the Minasragra deposit near Cerro de Pasco, Peru] (ICSD 64770 and PDF 19-1408)	VS_4 $M = 179.21$ 28.44 wt.% V 71.57 wt.% S Sulfides and sulfosalts	Monoclinic $a = 678$ pm $b = 1042$ pm $c = 1211$ pm $\beta = 100.8°$ $(Z = 8)$ P.G. 2/m S.G. I2/a	Biaxial (?) $R = 20–30\%$	2	2820 (2834)	**Habit:** massive to fine grains. **Color:** lead gray to black. **Diaphaneity:** opaque. **Luster:** metallic. **Occurrence:** asphaltite deposits.
Pearceite [Named after the American chemist, R. Pearce (1837–1927)]	$Ag_{16}As_2S_{11}$ $M = 2228.4604$ 77.45 wt.% Ag 6.72 wt.% As 15.83 wt.% S (Sulfides and sulfosalts)	Monoclinic $a = 1261$ pm $b = 728$ pm $c = 1188$ pm $\beta = 90°$ $(Z = 2)$ P.G. 2/m S.G. C2/m	Biaxial $R = 29.3–32.3\%$	2.5–3 (HV 153–164)	6790	**Habit:** massive, granular. **Color:** black. **Luster:** submetallic. **Diaphaneity:** opaque. **Streak:** reddish black. **Cleavage:** [001] poor. **Fracture:** uneven.
Pectolite [Named from the Greek, *pektos*, compacted, and *lithos*, stone] (ICSD 34945 and PDF 33-1223)	$Ca_2Na[Si_3O_8](OH)$ $M = 332.40$ 6.92 wt.% Na 24.11 wt.% Ca 25.35 wt.% Si 0.30 wt.% H 43.32 wt.% O Coordinence Ca(6), Na(6), Si(4) (Inosilicates, ribbon)	Triclinic $a = 799$ pm $b = 704$ pm $c = 702$ pm $\alpha = 90.05°$ $\beta = 92.58°$ $\gamma = 102.47°$ P.G. 1 S.G. P1 Pyroxenoid group	Biaxial (–) $\alpha = 1.590$ $\beta = 1.610$ $\gamma = 1.630$ $\delta = 0.04$ $2V = 35–63°$	4.5–5	2900	**Habit:** radiating, fibrous. **Color:** white. **Luster:** silky. **Diaphaneity:** transparent to translucent. **Streak:** white. **Fracture:** uneven. **Cleavage:** (100) perfect, (001) distinct. **Twinning:** {010}.
Pentlandite [Named after the Irish natural historian, Joseph Barclay Pentland (1797–1873)] (ICSD 61021 and PDF 8-90)	$(Fe,Ni)_9S_8$ $M = 771.94$ 32.56 wt.% Fe 34.21 wt.% Ni 33.23 wt.% S (Sulfides and sulfosalts) Coordinence Ni(6),Fe(6), and Fe(4)	Cubic $a = 1009.5$ pm $D8_9$, cF68 $(Z = 4)$ S.G. Fm-3m P.G. 4-32 Co_9S_8 type	Isotropic $R = 52\%$	3.5–4 (HV 202–230)	5000	**Habit:** massive, granular. **Color:** light bronze yellow. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** greenish black. **Cleavage:** perfect {100}, good {111}. **Fracture:** uneven, conchoidal. Electrical resistivity 1 to 11 μΩ.cm. **Deposits:** mafic intrusives igneous rocks.

Periclase [1309-48-4] (syn., magnesia) [from the Greek, *peri*, around, and *klao*, to cut in reference to its perfect cubic cleavage] (ICSD 9863 and PDF 43-1022)	MgO $M = 40.2990$ 60.31 wt.% Mg 39.69 wt.% O Coordinence Mg(6) (Oxides and hydroxides)	Cubic $a = 421.17$ pm B1, cF8 ($Z = 4$) S.G. Fm3m P.G. 4-32 Rock salt type	Isotropic $n_D = 1.736$	5.5	3560	**Habit:** granular, octahedral crystals. **Color:** white, gray, or green. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Luminescence:** fluorescent, long uv-light yellow. **Streak:** white. **Cleavage:** [001], [010], [100]. **Fracture:** uneven, brittle, conchoidal. **Occurrence:** contact metamorphism of dolomites and magnesites.
Perovskite or Perowskite [12049-50-2] [Named after the Russian mineralogist, count L.A. Perowski] (ICSD 37263 and PDF 42-423)	$CaTiO_3$ $MM = 135.9562$ 35.22 wt.% Ti 35.30 wt.% O 29.48 wt.% Ca Traces of rare earths, Nb, Ta, Th. Coordinence Ca(12), Ti(6) (Oxides and hydroxides)	Orthorhombic (pseudocubic) $a = 536.70$ pm $b = 764.38$ pm $c = 544.39$ pm E21, *cP5*, ($Z = 4$) P.G. mmm S.G. Pm3m Perovskite type	Biaxial (–) $\alpha = 2.34$ $\beta = 2.34$ $\gamma = 2.34$ $\delta = 0.002$ $2V = 90°$ $R = 16.7\%$	5.5 (HV 988– 1131)	4044	**Habit:** faces striated, reniform, pseudocubic, pseudohexagonal. **Color:** black, reddish brown, pale yellow, yellowish orange. **Diaphaneity:** transparent to translucent or opaque. **Luster:** adamantine, submetallic. **Streak:** light brown. **Fracture:** subconchoidal. **Cleavage:** (100). **Twinning:** {111}. **Chemical:** attacked by hot H_2SO_4, and HF. **Nonfusible:** m.p. 1980°C. **Deposits:** ultramafic igneous rocks, metamorphosed limestone in contact with mafic igneous rocks.
Petalite [Named from the Greek *petalon*, leaf and *lithos*, stone alluding to its leaflike cleavage] (ICSD 100348 and PDF 35–463)	$LiAlSi_4O_{10}$ $M = 305.15$ 2.09 wt.% Li 8.75 wt.% Al 36.72 wt.% Si 52.43 wt.% O Phyllosilicates	Monoclinic $a = 1175$ pm $b = 514$ pm $c = 763$ pm $\beta = 113.01°$ ($Z = 2$) S.G. P2/a	Biaxial (–) $\alpha = 1.504–1.507$ $\beta = 1.510–1.513$ $\gamma = 1.516–1.523$ $2V = 83°$	6–6.5	2300– 2500 (2398)	**Habit:** massive and blocky aggregates. **Color:** colorless, gray, yellow, yellow gray, white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous. **Cleavage:** [001] perfect. **Fracture:** conchoidal. **Streak:** colorless. insoluble in HCl. **Occurrence:** granite pegmatites.
Petzite [Named after the chemist, W. Petz] (ICSD 27539 and PDF 44-1420)	Ag_3AuTe_2 $M = 667.90294$ 32.30 wt.% Ag 38.21 wt.% Te 29.49 wt.% Au (Sulfides and sulfosalts)	Cubic P.G. 23	Isotropic $R = 45\%$	2.5	8700– 9140	**Habit:** massive, granular. **Color:** iron black or steel gray. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** grayish black. **Fracture:** brittle, sectile.
Pezzottaite [Named for Federico Pezzotta of the Museo Civico, Milano, Italy for his work on the granitic pegmatites of Madagascar]	$Cs(Be_2Li)Al_2Si_6O_{18}$ $M = 658.80$ 14.93 wt.% Cs 0.99 wt.% Li 4.19 wt.% Be 8.35 wt.% Al 25.58 wt.% Si 43.96 wt.% O	Trigonal $a = 1595$ pm $c = 2780$ pm ($Z = 18$) P.G. 3m S.G. R3c Beryl group	Uniaxial (–) $\varepsilon = 1.615–1.619$ $\omega = 1.607–1.610$ $\delta = 0.0080–0.009$	8	3090– 3110 (3220)	**Habit:** hexagonal tabular crystals. **Color:** raspberry to purplish pink. **Diaphaneity:** translucent to transparent. **Luster:** vitreous. **Clivage:** [001] imperfect. **Streak:** white. **Fracture:** conchoidal. **Occurrence:** Late-stage pocket mineral formed in a granitic pegmatites.
Phlogopite (1M) [Named from the Greek, *phlogopos*, to burn or inflame alluding to its reddish tinge resembling fire] (ICSD 21102 and PDF 10-495)	$KMg_3(Si_3Al)O_{10}(F,OH)_2$ $M = 417.26002$ 9.37 wt.% K 17.47 wt.% Mg 6.47 wt.% Al 20.19 wt.% Si 0.48 wt.% H 46.01 wt.% O Coordinence K(12), Mg(6), Si(4), Al(4) (Phyllosilicate, layered)	Monoclinic $a = 531$ pm $b = 923$ pm $c = 1015$ pm $\beta = 95.18°$ ($Z = 2$) P.G. 2/m S.G. C2/m Mica type	Biaxial (–) $\alpha = 1.53–1.573$ $\beta = 1.557–1.617$ $\gamma = 1.558–1.618$ $\delta = 0.028–0.045$ $2V = 0–12°$ Dispersion weak	2–2.5	2800	**Habit:** micaceous, scaly, lamellar. **Color:** brown, gray, green, yellow, or reddish brown. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous, pearly. **Cleavage:** (001) perfect. **Fracture:** uneven. **Twinning:** [310]. **Dielectric properties**. Relative permittivity: 6.5 to 8.7, dielectric field strength: 50–150 kV/mm, loss tangent 0.004 to 0.070, electrical resistivity 10^{12} to 10^{15} ohm.m. **Occurrence:** contact and regional metamorphic limestones and dolomites.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Piemontite (syn. piedmontite) [Named from the Piedmont region, Italy] (ICSD 24425 and PDF 29-288)	$Ca_2(Mn,Fe,Al)_2AlO(OH)[SiO_4][Si_2O_7]$ 23.5 wt.% CaO 24.1 wt.% Al2O3 12.6 wt.% Fe2O3 37.9 wt.% SiO2 1.9 wt.% H2O (Sorosilicates and nesosilicates)	Monoclinic a = 895.0 pm b = 570.0 pm c = 941.0 pm 115°70 (Z = 2) Epidote group	Biaxial (–) α = 1.732–1.794 β = 1.750–1.807 γ = 1.762–1.829 δ = 0.025–0.088 $2V$ = 64–85° Dispersion strong	6–6.5 (HV 680)	3450–3520	**Habit:** prismatic according to b, striated, columnar. **Color:** reddish-brown to dark red. **Diaphaneity:** transparent to opaque. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** [001] perfect. **Fracture:** uneven, conchoidal. **Chemical:** insoluble in strong mineral acids, fusible giving a black globule. **Occurrence:** regional metamorphic and pegmatite rocks.
Pirssonite [Named after the American mineralogist, Louis Valentine Pirsson (1860–1919)] (ICSD 9012 and PDF 22-476)	$Na_2Ca(CO_3)_2.2H_2O$ (Nitrates, carbonates, and borates)	Orthorhombic	Biaxial (+) α = 1.5 β = 1.5 γ = 1.57 δ = 0.070 $2V$ = 33° Dispersion weak	3	2350	**Color:** colorless or white. **Diaphaneity:** transparent to translucent. **Occurrence:** continental evaporite deposits under desert climates.
Pitchblende [Named after pitch and blende]	U_3O_8 M = 841.995 84.80 wt.% U 15.20 wt.% O Oxides and hydroxydes	Amorphous	Isotropic R = 16.0%	3–5 (HV 673–803)	8000–9000	**Habit:** amorphous botryoidal mass. **Color:** black. **Luster:** submetallic. Contains up to 20 wt.% PbO from decaying.
Platinum [7440-06-4] [from Spanish, *platina*, silver] (ICSD 64917 and PDF 4-802)	Pt M = 195.08 Coordinence Pt(12) (Native elements)	Cubic a = 392.36 pm A1, *cF4* (Z = 4) P.G. m3m S.G. Fm3m Copper type	Isotropic n_D = 4.28 R = 70%	4–4.5 (HV 125–127)	21,452	**Habit:** granular, nuggets. **Color:** grayish white. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** grayish white. **Cleavage:** none. **Twinning:** {111}. **Fracture:** hackly, malleable, ductile. **Chemical:** inert in most concentrated mineral acids (e.g., HCl, H_2SO_4, HF, HNO_3), but readily dissolved in aqua regia (i.e., 3 vol. HCl + 1 vol. HNO_3). **Occurrence:** mainly in grains and nuggets in alluvial placer deposits.
Plattnerite [Named after the German Professor of metallurgy, Karl Friedrich Plattner (1800–1858)] (ICSD 34234 and PDF 41-1492)	β-PbO_2 M = 239.1988 86.62 wt.% Pb 13.38 wt.% O (Oxides and hydroxides)	Tetragonal a = 495.25 pm c = 338.63 pm C4, *tP6* (Z = 2) P.G. 422 S.G $P4_2/mnm$ Rutile type	Uniaxial (–) ε = 2.25 ω = 2.35 δ = 0.100 R = 16.7–17.1%	5.5	8500-9630 (9563)	**Habit:** prismatic crystals, nodular, botryoidal, massive, encrustations. **Color:** black or grayish black. tarnish on sunlight exposure. **Luster:** submetallic to adamantine. **Diaphaneity:** subtranslucent to opaque. **Streak:** chestnut brown. **Cleavage:** none. **Twinning:** (001). **Fracture:** brittle. **Chemical properties:** easily fusible and decomposed at red-heat into minium (Mn_3O_4). Soluble in hot conc. HCl with chlorine evolution, and slightly soluble in sulfuric and nitric acids with oxygen evolution. Dimorphous with scrutinyite.
Pleonaste (syn. ceylonite, magnesioferrite) (ICSD 49551 and PDF 36-398)	$MgFe_2O_4$ M = 200.00 12.15 wt.% Mg 55.85 wt.% Fe 32.00 wt.% O Coordinence Mg(4), Fe(6) (Oxides and hydroxides)	Cubic a = 836.6 pm $H1_1$, cF56 (Z = 8) P.G. m3m S.G. Fd3m Spinel type (Ferrite series)	Isotropic n_D = 2.38 R = %	6–6.5	4650	**Habit:** massive granular and also as well-formed fine sized crystals. **Color:** brownish black, black. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** dark red. **Fracture:** uneven. **Occurrence:** igneous volcanic rocks, Vesuvius and Stromboli, Italy.

Pollucite [Named after Pollux, a figure from Greek mythology, the twin brother of Castor, in reference to its association with the mineral castor (old name for petalite] (ICSD 39895 and PDF 25-194)	$(Cs,Na)_2Al_2Si_4O_{12}\cdot H_2O$ (Tectosilicates)	Cubic a = 1368.2 pm (Z = 16) P.G. 432 S.G. I a3d	Isotropic n_D = 1.525	6.5	2900	**Habit:** massive. **Color:** colorless, gray, or white. **Diaphaneity:** transparent. **Luster:** vitreous, dull. **Cleavage:** none. **Fracture:** uneven, brittle. **Streak:** white. **Occurrence:** granitic pegmatites
Polybasite [Named from the Greek, *poly*, many and *basis*, base, in allusion to the basic character of the compound]	$(Ag,Cu)_{16}Sb_2S_{11}$ M = 2144.83 11.85 wt.% Cu 60.35 wt.% Ag 11.35 wt.% Sb 16.45 wt.% S (Sulfides and sulfosalts)	Monoclinic a = 2612 pm b = 1508 pm c = 23.89 β = 90° (Z = 16) P.G. 2/m S.G. C 2/m	Biaxial R = 30.8–32.8%	2.5–3	4600–5000	**Habit:** massive, granular, granular, pseudo hexagonal. **Color:** black. **Streak:** reddish black. **Luster:** sub metallic. **Diaphaneity:** opaque. **Cleavage:** [001] poor. **Fracture:** uneven.
Polyhalite [Named from the Greek, *polys*, much and *halos*, salt] (ICSD 6303 and PDF 21-982)	$K_2Ca_2Mg(SO_4)_4{\cdot}2H_2O$ M = 410.81536 19.03 wt.% K 19.51 wt.% Ca 5.92 wt.% Mg 0.98 wt.% H 15.61 wt.% S 38.95 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Triclinic a = 1169 pm b = 1633 pm c = 760 pm α = 91.6° β = 90° γ = 91.9° (Z = 4) P.G. -1 S.G. P1	Biaxial (–) α = 1.546–1.548 β = 1.558–1.562 γ = 1.567 δ = 0.019–0.02 $2V$ = 60–62°	2.5–3.5	2770–2780	**Habit:** massive, lamellar, fibrous. **Color:** white, yellowish white, gray, or flesh pink. **Luster:** vitreous (glassy). **Streak:** white. **Cleavage:** [101] perfect. **Fracture:** conchoidal, brittle. **Occurrence:** sedimentary marine evaporite deposits.
Powellite [7789-82-4] [Named after the American geologist, W. Powell] (ICSD 60552 and PDF 29-351)	$CaMoO_4$ M = 200.02 20.04 wt.% Ca 47.97 wt.% Mo 32.00 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Tetragonal a = 552.60 pm c = 1143.00 pm (Z = 4) Scheelite type	Uniaxial (+) ε = 1.971 ω = 1.980 δ = 0.010	3.8	4350	**Habit:** euhedral crystals. **Color:** yellow or greenish yellow. **Luster:** adamantine, resinous. **Cleavage:** (111) distinct. **Fracture:** conchoidal, brittle. **Streak:** light yellow.
Proustite (syn., ruby silver) [Named after the French chemist, J.L. Proust (1755–1826)] (ICSD 38388 and PDF 42-553)	Ag_3AsS_3 M = 494.72 65.41 wt.% Ag 15.14 wt.% As 19.44 wt.% S (Sulfides and sulfosalts) Coordinence Ag(2), As(3)	Trigonal (Rhombohedral) a = 1081.6 pm c = 869.48 pm (Z = 6) S.G. R3c P.G. 3m	Uniaxial (–) ω = 2.98 ε = 2.71 δ = 0.17 R = 25.0–27.7%	2–2.5 (HV 109–135)	5570	**Habit:** prismatic, rhomboedral crystals. **Color:** ruby red. **Luster:** adamantine. **Diaphaneity:** translucent to opaque. **Streak:** red. **Fracture:** subconchoidal. **Cleavage:** {101}. **Twinning:** {101}, {104}.
Pseudobrookite [1310-39-0] [from the Greek, *pseudo*, mislead and the mineral brookite] (ICSD 69038 and PDF 41-1432)	Fe_2TiO_5 M = 238.41 1.02 wt.% Mg 15.06 wt.% Ti 50.36 wt.% Fe 33.55 wt.% O (Oxides and hydroxides)	Orthorhombic a = 976.7 pm b = 994.7 pm c = 371.7 pm (Z = 4) P.G. 2/m 2/m 2/S.G. Bbmm Pseudobrookite type	Biaxial (+) α = 2.35–2.38 β = 2.36–2.39 γ = 2.38–2.42 δ = 0.0300–0.0400 $2V$ = 62–72° R = 15.6%	6	4406	**Habit:** well formed fine crystals. **Color:** brownish black, reddish brown, black. **Diaphaneity:** opaque. **Luster:** adamantine to submetallic. **Streak:** brown. **Fracture:** uneven. **Occurrence:** recent volcanic igneous rocks. m.p. 1375°C

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Pseudorutile [1310-39-0] [syn., arizonite, leucoxene] (ICSD 4131 and PDF 47-1777)	$Fe_2Ti_3O_9$ $M = 399.33$ 35.97 wt.% Ti 27.97 wt.% Fe 36.06 wt.% O (Oxides and hydroxides)	Hexagonal $a = 1437.5$ pm $c = 461.5$ pm $(Z = 6)$ P.G. 6/m2/m2/m S.G. $P6_322$	Uniaxial (?)	5.5	3800–4010 (4820)	**Habit:** thin irregular plates with fibrous texture, fine grained, massive. **Color:** black, brown, red, gray. **Diaphaneity:** opaque. **Luster:** submetallic. **Streak:** reddish brown. **Fracture:** subconchoidal. **Other properties:** ferromagnetic. **Occurrence:** intermediate product during the weathering of ilmenite, found in ilmenite rich beach mineral sands often called leucoxene.
Psilomelane (syn., Romanechite) [from Greek, *psilos*, smooth, and *melanos*, black, owing to the common smooth surface of the concretions; from Romanèche, Saône-et-Loire, France] (ICSD 202692 and PDF 42-618)	$BaMn^{II}Mn^{IV}_8O_{16}(OH)_4$ $M = 955.74568$ Coordinence Ba(10), Mn(6) (Oxides and hydroxides)	Monoclinic $a = 1392.9$ pm $b = 284.6$ pm $c = 967.8$ pm $\beta = 92.65°$ $(Z = 2)$ P.G. 2/m S.G. C2/m	Biaxial (n.a.) $R = 24.1–28.8\%$	5–6 (HV 503–627)	3950–4710 (4740)	**Habit:** massive, reniform, botryoidal, earthy, fibrous, dendritic. **Color:** dark black to dark steel gray. **Luster:** submetallic to dull. **Diaphaneity:** opaque. **Streak:** brown to black. **Cleavage:** none. **Fracture:** uneven to conchoidal, brittle. **Occurrence:** associated with cryptomelane. **Note:** *wad* is a common name for a low hardness varieties, while *manganomelane* describes high density varieties (i.e., above 3000 kg.m^{-3}).
Pyrargyrite (syn., dark red silver ore, ruby silver ore) [from the Greek, *pyros*, and *argyros*, fire-silver in allusion to color and silver content] (ICSD 38389 and PDF 21-1173)	Ag_3SbS_3 $M = 541.5526$ 59.75 wt.% Ag 22.48 wt.% Sb 17.76 wt.% S Coordinence Ag(2), Sb(3) (Sulfides and sulfosalts)	Trigonal (Rhombohedral) $a = 1105.2$ pm $c = 871.77$ pm $(Z = 6)$ P.G. 3m S.G. R3c	Uniaxial (–) $\varepsilon = 2.881$ $\omega = 3.084$ $\delta = 0.203$ $R = 29.6\%$	2–2.5 (HV 50–97 and 98–126 //)	5850	**Habit:** massive, crystalline, prismatic. **Color:** ruby red. **Luster:** adamantine to submetallic. **Diaphaneity:** translucent to opaque. **Streak:** red purple. **Fracture:** subconchoidal, brittle. **Cleavage:** (101). **Twinning:** {101}, {104}. **Chemical:** readily dissolved by HNO_3 with formation of free S and precipitation of Sb_2O_3. **Occurrence:** epithermal veins with other silver-bearing ores.
Pyrite [12068-85-8] (syn., Fool's gold) [from Greek, *pyros*, fire since it gives off sparks when struck] (ICSD 316 and PDF 42-1340)	FeS_2 $M = 119.979$ 46.55 wt.% Fe 53.45 wt.% S (Sulfides and sulfosalts) Coordinence Fe(6)	Cubic $a = 541.75$ pm C2, cP12 $(Z = 4)$ S.G. Pa3 P.G. 23 Pyrite type	Isotropic $R = 54.5\%$	6–6.5 (HV 1027–1240)	4950–5030 (5012)	**Habit:** faces striated, druse, stalactitic, pyritohedral cubic crystal. **Color:** pale brass yellow. **Luster:** metallic. **Diaphaneity:** opaque. **Fracture:** conchoidal. **Cleavage:** {100} poor, {110} poor. **Twinning:** {110} iron cross. **Streak:** greenish black. Pyroelectric. **Occurrence:** sedimentary, magmatic, metamorphic, and hydrothermal. **Others:** specific heat capacity 62.17 J.K^{-1}mol^{-1}; $a_L = 26$ µm/m.K; bulk modulus K = 149 GPa.
Pyrochlore [from the Greek, *pyros*, fire, and *chloros*, green owing to the green color after pyrolysis] (ICSD 27815 and PDF 17-746)	$(Na,Ca,)_2(U,Th,Ln)(Nb,Ta)_2O_{11}(OH,F)_2.nH_2O$ (Oxides and hydroxides)	Cubic (sometimes metamict or amorphous) $a = 1037$ pm $(Z = 8)$	Isotropic $n_D = 1.90–2.14$ $R = 13.0–13.8\%$	5–5.5 (HV 572–665)	3700–6400	**Habit:** octahedron, granular, disseminated. **Color:** brown, yellowish brown, yellow, greenish brown, or reddish brown. **Diaphaneity:** translucent to opaque. **Luster:** resinous, greasy or glassy. **Streak:** yellowish brown. **Cleavage:** [111]. **Fracture:** uneven to conchoidal. **Chemical:** insoluble in mineral acids. **Other:** Radioactive according to U content. Dielectric constant 3.4 to 5.1. **Occurrence:** in nepheline-syenite igneous rocks.
Pyrolusite (syn., wad, polianite) [from the Greek, *pyros*, fire and *louein*, to wash, because it was used to remove the yellowish color imparted to glass by iron compounds] (ICSD 73716 and PDF 24-735)	MnO_2 $M = 86.93685$ 63.19 wt.% Mn 36.81 wt.% O Traces of rare earths Coordinence Mn(6) (Oxides and hydroxides)	Tetragonal $a = 438.8$ pm $c = 286.5$ pm C4, *tP6* $(Z = 2)$ P.G. 422 S.G. P42/mnm Rutile group	Uniaxial $R = 30.0–41.5\%$	6–6.5 (HV 225–405)	5234	**Habit:** reniform, columnar, fibrous, dendritic, or earthy. **Color:** steel gray, iron gray, or bluish gray. **Diaphaneity:** opaque. **Luster:** metallic. **Cleavage:** [110] perfect. **Fracture:** uneven, brittle. **Chemical:** dissolved by HCl, give a green blue pearl with moltem KOH or NaOH. **Other:** dielectric constant above 81. Electrical resistivity 0.007 to 30 Ω.m. Antiferromagnetic. **Occurrence:** in the oxidation zone of manganese ores with rhodonite. In marine sedimentary rocks such as limestone, hydrothermal.

Pyromorphite (syn., green lead ore, campylite, phosphomimetite) [from the Greek, *pyros*, fire, and *morfe*, form because a molten drop has crystalline forms on solidifying] (ICSD 203075 and PDF 19-701)	$Pb_5(PO_4)_3Cl$ M = 1356.36678 6.85 wt.% P 76.38 wt.% Pb 2.61 wt.% Cl 14.15 wt.% O Traces of Ca, Ba, Sr, V, and F Coordinence Pb(6), P(4) (Phosphates, arsenates, and vanadates)	Hexagonal a = 997 pm c = 733 pm (Z = 2) P.G. 6/m S.G. $P6_3/m$ Apatite type	Uniaxial (–) ε = 2.048 ω = 2.058 δ = 0.010	3.5–4	6850–7000	**Habit:** reniform, prismatic, globular. **Color:** green, yellow, brown, grayish white, or yellowish red. **Diaphaneity:** transparent to translucent. **Luster:** adamantine, resinous. **Streak:** white. **Cleavage:** (1000) perfect, (1011) imperfect. **Fracture:** subconchoidal, brittle. **Chemical:** dissolved by HNO_3. **Fluorescence:** yellow. **Occurrence:** in the weathering zone of lead–zinc ores deposits with anglesite, cerussite, hemimorphite, smithonite, and malachite.
Pyrope (syn., rhodolite) [from the Greek, *pyropos*, fiery-eyed, in allusion to the red hue] (ICSD 71887 and PDF 15-742)	$Mg_3Al_2(SiO_4)_3$ M = 403.12738 18.09 wt.% Mg 13.39 wt.% Al 20.90 wt.% Si 47.63 wt.% O Coordinence Mg(8), Al(6), Si(4) (Nesosilicates)	Cubic a = 1145.9 pm (Z = 8) P.G. 432 S.G. Ia3d (Garnet group: Pyralspite series)	Isotropic n_D = 1.714	6–7.5	3582	**Habit:** dodecahedral, granular, crystalline, lamellar. **Color:** red or black. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Cleavage:** none. **Parting:** {110}. **Fracture:** conchoidal. **Diaphaneity:** transparent to translucent. **Chemical:** soluble in HF. **Occurrence:** ultrabasic igneous rocks.
Pyrophanite [12032-74-5] [from Greek *pyros*, fire and *phanos*, shinning] (ICSD 6006 and PDF 29-902)	$MnTiO_3$ M = 150.803 31.75 wt.% Ti 36.43 wt.% Mn 31.83 wt.% O (Oxides, and hydroxides) Coordinence Mn(6), Ti(6)	Trigonal (Rhombohedral) a = 513.7 pm c = 1428.3 pm (Z = 6) S.G. R3m P.G. 3 Ilmenite type	Uniaxal (–) ω = 2.481 ε = 2.210 δ = 0.2700 Dispersion strong	5	4537 (4596)	**Habit:** thin tabullar rhombohedral crystals, scaly. **Color:** deep blood red, green yellow, dark red. **Diaphaneity:** opaque. **Luster:** vitreous to submetallic. **Streak:** ocher yellow. **Fracture:** subconchoidal. **Cleavage:** [0221]. **Other:** melting point at 1360°C. **Deposits:** metamorphosed manganese deposits, accessory mineral in granite, amphibolite, and serpentinites.
Pyrophyllite (1Tc) [Named after the Greek, *pyros*, fire, and *phyllos*, leaf referring to the effect of heat separating the laminae in foliated varieties] (ICSD 26742 and PDF 12-203)	$Al_2Si_4O_{10}(OH)_2$ M = 360.31 14.98 wt.% Al 31.18 wt.% Si 0.56 wt.% H 53.28 wt.% O Coordinence Al(6), Si(4) (Phyllosilicates, layered)	Triclinic a = 516 pm b = 896 pm c = 935 pm α = 90.03° β = 100.37° γ = 89.75° (Z = 2) P.G. 1 S.G. P1	Biaxial (–) α = 1.534–1.556 β = 1.586–1.589 γ = 1.596–1.601 δ = 0.045–0.062 $2V$ = 52–62° Dispersion weak	1.5–2	2650–2900	**Habit:** platy, foliated. **Color:** white, greenish white, or yellowish white. **Diaphaneity:** translucent to opaque. **Luster:** pearly. **Luminescence:** fluorescent. **Streak:** white. **Cleavage:** [001] perfect. **Fracture:** flexible.
Pyrrhotite (syn., magnetic pyrite) [from the Greek, *pyrrhotes*, redness, in allusion to its color] (ICSD 8064 and PDF 24-220)	$Fe_{1-x}S$ (x = 0–0.17) M = 85.12065 62.33 wt.% Fe 37.67 wt.% S (Sulfides and sulfosalts) Coordinence Fe(6)	Hexagonal a = 345.2 pm c = 576.2 pm (Z = 2) S.G. P-62c P.G. -62m Defect Niccolite type	Uniaxial R = 41.6%	3.5–4.5 (HV 230–318)	4600	**Habit:** tabular, platy, massive, granular. **Color:** bronze yellow or red. **Diaphaneity:** opaque. **Luster:** metallic. **Cleavage:** (0001) imperfect, (1120) poor. **Fracture:** uneven. **Streak:** gray black. Electrical resistivity 2 to 160 μΩ.cm. **Occurrence:** wide spread occurrences in igneous and metamorphic rocks. Magnetic.
Qandilite [12032-52-9] [Named after Qandil rocks intrusion, Qala-Dizeh region, Iraq] (ICSD 65792 and PDF 25-1157)	Mg_2TiO_4 M = 160.474 49.77 wt.% TiO_2 50.23 wt.% MgO (Oxides and hydroxides)	Cubic a = 843.76 pm $H1_1$, cF56 (Z = 8) S.G. Fd3m P.G. 432 Spinel type	Isotrope R = 12.9%	ca. 7	4030–4080 (4040)	**Habit:** small euhedral crystals. **Color:** iron-black; light gray with a pinkish tint in reflected light. **Diaphaneity:** opaque. **Luster:** submetallic to metallic. **Streak:** black. **Fracture:** brittle. **Cleavage:** [111] perfect. **Other:** strongly ferromagnetic like magnetite. Soluble in hot concentrated HCl. **Occurrence:** contact metamorphism with Ti-rich ultramafic intrusion. **Melting point:** 1732°C.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Quartz (High-temperature) [14808-60-7] [from the German, *quarz*, of uncertain origin probably from Saxon word querkluftertz meaning cross-vein ore]	β-SiO_2 $M = 60.0843$ 46.74 wt.% Si 53.26 wt.% O (Tectosilicates, framework) Coordinence Si (4)	Trigonal (Hexagonal) $a = 499.9$ pm $c = 545.7$ pm C8, hP9 ($Z = 3$) S.G. $P6_222$ (Dextrogyre), and $P6_422$ (Levogyre) P.G. 622	Uniaxial (+) $\varepsilon = 1.53$ $\omega = 1.54$ $\delta = 0.007$	7	2530	**Habit:** stubby bipyramidal. **Color:** colorless. **Luster:** vitreous (i.e., glassy). **Luminescence:** triboluminescent. **Streak:** white. **Twinning:** {102}, {302}, {201}, {112}. **Fracture:** conchoidal. **Chemical:** resistant to strong mineral acids, attacked by HF, transition temperature 867°C.
Quartz (Low-temperature) [14808-60-7] (syn., rock crystal, smoky quartz: brown to black, amethyst: purple, citrine: yellow) [from the German, *quarz*, of uncertain origin] (ICSD 174 and PDF 46-1045)	α-SiO_2 $M = 60.0843$ 46.74 wt.% Si 53.26 wt.% O (Tectosilicates, framework) Coordinence Si (4)	Trigonal (Rhombohedral) $a = 491.3$ pm $c = 540.5$ pm ($Z = 3$) S.G. $R3_221$ (Dextrogyre), and $R3_121$ (Levogyre) P.G. 32	Uniaxial (+) $\varepsilon = 1.543–1.545$ $\omega = 1.552–1.554$ $\delta = 0.009$	7	2650	**Habit:** prismatic, massive, crystalline, coarse, druse. **Color:** colorless, yellow, red, or brown. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Luminescence:** triboluminescent. **Streak:** white. **Cleavage:** (0110) indistinct. **Twinning:** {001}. **Fracture:** conchoidal. **Chemical:** resistant to strong mineral acids, attacked by HF. Transition temperature 573°C. **Occurrence:** granitic igneous rocks, metamorphic rocks. **Other:** high-purity and dry synthetic quartz crystals are hard and brittle capable of withstanding high pressure up to 3GPa and 1600K while natural quartz is easily deformed by creep at temperature not exceeding 700K and pressure below 0.2GPa.
Rammelsbergite [Named after the German chemist and mineralogist, Karl F. Rammelsberg (1813–1899)] (ICSD 42571 and PDF 15-441)	$NiAs_2$ $M = 208.53$ 28.14 wt.% Ni 71.86 wt.% As (Sulfides and sulfosalts)	Orthorhombic $a = 475.9$ pm $b = 579.7$ pm $c = 353.9$ pm ($Z = 2$) P.G. 2/m2/m2/m S.G. Pnnm Marcassite group	Biaxial (?) $R = 58.0–60.0\%$	5.5–6 (HV 687–778)	7000–7200 (7090)	**Habit:** rare prismatic crystals. **Color:** tin white to reddish white. **Luster:** metallic. **Diaphaneity:** opaque. **Cleavage:** (101). **Fracture:** uneven. **Streak:** grayish black. **Occurrence:** in Ni-Co-Ag-bearing vein deposits.
Ramsdellite [Named after the American mineralogist, Lewis Stephen Ramsdell (1895–1975) who first described the mineral] (ICSD 78331 and PDF 44-142)	MnO_2 $M = 86.93685$ 63.19 wt.% Mn 36.81 wt.% O (Oxides, and hydroxides)	Orthorhombic	Biaxial	3	4370	**Habit:** massive, fibrous, platy. **Color:** steel gray or black. **Diaphaneity:** opaque. **Luster:** metallic. **Fracture:** brittle. **Streak:** brownish black. **Occurrence:** manganese deposits with pyrolucite.
Realgar [Named from the Arabic, *rahj al ghar*, powder of the mine] (ICSD 15238 and PDF 41-1494)	AsS (= As_4S_4) $M = 106.9876$ 70.03 wt.% As 29.97 wt.% S (Sulfides and sulfosalts) Coordinence AsS molecules	Monoclinic $a = 929$ pm $b = 1353$ pm $c = 657$ pm $\beta = 106.55°$ Bl, mP32 ($Z = 16$) S.G. P21/c P.G. 2/m Realgar type	Biaxial (–) $\alpha = 2.538$ $\beta = 2.684$ $\gamma = 2.704$ $\delta = 0.166$ $2V = 40°$ Dispersion strong $R = 18.5\%$	1.5–2 (HV 47–60)	3560	**Habit:** prismatic, massive, granular, druse, earthy. **Color:** aurora red, orange yellow, or dark red. **Diaphaneity:** translucent to opaque. **Luster:** resinous, glassy, adamantine. **Streak:** orange red. **Cleavage:** [010], [001], and [100]. **Twinning:** (100). **Fracture:** brittle, sectile. **Chemical:** dissolved by HNO_3, evolved a garlic odor when calcinated and gives sublimated As_2O_3 deposit on cold wall. Electrical resistivity 1 to 150 mΩ.m. **Occurrence:** hydrothermal with orpiment. Marcasite, and stibine. Sedimentary rocks.
Rhodochrosite (syn., ponite: rich Fe varieties) [from Greek, *rhodos*, pink]	$MnCO_3$ $M = 114.946949$ 47.79 wt.% Mn	Trigonal $a = 477.1$ pm $c = 1566.4$ pm ($Z = 6$)	Uniaxial (–) $\varepsilon = 1.540–1.617$ $\omega = 1.750–1.850$	3.5–4	3200–4050	**Habit:** massive. **Color:** rose-pink, pink, red, brown or brownish yellow, colorless. **Luster:** pearly, vitreous. **Diaphaneity:** transparent to translucent. **Cleavage:** (1011) perfect. **Twinning:** (0112). **Fracture:** uneven. **Chemical:** dissolved with effervescence in warm

(ICSD 100677 and PDF 44-1472)	52.21 wt.% CO_2 Coordinence Mn(6), C(3) (Nitrates, carbonates, and borates)	P.G. 32/m S.G. R3c Calcite type	δ= 0.190–0.230 Dispersion strong			dilute acids. On exposure to air develop a brown or black surface alteration layer. **Deposits:** high-temperature metasomatic deposits.
Rhodonite [Named after the Greek, *rhodos*, pink alluding to its color] (ICSD 200452 and PDF 13-138)	$Mn[SiO_3]$ M = 131.0218 41.96 wt.% Mn 21.37 wt.% Si 36.67 wt.% O Coordinence Mn(6), Ca(6), Si(4) (Inosilicates, chain) Traces of Fe and Ca	Triclinic a = 768 pm b = 1182 pm c = 671 pm α= 92.35° β= 93.95° γ= 105.67°, (Z = 2) P.G. 1, S.G. P1 Pyroxenoid group	Biaxial (+) α= 1.717 β= 1.720 γ= 1.730 δ= 0.013 2V = 63–76° Dispersion weak	4.5–5	3500–3700	**Habit:** tabular, massive. **Color:** pink, red. **Luster:** vitreous. **Diaphaneity:** transparent to translucent. **Streak:** white. **Fracture:** conchoidal. **Cleavage:** (110) perfect, (001) distinct. **Twinning:** {010}.
Riebeckite (syn., glaucophane, crocidolite for the asbestos form) [Named after the German traveler, E. Riebeck while crocidolite is named after the Greek, *krokidos*, the nap on cloth and *lithos*, stone] (ICSD 38218 and PDF 19-1061)	$Na_2Fe_3Fe_2Si_8O_{22}(OH)_2$ M = 935.90 4.91 wt.% Na 29.84 wt.% Fe 24.01 wt.% Si 0.22 wt.% H 41.03 wt.% O Inosilicates (double chains)	Monoclinic a = 953.1 pm b = 1775.9 pm c = 530.3 pm β= 103.59° S.G. C2/m (Z = 2)	Biaxial (–) α= 1.68–1.698 β= 1.683–1.700 γ= 1.685–1.706 δ= 0.005–0.008 2V = 68–85° Dispersion strong	4	3020–3420 (3130)	**Habit:** gray to lavender blue crystals, striated, fibrous, massive. **Color:** blue, black, or dark green. **Diaphaneity:** translucent to opaque. **Luster:** vitreous, silky. **Cleavage:** (110) perfect. **Streak:** greenish brown. **Occurrence:** magmatic and metamorphic rocks.
Ringwoodite [Named after the Austalian petrologist Alfred Edward Ringwood (1930–1993)] (ICSD 27531 and PDF 21-1258)	Mg_2SiO_4 M = 140.69 34.55 wt.% Mg 19.96 wt.% Si 45.49 wt.% O (Nesosilicates)	Cubic a = 812.2 pm (Z = 4) P.G. 432 S.G. Fd3m Spinel group	Isotropic n_D = 1.768	n.a.	3900 (3900)	**Habit:** anhedral microscopic grains. **Color:** purple to bluish gray. **Luster:** vitreous. **Diaphaneity:** translucent. **Cleavage:** unknown. **Fracture:** brittle, uneven. **Streak:** white. **Occurrence:** chondrite meteorite.
Rosenbuschite [Named after the German mineralogist and geologist K.h.F. Rosenbuch (1836–1914)] (ICSD 22334 and PDF 14-447)	$(Ca,Na,Mn)_3(Zr,Ti,Fe)[SiO_4]_2(F,OH)$ (Nesosilicates)	Triclinic a = 1012.6 pm b = 1137.7 pm c = 735.8 pm α= 91.3° β= 101.15° γ= 112.02 (Z = 4)	Biaxial (+) α= 1.678–1.680 β= 1.687–1.688 γ= 1.705–1.708 δ= 0.027–0.028 2V = 68–78°	5–6	3310–3380	**Habit:** acicular to prismatic crystals. **Color:** pale yellow to orange. **Luster:** vitreous. **Diaphaneity:** translucent. **Cleavage:** (010). **Fracture:** brittle, uneven. **Streak:** white. Gelatinizes in HCl. **Occurrence:** nepheline syenite.
Rutile [13463-67-7] [Named from the Latin, *rutilus*, meaning reddish] (ICSD 62677 and PDF 16-934)	TiO_2 M = 79.8788 59.94 wt.% Ti 40.06 wt.% O Coordinence Ti(6) (Oxides and hydroxides)	Tetragonal a = 459.37 pm c = 296.18 pm C4, *tP6* (Z = 2) P.G. 422 S.G. P4/mnm Rutile type Packing fraction = 70%	Uniaxial (+) ε = 2.605–2.613 ω= 2.899–2.901 δ= 0.286–0.296 Dispersion strong R = 20.2%	6–6.5 (HV 1074–1210)	4230–4250 (4245)	**Habit:** acicular, prismatic, massive. **Color:** reddish brown, yellowish brown, black or bluish violet, inclusion in quartz. **Diaphaneity:** transparent, translucent, opaque. **Luster:** adamantine. **Streak:** grayish black. **Fracture:** uneven. **Cleavage:** {111}. **Twinning:** {101}, {301}. **Chemical:** insoluble in water, slightly soluble in HCl, HNO_3, sol. HF and in hot H_2SO_4 or $KHSO_4$. Attacked by molten Na_2CO_3. **Other properties:** Melting point of 1847°C. Electrical resistivity ranging from 29 to 910 Ω.m. $Cp = 50\ J.K^{-1}mol^{-1}$. Slightly paramagnetic with a specific magnetic susceptibility of $+74 \times 10^{-9}\ m^3.kg^{-1}$. Dielectric constant of 110–117.
Sanidine (syn., anorthoclase) [from the Greek, *sanis*, little plate, and *idos*, to see in reference to its tabular habit] (ICSD 39747 and PDF 25-618)	$(K,Na)(Si,Al)_4O_8$ Coordinence K(10), Si(4), Al(4) (Tectosilicates, framework)	Monoclinic a = 856. 2 pm b = 1303.6 pm c = 719.3 pm β= 116.58° (Z = 4) P.G. 2/m S.G. C2/m	Biaxial (–) α= 1.518–1.527 β= 1.522–1.532 γ= 1.525–1.534 δ= 0.006–0.007 2V = 80–85°	6	2560	**Habit:** blocky, prismatic, massive, granular. **Color:** colorless, white, gray, yellowish white, or reddish white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous, pearly. **Cleavage:** [001] perfect, [010] good. **Twinning:** Carlsbad [001]. **Fracture:** uneven. **Streak:** white. **Occurrence:** acid volcanic igneous rocks.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Sapphirine [Named after its blue color] (ICSD 100297 and PDF 44-1430)	$(Mg,Fe)_2Al_2O_6[SiO_4]$ $M = 683.33$ 21.34 wt.% Mg 25.67 wt.% Al 6.17 wt.% Si 46.83 wt.% O (Nesosilicates)	Monoclinic $a = 996$ pm $b = 2860$ pm $c = 985$ pm 110.5° ($Z = 8$)	Biaxial (–) $\alpha = 1.701–1.725$ $\beta = 1.703–1.728$ $\gamma = 1.705–1.732$ $\delta = 0.005–0.007$ $2V = 50–114°$ O.A.P. (010)	7.5	3400–3580	**Habit:** granular or tabular crystals. **Color:** light to medium blue. **Luster:** vitreous. **Diaphaneity:** transparent to translucent. **Cleavage:** (010). **Fracture:** brittle, uneven. **Streak:** pale blue. Insoluble in conentrated mineral acids but dissolves readily in molten sodium carbonate or $KHSO_4$. **Occurrence:** magnesium- and aluminum-rich metamorphic rocks.
Scheelite [7790-75-2] [Named after the Swedish chemist, K.W. Scheele] (ICSD 60547 and PDF 41-1431)	$CaWO_4$ $M = 287.9256$ 13.92 wt.% Ca 63.85 wt.% W 22.23 wt.% O Coordinence Ca(4),W(4) (Sulfates, chromates, molybdates, and tungstates)	Tetragonal $a = 524.2$ pm $c = 1137.20$ pm ($Z = 4$) P.G. 4/m S.G. I4$_1$/a Scheelite type	Uniaxial (+) $\varepsilon = 1.918–1.920$ $\omega = 1.934–1.937$ $\delta = 0.016–0.017$ $R = 10.0\%$	4.5–5 (HV 285–429)	6060–6110	**Habit:** massive, granular, disseminated, tabular, columnar, bypiramidal or pseudo-octaedrons. **Color:** colorless, white, pale yellow, greenish, brownish yellow, or reddish yellow. **Luster:** vitreous (i.e., glassy), greasy or subadamantine. **Diaphaneity:** transparent to translucent. **Luminescence:** fluorescent under short UV light, bright bluish white, sometimes pale yellow (traces of Mo). **Streak:** white. **Cleavage:** (101) distinct, (112) poor. **Twinning:** {110}. **Fracture:** uneven, brittle. **Chemical:** soluble in HCl or HNO_3 giving a yellow solid residue of WO_3 soluble in NH_4OH. The soln. in HCl gives a deep blue color when a crystal of pure Sn, or Zn is added. **Other:** dielectric constant 3.5 to 5.75. **Melting point:** 1620°C. **Occurrence:** high-temperature quartz veins, in metamorphism contact halo of intrusive granitic ingneous rocks, in detritic sedimendary rocks near granites.
Schorl [Named from the German word *Schörl* for tourmaline] (ICSD 74180 and PDF 43-1464)	$NaFe_3Al_6(OH)_4B_3O_9[Si_6O_{18}]$ Coordinence Na(6), Fe(6), Al(6), B(3), Si(4) (Cyclosilicates, ring)	Trigonal $a = 1646$ pm $c = 715$ pm ($Z = 3$) P.G. 3m S.G. R3m Tourmaline group	Uniaxial (–) $\varepsilon = 1.668$ $\omega = 1.639$ $\delta = 0.029$	7–7.5	3270	**Habit:** prismatic. **Color:** white. **Luster:** resinous. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (101) poor, {110} poor. **Twinning:** {101}. **Fracture:** subconchoidal.
Schreyerite [60430-06-0] [Named after German mineralogist Werner Schreyer]	$V_2Ti_3O_9$ $M = 389.4786$ 26.16 wt.% V 36.87 wt.% Ti 36.97 wt.% O Coordinence Ti(6) (Oxides, and hydroxides)	Monoclinic $a = 706$ pm $b = 501$ pm $c = 1874$ pm $\beta = 119.4°$ ($Z = 6$)	Biaxial (?) $n_D = 2.7$	HV 1150	4480	**Habit:** tiny crystals with lamellar twinning embedded in rutile crystals. **Color:** black. **Luster:** vitreous to resinous. Insoluble in acids. **Melting point:** 1740°C. **Occurrence:** in vanadium-rich gneisses associated with kyanite and rutile.
Scorodite [10102-49-5] [Named from the Greek, *skorodon*, garlic, alluding to the arsenic odor when heated] (ICSD 627 and PDF 37-468)	$Fe(AsO_4).2H_2O$ $M = 230.795$ 20.92 wt.% Fe 28.08 wt.% As 47.97 wt.% O 3.03 wt.% H Coordinence Fe(6), As(4) (Phosphates, arsenates, and vanadates)	Orthorhombic $a = 1043$ pm $b = 896$ pm $c = 1015$ pm ($Z = 8$) P.G. mmm S.G. P2$_1$/cab Scorodite type	Biaxial(+) $\alpha = 1.784$ $\beta = 1.796$ $\gamma = 1.814$ $\delta = 0.030$ $2V = 54°$	3–4	3200	**Habit:** prismatic, dipyramidal. **Color:** green, brown. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** resinous. **Fracture:** uneven. **Cleavage:** (120) good, (100) perfect, (010) poor.
Scrutinyite [Named after the close examination	α-PbO_2 $M = 239.1988$	Orthorhombic $a = 497.1$ pm	Biaxial (?) $R = 17.9–18.8\%$	n.a.	(9867)	**Habit:** platty crystals. **Color:** dark reddish brown. **Luster:** submetallic. **Diaphaneity:** translucent in thin flakes to opaque. **Streak:** dark brown.

required clearly to indentify the mineral] (ICSD 20362 and PDF 45-1416)	86.62 wt.% Pb 13.38 wt.% O (Oxides and hydroxides)	b = 595.6 pm c = 543.8 pm oP12 (Z = 4) P.G. 222 S.G. Pbcn				**Cleavage:** (100) perfect; (010) imperfect. **Fracture:** brittle. **Chemical properties:** easily fusible and decomposed at red-heat into minium (Mn_3O_4). Soluble in hot conc. HCl with chlorine evolution, and slightly soluble in sulfuric and nitric acids with oxygen evolution. Dimporphous with plattnerite.
Senarmontite [Named after the French mineralogist, H.H. de Senarmont (1808–1862)] (ICSD 1944 and PDF 43-1071)	Sb_2O_3 M = 275.4988 88.39 wt.% Sb 11.61 wt.% O (Oxides and hydroxides)	Cubic a = 1114 pm (Z = 16) P.G. 432 S.G. Fd3m	Isotropic n_D = 2.087	2	5200–5300	**Habit:** euhedral crystals, massive-granular, encrustations. **Color:** white, colorless, or gray. **Luster:** adamantine. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (111) imperfect. **Fracture:** uneven. **Occurrence:** oxidation of stibnite and other antimony minerals.
Shortite [Named after the American mineralogist, Maxwell Naylor Short (1889–1952)] (ICSD 16495 and PDF 21-1348)	$Na_2Ca_2(CO_3)_3$ M = 306.16 15.02 wt.% Na 26.18 wt.% Ca 11.77 wt.% C 47.03 wt.% O (Nitrates, carbonates, and borates)	Orthorhombic a = 496.1 pm b = 1103 pm c = 712 pm (Z = 2) P.G.mm2 S.G.Amm2	Biaxial α = 1.531 β = 1.555 γ = 1.570 $2V$ = 75°	3	2600 (2610)	**Habit:** wedge-shaped, equant, or short prismatic crystals. **Color:** colorless to pale yellow. **Diaphaneity:** transparent. **Luster:** vitreous. **Streak:** n.a. **Cleavage:** (010). **Fracture:** conchoidal. Decomposes in water releasing an insoluble residue of calcium carbonate. Fluorescent under UV radiation. **Occurrence:** with calcite and pyrite.
Siderite (Siderose) [Named from Greek, *sideros*, iron] (ICSD 100678 and PDF 29-696)	$FeCO_3$ M = 115.8539 62.1 wt.% FeO 37.9 wt.% CO_2 Coordinence Fe(6), C(3) (Nitrates, carbonates, and borates)	Trigonal (Rhombohedral) a = 468.87 pm c = 1537.3 pm (Z = 6) P.G. 32/m S.G. R3c Calcite type	Uniaxial (–) ε = 1.575–1.637 ω = 1.782–1.875 δ = 0.207–0.242 Dispersion strong	4.5–5	3500–3960	**Habit:** rhombohedral, crystalline, coarse, stalactitic, massive. **Color:** yellow brown. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent, translucent, to opaque. **Streak:** white. **Cleavage:** (1014) perfect. **Twinning:** {0118}. **Fracture:** brittle, subconchoidal. **Chemical:** readily dissolved in diluted acids with evolution of carbon dioxide; natural siderite when heated in air above 425°C is subject to thermal decomposition the final product is hematite while magnetite and maghemite form as intermediate decomposition products. **Occurrence:** sedimentary rocks.
Sillimanite (syn., fibrolite, viridine: green, fibrolite: acicular) [Named after the American chemist and mineralogist, Benjamin Silliman (1779–1864)] (ICSD 100450 and PDF 38-471)	$Al_2O[SiO_4] = Al_2SiO_5$ M = 162.04558 33.30 wt.% Al 17.33 wt.% Si 49.37 wt.% O Coordinence Al(6), Si(4), Al(4) Traces of Fe, Mn (Nesosubsilicates)	Orthorhombic a = 748.43 pm b = 767.30 pm c = 577.11 pm (Z = 4) P.G. mmm S.G. Pbmn	Biaxial (+) α = 1.653–1.661 β = 1.658–1.662 γ = 1.673–1.684 δ = 0.020–0.023 $2V$ = 21–30° O.A.P. (010) Dispersion strong	6.5–7.5	3240	**Habit:** fibrous, prismatic, acicular. **Color:** colorless, white, yellowish or green. **Fracture:** splintery, brittle. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Cleavage:** (010) perfect. **Streak:** white. **Fluorescence:** white-bluish. **Cleavage:** (010) perfect. **Chemical:** insoluble in strong mineral acids, decomposed by molten Na_2CO_3. When heated in an aqueous solution of $Co(NO_3)_2$ gives a blue color (Thénard blue). **Other properties:** Unfusible and the most stable of the three aluminum silicates but when heated above 1600°C transforms to a mixture of silica and mullite ($Al_6Si_2O_{13}$). Dielectric constant of 9.29. Diamagnetic with a specific magnetic susceptibility of -10^{-10} $m^3.kg^{-1}$. **Occurrence:** Metamorphosed peri-aluminous sedimentary rocks. Gneiss and shales.
Silver [7440-22-4] (syn., argentum) (ICSD 64994 and PDF 4-783)	Ag M = 107.8682 Coordinence Ag(12) (Native elements)	Cubic a = 408.56 pm A1, *cF4* (Z = 4) P.G. m3m S.G. Fm3m Copper type	Isotropic n_D = 0.181 R = 95%	2.5–3 (HV 48–63)	10,506	**Habit:** octahedral, dendritic. **Color:** silver white. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** gray. **Cleavage:** none. **Twinning:** {111}. **Fracture:** hackly, malleable, ductile. **Chemical:** readily dissloved in nitric acid, HNO_3.
Sinhalite [Named after the Sanskrit, *Sinhala*, for Sri Lanka] (ICSD 75942 and PDF 25-1379)	$MgAlBO_4$ M = 126.095138 19.28 wt.% Mg 21.40 wt.% Al 8.57 wt.% B 50.75 wt.% O Coordinence Mg(6), Al(6), B(4) (Nitrates, carbonates and borates)	Orthorhombic a = 432.8 pm b = 987.8 pm c = 567.5 pm (Z = 4) P.G. mmm S.G. $P2_1/mcn$ Olivine type	Biaxial (+) α = 1.670 β = 1.700 γ = 1.710 δ = 0.04 $2V$ = 55°	6.5–7	3420	**Habit:** prismatic. **Color:** white, yellow. **Diaphaneity:** transparent to translucent. **Luster:** vitreous. **Streak:** green blue. **Cleavage:** good (010). **Fracture:** conchoidal.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Skutterudite [Named after the Norvegian locality, Skutterud] (ICSD 9188 and PDF 10-328)	$(Co,Ni)As_3$ $M = 246.18$ 17.95 wt.% Co 5.96 wt.% Ni 76.09 wt.% As (Sulfides and sulfosalts) Coordinence Co(6), Ni(6)	Cubic $a = 820$ pm D02, cI32 ($Z = 8$) S.G. Im-3 P.G. m-3 CoAs3 type	Isotropic $R = 55.8\%$	5.5–6 (HV 589–724)	6100–6800	**Habit:** skeletal, cubic crystals. **Color:** tin white. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** black. **Fracture:** uneven. **Cleavage:** {100}, {111}. **Twinning:** {112}. Electrical resistivity 5 to 400 μΩ.cm.
Smithsonite [3486-35-9] (syn., galmei, calamine, zinc spar) [Named after the English mineralogist, J. Smithson] (ICSD 100679 and PDF 8-449)	$ZnCO_3$ $M = 125.3992$ 52.15 wt.% Zn 9.58 wt.% C 38.28 wt.% O Coordinence Zn(6), C(3) (Nitrates, carbonates, and borates)	Trigonal (Rhombohedral) $a = 465.28$ pm $c = 1502.8$ pm ($Z = 6$) P.G. -32/m S.G. R-3c Calcite type	Uniaxial (–) $\varepsilon = 1.625$ $\omega = 1.848$ $\delta = 0.225$	4.5	4450	**Habit:** massive, botryoidal, reniform, earthy. **Color:** grayish white, dark gray, green, blue, or yellow. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy), pearly. **Streak:** white. **Cleavage:** (1011) perfect. **Fracture:** subconchoidal, brittle. **Chemical:** readily attacked by strong mineral acids with evolution of carbon dioxide.
Sodalite [from its chemical composition, Latin *solidus*, solid since it was a solid used in glassmaking] (ICSD 36050 and PDF 37-476)	$Na_4[Al_3Si_3O_{12}]Cl$ $M = 933.75868$ 19.70 wt.% Na 17.34 wt.% Al 18.05 wt.% Si 3.80 wt.% Cl 41.12 wt.% O Coordinence Na(7), Si(4), Al(4) Traces of K and Ca (Tectosilicates, framework)	Cubic $a = 891$ pm ($Z = 1$) P.G. 43m S.G. P43m (Sodalite type)	Isotropic $n_D = 1.483–1.487$	5.5–6	2270–2330	**Habit:** massive, granular, disseminated. **Color:** azure blue, white, yellow, pale pink, colorless, gray, or green. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy), greasy. **Streak:** white. **Cleavage:** (110) good. **Twinning:** {111}. **Fracture:** conchoidal. **Occurrence:** volcanic tuffs and volcano-clastic sediments.
Sperylite [Named after the American chemist, Francis L. Sperry (1861–1906)] (ICSD 38428 and PDF 42-1341)	$PtAs_2$ $M = 344.92$ 43.44 wt.% As 56.56 wt.% Pt (Sulfides and sulfosalts)	Cubic $a = 597$ pm ($Z = 4$) P.G. 432 S.G. Pa3 Pyrite group	Isotropic $R = 22.8\%$	6.5 (HV 960–1277	10,600 (10,780)	**Habit:** cubic to cuboctahedral crystals. **Color:** tin white. **Luster:** metallic. **Diaphaneity:** opaque. **Cleavage:** (100) indistinct. **Fracture:** brittle, conchoidal. **Streak:** black. **Occurrence:** epithermal sulfide vein deposits.
Spessartine (syn., spessartite) [Named after the locality, Spessart, northwestern Bavaria, Germany] (ICSD 27365 and PDF 47-1815)	$Mn_3Al_2(SiO_4)_3$ $M = 495.02653$ 33.29 wt.% Mn 10.90 wt.% Al 17.02 wt.% Si 38.78 wt.% O Coordinence Mn(8), Al(6), Si(4) (Nesosilicates)	Cubic $a = 1162$ pm ($Z = 8$) P.G. 432 S.G. Ia3d Garnet group (Pyralspite series)	Isotropic $n_D = 1.805$	6.5–7.5	4180	**Habit:** massive, crystalline, lamellar. **Color:** red or brownish red. **Diaphaneity:** transparent to translucent. **Luster:** vitreous, resinous. **Streak:** white. **Parting:** {110}. **Fracture:** Subconchoidal. **Occurrence:** magmatic, metamorphic, and pegmatitic rocks.
Sphalerite [1314-98-3] (syn., zinc blende, mock, lead ore, black Jack, False Galena)	ZnS $M = 97.456$ 67.10 wt.% Zn 32.90 wt.% S	Cubic $a = 540.93$ pm B3, cF8 ($Z = 4$)	Isotropic $n_D = 2.369$ $R = 17.5\%$	3.5–4 (HV 186–209)	4089	**Habit:** tetrahedral crystals, granular, colloform. **Color:** brown, yellow, orange, red, green, or black. **Luster:** resinous, metallic, greasy. **Diaphaneity:** transparent to opaque. **Luminescence:** fluorescent and triboluminescent. **Streak:** brownish white. **Cleavage:** {110}. **Fracture:** uneven, conchoidal. **Twinning:** {111}. **Chemical:** attacked by strong mineral

[from the Greek, *sphaleros*, misleading since it was often mistaken for galena but yielded no lead] (ICSD 60378 and PDF 5-566)	Traces Fe, (Sulfides and sulfosalts) Coordinence Zn(4)	S.G. F-43m P.G. -43m Blende type				acids, HCl, or HNO_3 with evolution of H_2S and yellow precipitate of sulfur. Infusible. Electrical resistivity 2.7 mΩ.m. **Occurrence:** veins in igneous, sedimentary and metamorphic rocks.
Spinel (syn., ruby spinal, Balas ruby, red rubicelle) [from Latin, *spina*, thorn, in allusion to sharply-pointed crystals] (ICSD 79000 and PDF 21-1152)	$MgAl_2O_4$ $M = 142.26568$ 17.08 wt.% Mg 37.93 wt.% Al 44.98 wt.% O Coordinence Mg(4), Al(6) (Oxides and hydroxides)	Cubic $a = 808.0$ pm H1$_1$, *cF56* ($Z = 8$) P.G. m3m S.G. Fd3m Spinel type	Isotropic $n_D = 1.719$	7.5–8	3583	**Habit:** euhedral crystals, massive, granular. **Color:** colorless, red, blue, green, or brown. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent, translucent, opaque. **Streak:** grayish white. **Cleavage:** {111} poor. **Twinning:** {111}. **Fracture:** conchoidal or uneven.
Spodumene (syn., pink: kunzite, hiddenite) [Named from the Greek *spodoun*, to reduce to ashes refers either to its ash-gray color or the ash-colored mass formed when heated before the blowpipe] (ICSD 30521 and PDF 33-786)	$LiAl[Si_2O_6]$ $M = 186.09$ 3.73 wt.% Li 14.50 wt.% Al 30.18 wt.% Si 51.59 wt.% O Coordinence Li(6), Al(6), and Si(4) (Inosilicates, chains)	Monoclinic $a = 952$ pm $b = 832$ pm $c = 525$ pm 110.46° ($Z = 4$) P.G. 2/m S.G. C2/m	Biaxial (+) $\alpha = 1.650$ $\beta = 1.660$ $\gamma = 1.670$ $\delta = 0.02$ $2V = 60–80°$ Dispersion weak	6.5–7	3150	**Habit:** euhedral prismatic or long tabular crystals. **Color:** colorless to pink. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent, translucent. **Streak:** white. **Cleavage:** {110} perfect. **Twinning:** {100}. **Fracture:** uneven. **Chemical:** insoluble in strong mineral acids. Nevertheless when alpha-spodumene is heated above 1082°C it transforms irreversibly into beta spodumene which is , accompanied by a 30% volume increase and subsequent decrease in the specific gravity from 3.2 to 2.4 in addition beta-spodumene has a very low coefficient of thermal expansion of about 1×10^{-6} K^{-1} for the range 25°C to 1000°C and is readily attacked by hot concentrated H_2SO_4. **Others.** Bond's work index of 21 kWh/tonne and Pennsylvania abrasive index of 0.416. **Occurrence:** granitic pegmatites.
Spurrite [Named after the American Geologist, Josiah Edward Spurr (1870–1950)] (ICSD 25830 and PDF 13-496)	$2Ca_2[SiO_4].CaCO_3$ $M = 444.57$ 45.08 wt.% Ca 12.64 wt.% Si 2.70 wt.% C 39.59 wt.% O	Monoclinic $a = 1049$ pm $b = 671$ pm $c = 1415$ pm $\beta = 101.317°$ ($Z = 4$) P.G. 2/m S.G. P2$_1$a	Biaxial (–) $\alpha = 1.637–1.641$ $\beta = 1.672–1.676$ $\gamma = 1.676–1.681$ $\delta = 0.039–0.040$ $2V = 35–41°$	5	3010	**Habit:** granular masses. **Color:** white, pale blue to yellow. **Diaphaneity:** translucent. **Luster:** vitreous. **Streak:** white. **Cleavage:** (001). **Fracture:** uneven. Effervesce with dilute HCl. **Occurrence:** high-temperature contact metamorphism.
Stannite (syn., tin pyrites, Bell metal ore) [Named from the Latin, *stannum*, tin] (ICSD 200420 and PDF 44-1476)	Cu_2FeSnS_4 $M = 429.913$ 12.99 wt.% Fe 29.56 wt.% Cu 27.61 wt.% Sn 29.83 wt.% S (Sulfides and sulfosalts)	Tetragonal $a = 546$ pm $c = 1072$ pm H26, tI16 ($Z = 2$) S.G. I42m	Uniaxial $R = 28\%$	3.5–4 (HV 197–221)	4400	**Habit:** massive, euhedral crystals. **Color:** steel gray or olive green. **Diaphaneity:** opaque. **Luster:** metallic. **Cleavage:** [110] poor. **Fracture:** uneven. **Streak:** black. Electrical resistivity 1.2 to 570 mΩ.m.
Staurolite (syn., staurotide) [from the Greek, *stauros*, cross, and *lithos*, stone, in allusion to the common cross shaped twins of the crystals] (ICSD 67446 and PDF 41-1484)	$(Fe,Mg,Zn)_2(Al,Fe)_9(Si,Al)_4O_{22}(OH)_2$ 27–29 wt.% SiO_2 53–54 wt.% Al_2O_3 1–3 wt.% Fe_2O_3 11–12 wt.% FeO 2–3 wt.% MgO Coordinence Al(6), Si(4), Fe(4) (Nesosubsilicates)	Monoclinic (pseudo-orthorhombic) $a = 790$ pm $b = 1665$ pm $c = 563$ pm 90.0° ($Z = 2$) P.G. 2/m S.G. C2/m	Biaxial (+) $\alpha = 1.739–1.747$ $\beta = 1.745–1.753$ $\gamma = 1.752–1.761$ $\delta = 0.012–0.014$ $2V = 82–90°$ O.A.P. (100) Dispersion weak	7–7.5	3740–3830	**Habit:** tabular, prismatic. **Color:** reddish brown, brownish black, or yellowish brown. **Diaphaneity:** translucent to opaque. **Luster:** vitreous (i.e., glassy), dull. **Streak:** gray. **Twinning:** common in cross. **Cleavage:** (001) distinct. **Twinning:** {031}, and {231}. **Fracture:** Subconchoidal. **Chemical:** attacked by hot conc. H_2SO_4. Unfusible. **Other properties:** dielectric constant of 6.80. Diagnetic with a specific magnetic susceptibility of $+10^{-6}$ $m^3.kg^{-1}$. **Occurrence:** metamorphosed aluminous sedimentary rocks.
Stephanite (syn., Brittle Silver Ore) [Named after the Austrian engineer, A. Stephan] (ICSD 16987 and PDF 11-108)	Ag_5SbS_4 $M = 789.355$ 68.33 wt.% Ag 15.42 wt.% Sb 16.25 wt.% S (Sulfides and sulfosalts)	Orthorhombic P.G. mm2	Biaxial	2–2.5	6250	**Habit:** pseudo hexagonal, tabular, massive. **Color:** iron black. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** black. **Fracture:** subconchoidal. **Cleavage:** [010] imperfect, [021] poor.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Stibnite (syn., antimonite, antimony glance, gray antimony, Stibium) [from the Greek, *stimmi* or *stibi*, antimony, hence to the Latin, *stibium*] (ICSD 15236 and PDF 42-1393)	Sb_2S_3 $M = 339.698$ 71.68 wt.% Sb 28.32 wt.% S (Sulfides and sulfosalts) Coordinence Sb(7)	Orthorhombic $a = 1122.9$ pm $b = 1131.0$ pm $c = 383.89$ pm $D5_{13}$, oP20 ($Z = 4$) S.G. Pccn P.G. 222 Stibnite type	Biaxial (?) $\alpha = 3.194$ $\beta = 4.046$ $\gamma = 4.303$ $\delta = 1.110$ $2V = 26°$ $R = 30.2–40.0\%$	2 (HV 42–109)	4630	**Habit:** prismatic, faces striated, granular. **Color:** lead gray, bluish lead gray, steel gray, or black. **Diaphaneity:** opaque. **Luster:** Metallic. **Streak:** blackish gray. **Cleavage:** [010] perfect. **Fracture:** subconchoidal.
Stilbite (ICSD 63232 and PDF 44-1479)	$(Ca,Na)Si_7Al_2O_{18}.7H_2O$ Coordinence Ca(6), Na(6), Si(4), and Al(4). (Tectosilicates, framework)	Monoclinic $a = 1364$ pm $b = 1824$ pm $c = 1127$ pm 129.16° ($Z = 4$) P.G.: 2/m S.G. C2/m	Biaxial (–) $\alpha = 1.490$ $\beta = 1.500$ $\gamma = 1.500$ $\delta = 0.010$ $2V = 30–50°$	3.5–4	2150	**Habit:** prismatic, striated, curved crystals. **Color:** gray. **Diaphaneity:** translucent to transparent. **Luster:** pearly. **Streak:** gray. **Cleavage:** (010) distinct, (0010 poor, (101) poor. **Fracture:** Subconchoidal.
Stishovite [Named after the Russian crystallographer M.S. Stishov (1937–) who first synthesized the mineral in 1961] (ICSD 68409 and PDF 45-1374)	SiO_2 $M = 60.0843$ 46.74 wt.% Si 53.26 wt.% O (Tectosilicates, framework) Coordinence Si (4)	Tetragonal $a = 417.9$ pm $c = 266.49$ pm C4, *tP6* ($Z = 2$) P.G. 422 S.G. P4/mnm Rutile type	Uniaxial (+) $\varepsilon = 1.826$ $\omega = 1.799$ $\delta = 0.027$	6	4300	**Habit:** prismatic. **Color:** colorless. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Twinning:** {011}. **Fracture:** conchoidal. **Chemical:** resistant to strong mineral acids, attacked by HF and molten alkali-metal hydroxides.
Stromeyerite [Named after the German chemist, F. Stromeyer] (ICSD 66580 and PDF 44-1436)	AgCuS $M = 203.4802$ 31.23 wt.% Cu 53.01 wt.% Ag 15.76 wt.% S (Sulfides and sulfosalts)	Orthorhombic P.G. 222	Biaxial $R = 32.3\%$	2.5–3 (HV 38–44)	6000–6300	**Habit:** granular, massive, pseudo hexagonal. **Color:** steel gray. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** steel gray. **Fracture:** conchoidal. **Occurrence:** copper–silver veins where silver replaces copper in bornite.
Strontianite [1633-05-2] [Named after Strontian, a small town in Argyllshire, Scotland] (ICSD 202793 and PDF 5-418)	$SrCO_3$ $M = 147.6292$ 59.35 wt.% Sr 8.14 wt.% C 32.51 wt.% O (Sulfates, chromates, molybdates, and tungstates)	Orthorhombic $a = 602.9$ pm $b = 841.4$ pm $c = 510.7$ pm ($Z = 4$) P.G. mmm S.G. Pmcn Aragonite type	Biaxial (–) $\alpha = 1.516–1.520$ $\beta = 1.664–1.667$ $\gamma = 1.666–1.669$ $\delta = 0.149–0.150$ $2V = 7–10°$ Dispersion weak	3.5	3720	**Habit:** pseudohexagonal, columnar, massive, granular, acicular, spadelike. **Color:** white, yellowish gray, greenish gray, or bluish white. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Cleavage:** (110) good. **Fracture:** uneveven, conchoidal, brittle. **Streak:** white. **Chemical:** decomposed at 1494°C giving off SrO and CO_2. Soluble in strong mineral acids with evolution of CO_2.
Sulfur or Sulphur [from Sanskrit, *sulvere*, and Latin, *sulfurium*] (ICSD 63082 and PDF 8-247)	S_8 $M = 256.528$ Coordinence S(2) (Native elements)	Orthorhombic $a = 1046.46$ pm $b = 1286.60$ pm $c = 2448.60$ pm A16, *oF128*	Biaxial (+) $\alpha = 1.958$ $\beta = 2.038$ $\gamma = 2.245$ $\delta = 0.290$	1.5–2.5	2068	**Habit:** massive, reniform, stalactitic. **Color:** yellow, yellowish brown, or gray. **Diaphaneity:** transparent to translucent. **Luster:** resinous. **Streak:** white. **Cleavage:** (101), (110). **Fracture:** sectile. **Chemical:** highly soluble in carbon disulfide CS_2. **Occurrence:** volcanic exhalations and bacterial reduction of sulfates in sediments.

		(Z = 128 S or 16 S_8) Sulfur type P.G. 222 S.G. Fddd	$2V$ = 68.58° Dispersion weak R = 13%			
Sylvanite [Named after Transylvania] (ICSD 30874 and PDF 9-477)	$(Au,Ag)_2Te_4$ (Sulfides and Sulfosalts)	Monoclinic a = 896 pm b = 449 pm c = 1462 pm (Z = 4) P.G. 2/m	Biaxial R = 48.0–60.0%	1.5–2 (HV 102– 125)	7900– 8300	**Habit:** prismatic, skeletal, platy. **Color:** yellowish silver white or white. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** steel gray. **Cleavage:** [010] perfect. **Fracture:** uneven.
Sylvite (syn., sylvinite) [7447-40-7] [Named after the Dutch chemist and physician of Leyden, Sylvia de la Boe (1614–1672)] (ICSD 22156 and PDF 41-1476)	KCl M = 74.551 52.45 wt.% K 47.55 wt.% Cl (Halides) Coordinence K(6)	Cubic a = 629.31 pm B1, cF8 (Z = 4) S.G. Fm3m P.G. 4-32 Rock salt type	Isotropic n_D = 1.490	2.0	1988	**Habit:** massive, cubic euhedral crystals, fibrous. **Color:** white, yellowish white, reddish white, bluish white, or brownish white. **Luster:** vitreous, greasy. **Diaphaneity:** transparent to translucent. **Streak:** white. **Cleavage:** (100), (010), (001). **Fracture:** uneven, brittle, sectile. Soluble in water, the soln. color the flame of a bunsen in violet. Bitter taste. Fusible (m.p. 778°C).
Talc (2M1) (syn., steatite: massive, soapstone, kerolite) [Named from the Arabic] (ICSD 26741 and PDF 29-1493)	$Mg_3Si_4O_{10}(OH)_2$ M = 379.26568 19.23 wt.% Mg 29.62 wt.% Si 0.53 wt.% H 50.62 wt.% O Coordinence Mg(6), Si(4) (Phyllosilicates, layered)	Monoclinic a = 528.7 pm b = 915.8 pm c = 1895 pm β = 99.50° (Z = 4) P.G. m S.G. Cc Type 2M1 mica	Biaxial (–) α = 1.539–1.550 β = 1.589–1.594 γ = 1.589–1.600 δ = 0.037–0.050 $2V$ = 6–30°	1	2580– 2830	**Habit:** foliated, scaly, massive. **Color:** pale green, white, gray white, yellowish white, or brownish white. **Diaphaneity:** translucent. **Luster:** vitreous (i.e., glassy), pearly. **Streak:** white. **Cleavage:** (001) perfect. **Fracture:** uneven. **Occurrence:** hydrothermal alteration of non-aluminous magnesian silicates.
Tapiolite (syn., tantalite) [Named after the god Tapio of Finnish mythology] (ICSD 79685 and PDF 23-1124)	$(Fe,Mn)(Ta,Nb)_2O_6$ M = 513.7392 70.44 wt.% Ta 10.87 wt.% Fe 18.69 wt.% O (Oxides, and hydroxides)	Tetragonal a = 475.4 c = 922.8 (Z = 2)	Biaxial	6–6.5	8170	**Habit:** granular. **Color:** black. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** brown. **Cleavage:** (110) imperfect. **Fracture:** uneven. **Occurrence:** pegmatites and alluvial deposits.
Tellurium [Named from Latin, *tellus*, earth] (ICSD 23058 and PDF 36-1452)	Te M = 127.60 (Native elements)	Hexagonal a = 446 pm c = 593 pm (Z = 3) S.G. $P6_3/mmc$	Uniaxial R = 57–68%	2–2.5	6100– 6300 (6230)	**Habit:** prismatic, columnar and granular crystals. **Color:** tin white. **Luster:** metallic. **Diaphaneity:** opaque. **Cleavage:** (010) perfect. **Fracture:** conchoidal. **Streak:** gray. **Occurrence:** hydrothermal veins.
Tenorite (syn., melaconite, melanochalcite) [Named after the Italian botanist, M. Tenor] (ICSD 67850 and PDF 45-937)	CuO M = 79.5454 79.89 wt.% Cu 20.11 wt.% O	Triclinic P.G. -1	Biaxial R = 23.4%	3.5–4 (HV 209– 254)	6500	**Habit:** scaly, earthy, massive. **Color:** black. **Luster:** earthy (dull). **Diaphaneity:** opaque. **Streak:** black. **Cleavage:** none. **Fracture:** conchoidal. **Occurrence:** secondary copper mineral.
Tephroite [Named from the Greek, *tephros*, ash gray for its color] (ICSD 100433 and PDF 35-748)	Mn_2SiO_4 M = 201.96 gm 54.41 wt.% Mn 13.91 wt.% Si 31.69 wt.% O (Nesosilicates)	Orthorhombic a = 476 pm b = 102 pm c = 598 pm (Z = 4) P.G. mmm Olivine group	Biaxial (+) α = 1.759 β = 1.797 γ = 1.86 δ = 0.101 $2V$ = 78°	6.5	4110– 4390	**Habit:** massive-granular, granular, prismatic. **Color:** gray, olive gray, flesh pink, or reddish brown. **Luster:** vitreous-greasy. **Diaphaneity:** transparent to translucent. **Streak:** gray. **Cleavage:** [010] indistinct. **Fracture:** brittle-conchoidal. **Occurrence:** Contact metamorphism of manganese-bearing rocks.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Terlinguaite [Named after Terlingua, Texas, USA] (ICSD 65483 and PDF 25-559)	Hg_2ClO $M = 452.63$ 88.63 wt.% Hg 7.83 wt.% Cl 3.53 wt.% O (Halides)	Monoclinic $a = 1201$ pm $b = 591$ pm $c = 949$ pm $\beta = 106°$ ($Z = 8$) P.G. 2/m S.G. C2/c	Biaxial (–) $\alpha = 2.35$ $\beta = 2.64$ $\gamma = 2.66$ $\delta = 0.310$ $2V = 26°$ Dispersion strong	2–3	8700	**Habit:** striated, prismatic. **Color:** yellow or green. **Luster:** adamantine. **Diaphaneity:** transparent to translucent. **Cleavage:** [101] perfect. **Occurrence:** Oxidized portions of mercury deposits.
Tetradymite [Named from the Greek, *tetradymos*, fourfold] (ICSD 26720 and PDF 42-1447)	Bi_2Te_2S $M = 705.2268$ 59.27 wt.% Bi 36.19 wt.% Te 4.55 wt.% S (Sulfides and sulfosalts)	Trigonal $a = 424$ pm $b = 2959$ pm ($Z = 3$) P.G. 32/m S.G. R3m	Uniaxial $R = 56.9\%$	1.5–2	7550	**Habit:** lamellar, granular, pseudo hexagonal. **Color:** steel gray or yellow gray. **Diaphaneity:** opaque. **Luster:** metallic. **Cleavage:** (0001) perfect. **Fracture:** uneven. **Streak:** steel gray.
Tetrahedrite [Named in 1845 after its tetrahedral crystal form] (ICSD 62116 and PDF 42-561)	$(Cu,Fe)_{12}Sb_4S_{13}$ $M = 1643.31$ 10.20 wt.% Fe 34.80 wt.% Cu 29.64 wt.% Sb 25.37 wt.% S (Sulfides and sulfosalts) Coordinence Cu(3), Cu(4)	Cubic $a = 1027$ pm ($Z = 2$) P.G. 43m S.G. I43m Tetraedrite type	Isotropic $n_D = 2.720$ $R = 30.7\%$	3.5–4 (HV 328–367)	4600–5200 (5070)	**Habit:** tetrahedral crystals, granular, massive. **Color:** steel gray or black. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** brown, black. **Cleavage:** None. **Twinning:** {111}. **Fracture:** uneven, subconchoidal. Electrical resistivity 0.3 to 30,000 Ω.m. **Occurrence:** hydrothermal veins and contact metaporphism.
Thorianite [Named from the presence of thorium] (ICSD 28685 and PDF 42-1462)	ThO_2 $M = 264.04$ 87.88 wt.% Th 12.12 wt.% O (Oxides and hydroxides)	Cubic $a = 559.5$ pm ($Z = 4$) P.G. 432 S.G. Fm3m	Isotropic $R = 14.6\%$	6 (HV 988–1115)	10,000	**Habit:** pseudo hexagonal, granular. **Color:** black or brown. **Diaphaneity:** Opaque. **Luster:** metallic. **Cleavage:** (100), (010), (001) poor. **Fracture:** conchoidal, brittle. **Streak:** black. Radioactive. **Occurrence:** pegmatites and alluvial deposits.
Thorite (syn., orangite) [Named from the Scandinavian God, Thor] (ICSD 1615 and PDF 11-419)	$ThSiO_4$ $M = 324.1212$ 71.59 wt.% Th 8.67 wt.% Si 9.74 wt.% O (Nesosilicates)	Tetragonal $a = 711.7$ pm $c = 629.5$ pm ($Z = 4$)	Uniaxial (–) $\varepsilon = 1.78–1.82$ $\omega = 1.79–1.84$ $\delta = 0.010–0.020$	5	5350	**Habit:** prismatic, granular, massive. **Color:** reddish brown, black, or orange. **Diaphaneity:** transparent to translucent. **Luster:** resinous. **Cleavage:** (110) poor. **Fracture:** conchoidal. **Streak:** light brown. **Occurrence:** augite-syenite rocks.
Thorutite [Named after thorium and rutile] (ICSD 14341 and PDF 19-1351)	$(Th,U,Ca)Ti_2(O,OH)_6$ $M = 390.82$ 2.05 wt.% Ca 23.75 wt.% Th 24.36 wt.% U 24.50 wt.% Ti 0.77 wt.% H 24.56 wt.% O	Monoclinic $a = 982$ pm $b = 382$ pm $c = 704$ pm $\beta = 118.83°$ ($Z = 2$) P.G. 2/m S.G. C2/m	Biaxial (–) Usually metamict hence isotropic	4.5–5.5	5610–5820 (6080)	**Habit:** short prismatic crystals. **Color:** dark brown to black. **Luster:** resinous. **Diaphaneity:** translucent. **Cleavage:** (010) perfect. **Fracture:** conchoidal. **Streak:** light brown. Radioactive. **Occurrence:** in nepheline syenite, paragenesis with thorite and zircon.
Tialite [12004-39-6]	Al_2TiO_5 $M = 181.827$	Orthorhombic $a = 942.9$ pm	Biaxial (?)	n.a.	3702	Melts at 1860°C

(syn. tieilite) (ICSD 24133 and PDF 41-258)	29.70 wt.% Al 26.30 wt.% Ti 44.00 wt.% O Coordinence Ti(6)	b = 963.6 pm c = 359.1 pm (Z = 4) P.G. 2/m 2/m 2/S.G. Bbmm Pseudobrookite type				
Tiemannite [Named after C.W.F. Tiemann] (ICSD 24322 and PDF 8-469)	HgSe M = 279.55 71.75 wt.% Hg 28.25 wt.% Se (Sulfides and sulfosalts)	Cubic P.G. Diploidal	Isotropic R = 29.8%	2.5	8190–8470	**Habit:** euhedral crystals, granular. **Color:** dark lead gray. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** grayish black. **Cleavage:** none. **Fracture:** brittle.
Titanite (syn., sphene) [Named after titanium or from the Greek, *sphen*, coin] (ICSD 39870 and PDF 31-295)	$CaTi[SiO_4](O,OH,F)$ 28.6 wt.% CaO 40.8 wt.% TiO_2 30.6 wt.% SiO_2 Coordinence Ca(7), Ti(6), Si(4) (Nesosilicates)	Monoclinic a = 656 pm b = 872 pm c = 744 pm β = 119.72° (Z = 4) P.G. 2/m S.G. C2/c	Biaxial (+) α = 1.843–1.950 β = 1.870–2.034 γ = 1.943–2.110 δ = 0.100–0.192 $2V$ = 17–40° Dispersion strong O.A.P. (010)	5–5.5	3450–3550 (3480)	**Habit:** wedge shaped crystals, tabular, prismatic. **Color:** yellow, brown, white, greenish, gray, or red. **Luster:** adamantine, resinous, greasy. **Diaphaneity:** transparent to opaque. **Cleavage:** (110) perfect, (100) poor. **Fracture:** uneven, conchoidal. **Twinning:** {100}, {221} lamellar. **Streak:** reddish white. **Chemical:** insoluble in HCl, but decomposed by hot concentrated H_2SO_4. Fusible. **Occurrence:** igneous rocks, granitic, pegmatites.
Topaz (syn., pycnite: yellowish white) [Named after the locality, Topasos Island, in the Red Sea] (ICSD 75825 and PDF 12-765) (ICSD 75824 and PDF 44-269)	$Al_2[SiO_4](F,OH)_2$ M = 182.25 29.61 wt.% A 15.41 wt.% Si 0.50 wt.% H 43.02 wt.% O 11.47 wt.% F Coordinence Al(6), Si(4) (Nesosubsilicates)	Orthorhombic a = 464.9 pm b = 879.2 pm c = 839.4 pm (Z = 4) P.G. mmm S.G. Pbnm	Biaxial (+) α = 1.606–1.629 β = 1.609–1.631 γ = 1.616–1.638 δ = 0.009–0.011 $2V$ = 48–68° O.A.P. (010) Dispersion low	8	3490–3570	**Habit:** crystalline, well formed prismatic crystal with pinacoidal termination on one end and a small pinacoid face surrounded by pyramid and horizontal prism face at the other, massive, granular. **Color:** colorless, pale blue, yellow, yellowish brown, or red. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent. **Streak:** white. **Cleavage:** (001) perfect. **Fracture:** uneven, brittle. **Luminescence:** fluorescent under Short UV light: golden yellow, and long UV light: cream. **Chemical:** slightly attacked by hot conc. H_2SO_4. **Other:** dielectric constant 6.09 to 7.4. **Occurrence:** pegmatites and high-temperature quartz veins. Cavities in granites and rhyolites.
Torbernite [Named after the Swedish chemist, Tornbern Bergmann (1735–1784)]	$Cu(UO_2)_2(VO_4)_2.8H_2O$ Coordinence Cu(6), U(2), P(4) (Phosphates, arsenates, and vanadates)	Tetragonal a = 70 pm c = 206.7 pm P.G. 4/mmm S.G. I4/mmm (Z = 4)	Uniaxial (–)	2–2.5	3250	**Habit:** thin to thick tabullar crystals. **Color:** emerald to dark green. **Diaphaneity:** transparent to translucent. **Luster:** vitreous to adamantine. **Streak:** green. **Cleavage:** (001). **Fracture:** uneven. Soluble in acids. **Occurrence:** secondary uranium mineral.
Tremolite (syn., abestos) [Named after the Val Tremola, south side of mount Saint-Gothardt in the Swiss Alps] (ICSD 30126 and PDF 44-1402)	$Ca_2Mg_5Si_8O_{22}(OH)_2$ M = 812.37 9.87 wt.% Ca 14.96 wt.% Mg 27.66 wt.% Si 0.25 wt.% H 47.27 wt.% O Coordinence Ca(8), Mg(6), Si(4) (Inosilicates, double chain)	Monoclinic a = 984.00 pm b = 180.52 pm c = 527.5 pm β = 104.75° (Z = 2) P.G. 2/m S.G. C2/m Tremolite type	Biaxial (–) α = 1.613–1.625 β = 1.634–1.645 γ = 1.646–1.666 δ = 0.017–0.020 $2V$ = 65–86° Dispersion weak	5–6	3010–3490	**Habit:** silky acicular crystals forming fibrous masses (asbestos). **Color:** colorless to pale green (traces Fe) or pink (traces Mn). **Luster:** glassy or pearly. **Diaphaneity:** transparent to translucent. **Cleavage:** (110) perfect with 124°, (010) distinct. **Twinning:** {100}. **Fracture:** subconchoidal. **Streak:** white. **Others:** not attacked by acids. Melts with difficulties yielding a greenish glass. Dielectric permittivity of 7.03 to 7.60. **Luminescence:** fluorescent under short UV light: yellow, and long UV light: pink. **Occurrence:** regional metamorphism and contact metamorphism of Ca-rich rocks.
Trevorite [12186-55-9] [Named after the South-African geologist T.G. Trevor(1865–1958)] (ICSD 67846 and PDF 10-325)	$NiFe_2O_4$ M = 234.38 47.65 wt.% Fe 25.04 wt.% Ni 27.30 wt.% O (Oxides, and hydroxides)	Cubic a = 843 pm $H1_1$, cF56 (Z = 8) S.G. Fd3m Spinel type	Isotropic n_D = 2.30	5.5	5260	**Habit:** massive or octahedral crystals. **Color:** black. **Diaphaneity:** opaque. **Luster:** submetallic. **Streak:** brown. **Cleavage:** (001). **Fracture:** uneven. Ferromagnetic. **Occurrence:** peridotites.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Tridymite [15468-32-3] [Named from the Greek *tridymos*, threefold since the crystals are often trillings] (ICSD 29343 and PDF 18-1169)	SiO_2 $M = 60.0843$ 46.74 wt.% Si 53.26 wt.% O (Tectosilicates, framework) Coordinence Si (4)	Hexagonal $a = 504.63$ pm $c = 825.63$ pm C10, hP12 ($Z = 4$) P.G. 6mmm S.G. $P6_3/mmc$	Uniaxial (+) $\varepsilon = 1.475$ $\omega = 1.479$	6–7	2280	**Habit:** wedge shaped. **Color:** colorless. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** vitreous(i.e., glassy). **Fracture:** conchoidal. **Twinning:** (110). Transition temperature 1470°C.
Triphylite [Named from the Greek for threefold and family] (ICSD 72545 and PDF 40-1499)	$LiFePO_4$ $M = 157.76$ 4.40 wt.% Li 35.40 wt.% Fe 19.63 wt.% P 40.57 wt.% O Coordinence Li(8), Fe(8), and P(4) (Phosphates, arsenates, and vanadates) Traces of Mn	Orthorhombic $a = 601$ pm $b = 468$ pm $c = 1036$ pm ($Z = 4$) P.G. mmm S.G. $P2_1/mcn$	Biaxial(−) $\alpha = 1.680$ $\beta = 1.680$ $\gamma = 1.690$ $\delta = 0.01$ $2V = 0–56°$	5–5.5	3500–5500	**Habit:** coarse massive. **Color:** blue green. **Streak:** white gray. **Diaphaneity:** transparent to translucent. **Luster:** vitreous, resinous. **Fracture:** subconchoidal. **Cleavage:** (001) perfect, (010) good.
Troilite 1317-37-9 [Named after Domenico Troili the Italian Jesuit who first observed the mineral in the Albareto meteorite in 1776] (ICSD 68845 and PDF 37-477)	FeS $M = 87.911$ 63.52 wt.% Fe 36.48 wt.% S	Hexagonal $a = 596.8$ pm $c = 1174.0$ pm ($Z = 12$) S.G. *P62c* P.G. 6/m 2/m 2/m	Uniaxial (?)	3.5–4.5 (HV 250)	4670–4790 (4840)	**Habit:** in meteorites as rounded nodules in siderites or anhedral grains in litholites. **Color:** light grayish brown. **Luster:** metallic. **Diaphaneity:** opaque. **Streak:** dark grayish brown. **Occurrence:** rare terrestrial occurrence such as in the Cañon Diablo meteorite, Disco Island in Greenland.
Trona [Named from Arabic origins meaning, natron] (ICSD 62200 and PDF 29-1447)	$Na_3(CO_3)(HCO_3)\ 2H_2O$ $M = 226.0262$ 30.51 wt.% Na 2.23 wt.% H 10.63 wt.% C 56.63 wt.% O (Nitrates, carbonates, and borates)	Monoclinic P.G. 2/m	Biaxial (−) $\alpha = 1.412$ $\beta = 1.492$ $\gamma = 1.540$ $\delta = 0.128$ $2V = 72°$ Dispersion strong	2.5	2110–2170	**Habit:** fibrous, columnar, massive. **Color:** yellowish white, gray, or white. **Luster:** vitreous (glassy). **Diaphaneity:** translucent. **Streak:** white. **Cleavage:** [100] perfect, [111] indistinct, [001] indistinct. **Fracture:** subconchoidal.
Turquoise (syn., callaite) [Named after Turkey from where it was brought to Europe] (ICSD 21062 and PDF 6-214)	$CuAl_6(PO_4)_4(OH)_2{\cdot}4H2O$ $M = 813.44052$ 19.90 wt.% Al 7.81 wt.% Cu 15.23 wt.% P 1.98 wt.% H 55.07 wt.% O Coordinence Cu(6), Al(6), P(4) (Phosphates, arsenates, and vanadates)	Triclinic $a = 748$ pm $b = 995$ pm $c = 768$ pm $\alpha = 111.65°$ $\beta = 115.38°$ $\gamma = 69.43°$ ($Z = 1$) P.G. 1 S.G. P1	Biaxial (+) $\alpha = 1.610$ $\beta = 1.615$ $\gamma = 1.650$ $\delta = 0.040$ $2V = 40–44°$ Dispersion strong	5–6	2700	**Habit:** concretionary, reniform, massive, encrustations. **Color:** light blue, apple green, or greenish blue. **Diaphaneity:** translucent to opaque. **Luster:** resinous, waxy. **Streak:** pale bluish white. **Cleavage:** (001) perfect, (010) good. **Fracture:** subconchoidal, brittle.

Ulexite (syn., natroborocalcite) [Named after the German chemist, George Ludwig Ulex (1811–1883)] (ICSD 100565 and PDF 12-419)	$NaCaB_5O_6(OH)_6{\cdot}5H_2O$ $M = 405.23$ 5.67 wt.% Na 9.89 wt.% Ca 13.34 wt.% B 3.98 wt.% H 67.12 wt.% O Coordinence Na(6), Ca(9), B(3, and 4) (Nitrates, carbonates, and borates)	Triclinic $a = 882$ pm $b = 1287$ pm $c = 668$ pm $\alpha = 90.4°$ $\beta = 109.1°$ $\gamma = 105.0°$ ($Z = 2$) P.G. 1 S.G. P1	Biaxial (+) $\alpha = 1.493$ $\beta = 1.505$ $\gamma = 1.526$ $\delta = 0.029$ $2V = 73–78°$	2.5	1950–1960	**Habit:** nodules, needle-like crystals, and fibrous masses like cotton-balls. **Color:** colorless to white. **Luster:** chatoyant. **Diaphaneity:** translucent. **Cleavage:** [010] and [110] perfect. **Fracture:** brittle. **Streak:** white. Soluble in hot water. **Occurrence:** secondary borate mineral derived from weathering of primary borates such as borax.
Ullmannite [Named after the German chemist and mineralogist, J.Ch. Ullmann] (ICSD 100259 and PDF 41-1472)	NiSbS $M = 212.506$ 27.62 wt.% Ni 57.29 wt.% Sb 15.09 wt.% S (Sulfides and sulfosalts)	Cubic $a = 588$ pm FO_1, cP12 ($Z = 4$) S.G. $P2_13$ P.G. 23 Ullmanite type	Isotropic $R = 47.5\%$	5–5.5 (HV 498–542)	6700	**Habit:** tetrahedral crystals, massive, granular, massive. **Color:** steel gray or silvery white. **Luster:** metallic. **Diaphaneity:** opaque. **Cleavage:** [100], [010], [001]. **Fracture:** brittle uneven. **Streak:** grayish black.
Ulvospinel [12063-18-2] (syn., ulvöspinel, ulvite) [Named after the Sodra Ulvö island, Angermanland archipelago, Northern Sweden and the spinel group of minerals] (ICSD 75367 and PDF 34-177)	Fe_2TiO_4 $M = 223.555$ 21.42 wt.% Ti 49.96 wt.% Fe 28.63 wt.% O Coordinence Ti(4), Fe(6) (Oxides and hydroxides)	Cubic $a = 845.96$ pm $H1_1$, cF56 ($Z = 8$) P.G. m3m S.G. Fd3m P.G. 432 Spinel type (Ferrite series)	Isotropic $n_D = 2.16–2.28$ $R = \%$	5.5–6	4780 (4771)	**Habit:** massive or as very fine exsoution lamellae. **Cleavage:** none. **Color:** iron black. **Diaphaneity:** opaque. **Luster:** metallic. **Occurrence:** occurs in titanoferrous magnetites, as exsolution lamellae.
Uraninite [Named after its chemical composition] (ICSD 29085 and PDF 41-1422)	UO_2 $M = 270.0277$ 88.15 wt.% U 11.85 wt.% O Coordinence U(2) (Oxides, and hydroxides)	Cubic $a = 546.82$ pm C1, *cF12* ($Z = 4$) P.G. 432 S.G. Fm3m Fluorite type	Isotropic $R = 16.8\%$	5–6 (HV 782–839)	10,970	**Habit:** cubic, massive. **Color:** black. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** brown, black. **Cleavage:** (100). **Other:** electrical resistivity 1.5 to 200 Ω.m. Radioactive. **Occurrence:** granites and syenite pegmatites. Hydrothermal high-temperature tin veins; sandstones and uraniferous conglomerates.
Uranophane (syn., uranotile) [Named from Greek, *uran* and *phanos*, to appear] (ICSD 63029 and PDF 39-1360)	$Ca(UO_2)_2SiO_3(OH)_2{\cdot}5H_2O$ $M = 586.36418$ 6.84 wt.% Ca 40.59 wt.% U 9.58 wt.% Si 2.06 wt.% H 40.93 wt.% O (Inosilicates, chain)	Monoclinic $a = 1587$ pm $b = 705$ pm $c = 666$pm $\beta = 97.25°$ ($Z = 3$) P.G. 2 S.G. $P2_1$	Biaxial (–) $\alpha = 1.643$ $\beta = 1.666$ $\gamma = 1.669$ $\delta = 0.026$ $2V = 38°$ Dispersion strong	2.5	3900	**Habit:** radial, earthy, massive, fibrous. **Color:** yellow. **Diaphaneity:** translucent. **Luster:** vitreous (i.e., glassy). **Cleavage:** (100) perfect. **Fracture:** uneven. **Streak:** yellowish white. **Occurrence:** alteration product of gummite.
Uranothorite	$(Th,U)[SiO_4]$	Tetragonal	Uniaxial			
Uvarovite [Named after Count Sergei Semeonovich Uvarov (1786–1855), Russian statesman, member of the Imperial Academy of St. Petersburg and ardent amateur mineral collector] (ICSD 27368 and PDF 11-696)	$Ca_3Cr_2(SiO_4)_3$ $M = 500.4755$ 24.02 wt.% Ca 20.78 wt.% Cr 16.84 wt.% Si 38.36 wt.% O Coordinence Ca(8), Cr(6), Si(4) (Nesosilicates)	Cubic $a = 1200$ pm ($Z = 8$) P.G. 432 S.G. Ia3d Garnet group (Ugrandite series)	Isotropic $n_D = 1.860$	6.5–7.5	3900	**Habit:** dodecahedral crystals. **Color:** green. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy). **Streak:** white. **Fracture:** subconchoidal. **Occurrence:** metamorphosed chromite deposits.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Valentinite (syn., antimony bloom) [Named after the German alchemist Basilius Valentinus (pseudonym for Johannes Thölde), working on the properties of antimony in the late 17th and early 18th century] (ICSD 27595 and PDF 11-689)	Sb_2O_3 M = 291.4982 83.53 wt.% Sb 16.47 wt.% O (Oxides, and hydroxides)	Orthorhombic $D5_8$, oP20 (Z = 8) S.G. Pbnm P.G. 222	Biaxial (–) α = 2.18 β = 2.35 γ = 2.35 δ = 0.170	2.5–3	5600–5800	**Habit:** euhedral crystals, divergent, striated. **Color:** white, gray, or yellowish gray. **Luster:** adamantine. **Streak:** white. **Cleavage:** [110] perfect, [010] distinct. **Fracture:** uneven. **Occurrence:** occurs as an oxidation product of various antimony minerals.
Vanadinite [Named after its vanadium content] (ICSD 203074 and PDF 43-1461)	$Pb_5(VO_4)_3Cl$ M = 1186.3921 87.33 wt.% Pb 4.29 wt.% V 5.39 wt.% O 2.99 wt.% Cl Coordinence Pb(6), V(4) (Phosphates, arsenates, and vanadates)	Hexagonal a = 1033 pm c = 735 pm (Z = 2) P.G. 6/m S.G. $P6_3/m$ Apatite type	Uniaxial (–) ε = 2.350 ω = 2.416 δ = 0.066	3	6900	**Habit:** prismatic, hollow prisms, encrustation. **Color:** red orange. **Streak:** white yellow. **Diaphaneity:** translucent. **Luster:** resinous. **Fracture:** subconchoidal.
Variscite (syn., strengite: Fe) (ICSD 819 and PDF 33-33)	$Al(PO_4).2H_2O$ M = 157.983 17.08 wt.% Al 19.61 wt.% P 60.76 wt.% O 2.55 wt.% H Coordinence Al(6), P(4) (Phosphates, arsenates, and vanadates)	Orthorhombic a = 987 pm b = 957 pm c = 852 pm (Z = 8) P.G. mmm S.G. $P2_1/cab$ Scorodite type	Biaxial(–) α = 1.55–1.56 β = 1.57–1.58 γ = 1.58–1.59 δ = 0.03 $2V$ = 48–54°	4	2500	**Habit:** prismatic. **Color:** green, yellow. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** resinous. **Fracture:** subconchoidal, splintery. **Cleavage:** (010) good.
Vesuvianite (syn., idocrase, cyprine) [from Greek, *eidos*, appearence, *krasis*, mixture, owing to the resseamblance of its crystals to other species, from Mt. Vesuvius volcano, Italy] (ICSD 79151 and PDF 38-473)	$Ca_{10}(Mg,Fe)_2Al_4[Si_2O_7]_2[SiO_4]_5(OH,F)_4$ Coordinence Ca(8), Mg(6), Fe(6), Al(6), Si(4) (Nesosilicates and sorosilicates)	Tetragonal a = 1560 pm c = 1180 pm (Z = 4) P.G. 4/mmm S.G. Pnnc	Uniaxial (–) ε = 1.700–1.746 ω = 1.703–1.752 δ = 0.01–0.008 Dispersion strong	6–7	3330–3430	**Habit:** prismatic. **Color:** reddish brown to green, emerald green (Cr-rich), reddish brown (Ti-rich), pale yellow (Cu-rich). **Luster:** vitreous (i.e., glassy), greasy. **Diaphaneity:** transparent to opaque. **Cleavage:** (110), (100), (001). **Fracture:** uneven. **Chemical:** attacked by strong mineral acids after calcination. **Deposits:** contact metamorphism.
Villiaumite [7681-49-4] [Named after the French traveller and explorer,Villiaume who brought the specimen from Guinea] (ICSD 24443 and PDF 36-1455)	NaF M = 41.98817 54.75 wt.% Na 45.25 wt.% F (Halides)	Cubic a = 463.42 pm B1, cF8 (Z = 4) S.G. Fm3m Rock salt type	Isotropic n_D = 1.327	2.5	2785	**Habit:** massive, granular. **Color:** crimson red, dark cherry red, or colorless. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent. **Luminescence:** fluorescent. **Streak:** pinkish white. **Cleavage:** [100], [010], [001]. **Fracture:** brittle. **Occurrence:** nepheline–syenite rocks. Soluble in water. Fusible (m.p. 996°C).
Violarite [Named from the Latin, *violaris*, purple] (ICSD and PDF 42-1449)	$FeNi_2S_4$ M = 301.475 18.52 wt.% Fe 38.94 wt.% Ni	Cubic a = 946.4 pm $H1_1$, cF56 (Z = 8)	Isotropic R = 45%	4.5–5.5	4500–4800	**Habit:** octahedral crystals. **Color:** violet gray. **Diaphaneity:** opaque. **Luster:** metallic. **Streak:** gray. **Cleavage:** perfect {111}. **Twinning:** {111}. **Fracture:** uneven, conchoidal.

	42.54 wt.% S (Sulfides and sulfosalts) Coordinence Ni(6), Fe(4)	S.G. Fd-3m P.G. 4-32 Spinel type				
Vivianite [Named after the English mineralogist, J.G. Vivian] (ICSD 200703 and PDF 30-662)	$Fe_3(PO_4)_2.8H_2O$ $M = 596.57180$ 28.08 wt.% Fe 15.58 wt.% P 53.64 wt.% O 2.70 wt.% H Coordinence Fe(6), P(4) (Phosphates, arsenates, and vanadates)	Monoclinic $a = 1008$ pm $b = 1343$ pm $c = 470$ pm $\beta = 104.5°$ ($Z = 2$) P.G. 2/m S.G. C2/m	Biaxial(+) $\alpha = 1.579$ $\beta = 1.603$ $\gamma = 1.633$ $\delta = 0.054$ $2V = 83°$	2	2580	**Habit:** reniform, lamellar, fibrous. **Color:** colorless, green. **Streak:** white. **Diaphaneity:** transparent to translucent. **Luster:** pearly, vitreous. **Fracture:** sectile. **Cleavage:** (010) perfect, (100) perfect.
Wadsleyite [Named after crystallographer A.D. Wadsley] (ICSD 66490 and PDF 37-415)	β-$(Mg,Fe^{2+})_2SiO_4$ $M = 156.46$ 23.30 wt.% Mg 17.85 wt.% Fe 17.95 wt.% Si 40.90 wt.% O (Nesosilicates)	Orthorhombic $a = 567$ pm $b = 1151$ pm $c = 826$ pm ($Z = 8$) P.G. 2/m2/m2/m S.G. Imma	Biaxial (?)	n.a.	3840 (3840)	**Habit:** fine-grained aggregates. **Color:** light grayish brown. **Luster:** vitreous. **Diaphaneity:** translucent. **Cleavage:** unknown. **Fracture:** brittle, uneven. **Streak:** white. **Occurrence:** impact meteorite.
Wavellite [Named after the English physician William Wavell (died 1829)] (ICSD 26816 and PDF 41-1360)	$Al_3(PO_4)_2(OH)_3.5H_2O$ $M = 506.957507$ 15.97 wt.% Al 18.33 wt.% P 63.12 wt.% O 2.58 wt.% H Coordinence Al(6), P(4) (Phosphates, arsenates, and vanadates)	Orthorhombic $a = 962$ pm $b = 1736$ pm $c = 699$ pm ($Z = 4$) P.G. mmm S.G. $P2_12_12_1/cmn$	Biaxial(+) $\alpha = 1.525$ $\beta = 1.534$ $\gamma = 1.552$ $\delta = 0.027$ $2V = 72°$	3–4	2360	**Habit:** globular, radiating, spherolitic. **Color:** white, yellow, green. **Streak:** white. **Diaphaneity:** translucent. **Luster:** vitreous. **Fracture:** subconchoidal. **Cleavage:** (101) perfect, (010) perfect.
Willemite (syn., Troostite) [Named after Willem I, King of the Netherlands] (ICSD 2425 and PDF 46-1316)	Zn_2SiO_4 $M = 222.8631$ 58.68 wt.% Zn 12.60 wt.% Si 28.72 wt.% O (Nesosilicates)	Trigonal (Rhombohedral) $a = 1394$ pm $c = 931$ pm ($Z = 18$) P.G. 3	Uniaxial (+) $\omega = 1.691–1.72$ $\varepsilon = 1.719–1.73$ $\delta = 0.010–0.028$	5.5	3900– 4200	**Habit:** prismatic, massive-granular, massive. **Color:** white, yellow, green, reddish brown, or black. **Luster:** vitreous-resinous. **Diaphaneity:** transparent to translucent to opaque. **Streak:** white. **Luminescence:** fluorescent, green under short uv wavelength. **Cleavage:** [0001] poor, [1120] poor. **Occurrence:** main ore mineral at franklin, a metamorphosed zinc orebody. **Fracture:** uneven.
Witherite [513-77-9] [Named after the English physician, botanist & mineralogist, William Withering (1741–1799)] (ICSD 15196 and PDF 45-1471)	$BaCO_3$ $M = 197.336$ 77.54 wt.% Ba 4.49 wt.% C 17.96 wt.% O Coordinence Ba(6), C(3) (Nitrates, carbonates, and borates)	Orthorhombic $a = 643.0$ pm $b = 890.4$ pm $c = 531.4$ pm ($Z = 4$) S.G. Pmcn P.G. mmm Aragonite type	Biaxial (–) $\alpha = 1.529$ $\beta = 1.676$ $\gamma = 1.677$ $\delta = 0.148$ $2V = 16°$ Dispersion weak	3.5	4290– 4300	**Habit:** pseudo hexagonal, columnar, globular, reniform, fibrous. **Color:** colorless, milky white, grayish white, pale yellowish white, or pale brownish white. **Luster:** vitreous (i.e., glassy). **Diaphaneity:** transparent to translucent. **Streak:** white. **Fracture:** subconchoidal. **Cleavage:** (010), (110) distinct. **Twinning:** {110}. **Chemical:** decomposed at 1555°C giving off CO_2. Soluble in diluted HCl with evolution of CO_2.
Wolframite [13870-24-1] [Named from the German, *wolfram*, name for tungsten] (ICSD 15192 and PDF 12-727)	$Fe_{0.5}Mn_{0.5}WO_4$ $M = 303.2291$ 9.06 wt.% Mn 9.21 wt.% Fe 60.63 wt.% W 21.10 wt.% O Traces of V, Nb, Ta, Sc, Ti, Mo, Al, and In. (Sulfates, chromates, molybdates, and tungstates)	Monoclinic $a = 478.2$ pm $b = 573.1$ pm $c = 498.2$ pm 90.57° ($Z = 2$) Wolframite type (Ferberite-Hubnerite)	Biaxial (+) $\alpha = 2.20–2.26$ $\beta = 2.22–2.32$ $\gamma = 2.30–2.42$ $\delta = 0.10–0.16$ $2V = 73–90°$ Dispersion none $R = 17.3\%$	4–4.5 (HV 357– 394)	7510	**Habit:** prismatic, lamellar, tabular, massive, granular. **Color:** reddish and brownish black to iron black. **Luster:** resinous to submetallic. **Diaphaneity:** transparent to opaque. **Streak:** reddish brown. **Cleavage:** [010] perfect. **Fracture:** uneven, brittle. **Chemical:** attacked by conc. and hot HCl and H_2SO_4. **Other:** dielectric constant 12.51. Magnetic. **Occurrence:** high-temperature quartz veins, in greisen, pegmaties and skarns.

Table 12.23. *(continued)*

Mineral name (IMA) [CAS RN] (Synonyms) [Etymology] (ICSD and PDF diffraction files numbers)	Theoretical chemical formula, relative molecular mass ($^{12}C = 12$), mass percentages, coordinence number, major impurities, Strunz's mineral class	Crystal system, lattice parameters, Strukturbericht, Pearson symbol, (Z), point group, space group, structure type	Optical properties	Mohs hardness (/HM) (Vickers)	Density (ρ/kg.m^{-3}) (calc.)	Other relevant mineralogical, physical, and chemical properties with occurrence
Wollastonite [Named after the English chemist and mineralogist William Hyde Wollaston (1766–1828)] (ICSD 201537 and PDF 42-547)	$Ca[SiO_3]$ Coordinence Ca(6), Si(4) (Inosilicates, chain)	Triclinic $a = 794$ pm $b = 732$ pm $c = 707$ pm $\alpha = 90.03°$ $\beta = 95.37°$ $\gamma = 103.43°$ P.G. 1 S.G. P1 ($Z = 4$) Pyroxenoid group	Biaxial (–) $\alpha = 1.620$ $\beta = 1.632$ $\gamma = 1.634$ $\delta = 0.014$ $2V = 39°$ Dispersion weak	4.5–5	3100	**Habit:** prismatic, needlelike. **Color:** white. **Luster:** silky. **Diaphaneity:** transparent to translucent. **Streak:** white. **Fracture:** uneven. **Cleavage:** (100) perfect, (001) distinct. **Twinning:** {010}.
Wulfenite [10190-55-3] (syn., yellow lead ore) [Named after the Austrian mineralogist, F.X. Wulfen] (ICSD 26784 and PDF 44-1486)	$PbMoO_4$ $M = 367.1376$ 26.13 wt.% Mo 56.44 wt.% Pb 17.43 wt.% O Coordinence Pb(6), Mo(4) (Sulfates, chromates, molybdates, and tungstates)	Tetragonal $a = 543.5$ pm $c = 1211.0$ pm ($Z = 4$) P.G. 4/m S.G. $I4_1/a$ Scheelite type	Uniaxial (–) $\varepsilon = 2.283$ $\omega = 2.404$ $\delta = 0.121$	2.9	6750–7000	**Habit:** tabular, massive, granular, bipyramidal pseudooctahedron. **Luster:** resinous, greasy, or adamantine. **Diaphaneity:** subtransparent to subtranslucent. **Color:** orange yellow, waxy yellow, yellowish gray, olive green, or brown. **Streak:** yellowish white. **Cleavage:** (101) imperfect. **Twinning:** {001}. **Fracture:** subconchoidal, brittle.
Wurtzite (syn., radial blende, HT ZnS) [Named after the French chemist, Ch.A. Wurtze] (ICSD 67453 and PDF 36-1450)	ZnS $M = 97.456$ 67.10 wt.% Zn 32.90 wt.% S Traces Fe (Sulfides and sulfosalts) Coordinence Zn(4)	Hexagonal $a = 382.30$ pm $c = 625.65$ pm B4, hP4 ($Z = 2$) S.G. $P6_3mc$ P.G. 6mm Wurtzite type	Uniaxial (+) $\varepsilon = 2.356$ $\omega = 2.378$ $\delta = 0.022$ $R = 17.4\%$	3.5–4	4030	**Habit:** pyramidal, radial, tabular, colloform. **Color:** orange red, light brown or dark brown. **Luster:** resinous. **Luster:** adamantine, resinous. **Streak:** brown yellow. **Cleavage:** {1010}, {0001}. **Fracture:** uneven. Conchoidal. **Chemical:** attacked by strong mineral acids, such as HCl, or HNO_3 with evolution of H_2S and yellow precipitate of sulfur. Infusible.
Wustite [1345-25-1] (syn. ferrous oxide) [Named after the German metallurgist Friedrich Wüst (1860–1938)] (ICSD 24695 and PDF 46-1312)	FeO $M = 71.8444$ 77.73 wt.% Fe 22.27 wt.% O (Oxides and hydroxides) Coordinence Fe(6)	Cubic $a = 430.7$ pm B1, cF8 ($Z = 4$) S.G. Fm3m P.G. 432 Rock salt type Periclase group	Isotropic	5	5740 (5973)	**Habit:** tiny octahedral crystals or microspherules. **Color:** black to brown, gray in reflected light. **Luster:** metallic. **Diaphaneity:** opaque. **Cleavage:** (unknown). **Fracture:** (unknown). **Streak:** (unknown). **Other:** antiferromagnetic, melts at 1380°C. **Chemical:** dissolves in HCl. **Occurrence:** in iron meteorites (siderites), in deep-sea ferromanganese nodules, in highly reduced iron-bearing basalts (Disco Island, Greenland) and in natural coke from fired coal fields (Bihar, India).
Xenotime [Named from the Greek, *xenos*, foreign, and time, *honor*, owing to the rarity and the small size of its crystals] (ICSD 79754 and PDF 11-254)	YPO_4 $M = 183.87721$ 48.35 wt.% Y 16.84 wt.% P 34.80 wt.% O Traces of U, Th, Zr, Si, and rare earths Coordinence Y(6), P(4) (Phosphates, arsenates, and vanadates)	Tetragonal $a = 688.5$ pm $c = 598.2$ pm $I4_1/amd$ ($Z = 4$) P.G. 4/mmm S.G. $I4_1/amd$ Zircon type	Uniaxial (+) $\varepsilon = 1.720–1.721$ $\omega = 1.816–1.827$ $\delta = 0.095–0.107$	4.5–5	4750	**Habit:** radial, prismatic, massive, and granular. **Color:** yellowish brown, greenish brown, gray, reddish brown, or brown. **Luster:** vitreous (i.e., glassy), greasy or resinous. **Diaphaneity:** translucent to opaque. **Streak:** pale brown. **Cleavage:** (100) perfect. **Fracture:** uneven, splintery. **Chemical:** insoluble in strong mineral acids.

Zincite [1314-13-2] (syn., red zinc oxide) [Named from the German, *zink*] (ICSD 31052 and PDF 36-1451)	(Zn,Mn)O $M = 81.3894$ 80.34 wt.% Zn 19.66 wt.% O (Oxides, and hydroxides) Coordinence Zn(4)	Trigonal (Hexagonal) $a = 660.4$ pm $c = 597.9$ pm B4, hP4 ($Z = 2$) S.G. P63mc P.G. 6mm Wurtzite type	Uniaxial (+) $\varepsilon = 12.013$ $\omega = 12.029$ $\delta = 10.016$ $R = 11.2\%$	4–4.5 (HV 150–157 and 295–318 //)	5560	**Habit:** massive, fibrous, granular, disseminated. **Color:** deep red or yellowish orange. **Diaphaneity:** translucent to translucent. **Luster:** submetallic, subadamantine. **Streak:** yellowish orange. **Cleavage:** [0001]. **Parting:** [110]. **Fracture:** Subconchoidal. **Occurrence:** metamorphosed weathered ore deposit.
Zinnwaldite [Named after Zinnwald, Bohemia, itself named for the local tin (German *zinn*) veins] (ICSD 10401 and PDF 42-1399)	$KLiFeAl[Si_3AlO_{10}](F,OH)_2$ 8.94 wt.% K 1.59 wt.% Li 12.35 wt.% Al 12.78 wt.% Fe 19.28 wt.% Si 0.12 wt.% H 6.52 wt.% F 38.43 wt.% O Phyllosilicates	Monoclinic $a = 530$ pm $b = 914$ pm $c = 1010$ pm $\beta = 100.83°$ ($Z = 2$) S.G. C2/m Biotite group	Biaxial (–) $\alpha = 1.535–1.558$ $\beta = 1.570–1.589$ $\gamma = 1.572–1.590$ $2V = 0°–40°$	2.5–4	2900–3020	**Habit:** tabular or prismatic crystals. **Color:** grayish-brown to yellowish brown. **Diaphaneity:** transparent to translucent. **Luster:** vitreous to pearly. **Fracture:** conchoidal. **Cleavage:** (001) perfect yielding flexible lamellae. **Occurrence:** granite pegmatites and hydrothermal tin-bearing veins.
Zircon [10101-52-7] (syn., hyacinthe: orange, red, malacon: white] [Named from Arabic, *zar*, gold, and *gum*, color] (ICSD 71943 and PDF 6-266)	$Zr[SiO_4]$ $M = 183.3071$ 49.77 wt.% Zr 15.32 wt.% Si 34.91 wt.% O Traces of Hf, U, Th and daughter radionuclides Coordinence Zr(4), Si(4) (Nesosilicates)	Tetragonal $a = 660.70$ pm $c = 598.35$ pm c/a = 0.906 ($Z = 4$) P.G. 4/mmm S.G. I4$_1$amd Zircon type	Uniaxal (+) $\varepsilon = 1.923–1.960$ $\omega = 11.968–2.015$ $\delta = 10.042–0.065$ Dispersion very strong	7.5 (6–6.5 meta-mict)	4660 (3900–4200 meta-mict)	**Habit:** prismatic, tabular, crystalline. **Color:** brown, reddish brown, colorless, gray, green. **Diaphaneity:** transparent, translucent, opaque. **Luster:** adamantine. **Streak:** white. **Fracture:** uneven. **Cleavage:** (110). **Twinning:** {111}. **Chemical:** insoluble in HCl and HNO_3, slightly soluble in concentrated H_2SO_4, readily dissolved by 50 wt.% HF. Radioactive owing to the isomorphic substitution of Zr(IV) cations by U(IV) and Th(IV) can contain some Pb from decaying. Above 1690°C zircon dissociates into constituents oxides forming two immiscible phases of ZrO_2 and SiO_2. **Other:** zircon exhibits a low bulk coefficient of linear thermal expansion: 4.5 10^{-6} K^{-1}. Its bulk modulus of compressibility is comprised between 227 GPa and 234 GPa. Zircon is diamagnetic with a specific magnetic susceptibility of -0.78×10^{-6} $m^3.kg^{-1}$ along **a**-axis and $+3.37 \times 10^{-6}$ $m^3.kg^{-1}$ along **c**-axis.
Zirconolite (syn., zirkelite, polymignite) [Named after its chemical composition containing zirconium] (ICSD 71943 and PDF 6-266)	$CaZrTi_2O_7$ $M = 341.032$ 11.75 wt.% Ca 26.75 wt.% Zr 28.66 wt.% Ti 32.84 wt.% O (Oxides and hydroxides)	Hexagonal $a = 728.7$ pm $c = 1688.6$ pm $Z = 3$ S.G. P3$_1$2	Uniaxial ()	5.5	4720 (4880)	**Habit:** hexagonal platy crystal often metamict due to its U and Th content; small grains. **Color:** black, brownish black. **Diaphaneity:** opaque but transparent in thin sections. **Luster:** resinous to submetallic. **Cleavage:** {100}, {010}. **Twinning:** Polysynthetic. **Streak:** reddish brown. **Fracture:** splintery, brittle. **Occurrence:** in alkaline and ultramafic igneous rocks such as carbonatites, kimberlites or syenites associated to pyrochlore or as a detrital mineral.
Zoïsite (syn., tanzanite: blue, thulite: pink or red, anyolite: green) [Named after the Austrian natural scientist, Siegmund Zois, Baron von Edelstein (1747–1819)] (ICSD 200920 and PDF 25-1298)	$Ca_2Al_3O(OH)[SiO_4][Si_2O_7]$ $M = 427.37572$ 18.76 wt.% Ca 12.63 wt.% Al 19.71 wt.% Si 0.24 wt.% H 48.67 wt.% O Coordinence Ca(6, 9), Fe(6), Si(4) (Sorosilicates and nesosilicates)	Orthorhombic $a = 1615.0$ pm $b = 558.1$ pm $c = 1006.0$ pm ($Z = 4$) P.G. 2/m S.G. P2$_1$/m Epidote group	Biaxial (–) $\alpha = 1.685–1.705$ $\beta = 1.688–1.710$ $\gamma = 1.697–1.725$ $\delta = 0.004–0.008$ $2V = 0–60°$ Dispersion strong	6–6.5 (HV 680)	3150–3270	**Habit:** prismatic, striated, columnar. **Color:** gray, apple green, brown, blue, or rose red. **Diaphaneity:** transparent to translucent. **Luster:** vitreous (i.e., glassy), pearly. **Streak:** white. **Cleavage:** (100), perfect, (001) imperfect. **Twinning:** {100}. **Fracture:** uneven. **Chemical:** insoluble in strong mineral acids, fusible giving a white globule. **Occurrence:** regional metamorphic and pegmatite rocks.

12.8 Mineral Synonyms

Absite = Brannerite
Acerdese = Manganite
Achrematite = Mimetite + Wulfenite
Achroite = Elbaite
Acmite = Aegirine
Adularia = Orthoclase
Agalmatolite = Talc or Pyrophyllite or Pinite
Agate = Layered Chalcedony (Quartz)
Agricolite = Eulytite
Alabaster = Gypsum
Alexandrite = Chrysoberyl
Allcharite = Goethite
Allenite = Pentahydrite
Allopalladium = Stibiopalladinite
Altmarkite = Lead amalgam
Alum = Hydrous alkali alumiunium sulfates
Alurgite = Mg, Fe, Mn Muscovite
Alvite = Hf-Zircon
Amazonite = Microcline
Amethyst = Purple Quartz
Amianthus = Tremolite, Actinolite, Chrysotile
Amosite = Grunerite, Cummingtonite
Ampangabeite = Samarskite
Amphigene = Leucite
Anarakite = Paratacamite
Andrewsite = Hentschelite + Rockbridgeite + Chalcosiderite
Annivite = Bi-Tetrahedrite
Antimonite = Stibnite
Aplome = Andradite
Applelite = Calcite
Apyrite = Rubellite (Elbaite)
Aquamarine = Beryl
Arduinite = Mordenite
Argentite = Acanthite
Argyrose = Argentite-Acanthite
Argyrythrose = Pyrargyrite
Arizonite = Pseudorutile, leucoxene
Arkansite = Brookite
Asbestos = Tremolite, Actinolite, Chrysotile
Ashtonite = Mordenite
Asphaltum = Mineral Pitch
Astrakhanite = Bloedite
Aventurine = Quartz + Mica
Badenite = Bismuth + Safflorite + Modderite
Baikalite = Diopside
Barkevikite = Fe-hornblende
Barsanovite = Eudialyte
Baryte = Barite
Bastonite = Biotite
Bauxite = Hydroxides and oxides of Al and Fe
Bellite = Mimetite
Belorussite = Byelorussite
Bentonite = Montmorillonite

Bertonite = Bournonite
Binnite = Tennantite
Bisbeeite = Plancheite-Chrysocolla
Blackjack = Sphalerite
Blanchardite = Brochantite
Bleiglanz = Galena
Blende = Sphalerite
Blockite = Penroseite
Bloodstone = Chalcedony
Borickite = Delvauxite
Boronatrocalcite = Ulexite
Brandisite = Clintonite
Braunbleierz = Pyromorphite
Bravoite = Ni-Pyrite
Breislakite = Vonsenite (Ludwigite, Fibrous Ilvaite)
Breunnerite = Fe-Magnesite
Brocenite = Ce-Fergusonite
Broggerite = Th-Uraninite
Bromlite = Alstonite
Bromyrite = Bromargyrite
Bronzite = Fe-Enstatite
Buratite = Aurichalcite
Byssolite = Actinolite-Tremolite
Cabrerite = Mg-Annabergite
Cairngorm = Smoky Quartz
Calamine = Hemimorphite
Calciumlarsenite = Esperite
Californite = Vesuvianite
Campylite = P-Mimetite
Canbyite = Hisingerite
Carbonado = Black Diamond
Carbonytrine = Y-Tengerite
Carborundum = Synthetic Moissanite
Carnelian = Carneol (Cornaline, Agate, Quartz)
Carneol (Carnelian, Cornaline) = Red Chalcedony (Quartz)
Carpathite = Karpatite (Coronene)
Carphosiderite = Hydrogeno-Jarosite
Caryocerite = Th-Melanocerite
Cathophorite = Brabantite
Catoptrite = Katoptrite
Cenosite = Kainosite
Centrallasite = Gyrolite
Cerargyrite = Chlorargyrite
Chalcedony = Quartz
Chalcolite = Torbernite
Chalcosine = Chalcocite
Chalcotrichite = Cuprite
Challantite = Ferricopiapite
Chalmersite = Cubanite
Chalybite = Siderite
Chathamite = Fe-Skutterudite
Chavesite = Monetite
Chengbolite = Moncheite
Chessylite = Azurite
Chiastolite = Andalusite
Chile Saltpeter = Nitratine (Soda Niter, Nitronatrite)
Chileloeweite = Humberstonite

Chloanthite = Nickelskutterudite
Chlorastrolite = Pumpellyite
Chlormanasseite = Altered Koenenite
Chloromelanite = Jadeite
Chloropal = Nontronite
Chlorotile = Agardite
Christensenite = Tridymite
Christianite = Anorthite or Phillipsite
Chromrutile = Redledgeite
Chrysolite = Olivine
Chrysoprase = Green Chalcedony (Quartz)
Cinnamon Stone = Hessonite (Grossular)
Cirrolite = Attacolite (Bearthite, Lazulite, Cyanite)
Citrine = Yellow Quartz
Cleveite = Uraninite
Cleavelandite = Albite
Cliftonite = Graphite
Clinobarrandite = Al-Phosphosiderite
Clinoeulite = Mg-Clinoferrosilite
Clinostrengite = Phosphosiderite
Cobaltoadamite = Adamite
Cobaltocalcite = Sphaerocobaltite
Coccinite = Moschelite
Coccolite = Diopside
Cocinerite = Chalcocite + Silver
Collophanite = Carbonated Apatite
Colophonite = Andradite
Columbite = Ferrocolumbite (Magnocol, Maganocol)
Comptonite = Thomsonite
Connarite = Garnierite
Copperas = Melanterite
Corindon = Corundum
Cornaline = Agate (Quartz)
Corundophilite = Clinochlore
Corynite = Sb-Gersdorffite
Coutinite = Nd-Lanthanite
Crestmoreite = Tobermorite + Wilkeite
Crocidolite = Riebeckite
Csiklovaite = Tetradymite + Galenobismutite + Bismuthinite
Cummingtonite = Amosite, Grunerite
Cyanite = Kyanite
Cyanose = Chalcanthite
Cymatolite = Muscovite + Albite
Cymophane = Chrysoberyl
Cyrtolite = Zircon
D'ansite = Dansite
Dahllite = Carbonated Hydroxylapatite
Dakeite = Schroeckingerite
Damourite = Muscovite
Danaite = Co-Arsenopyrite
Daphnite = Mg-Chamosite
Dashkesanite = K- Hastingsite
Davisonite = Apatite + Crandallite
Dehrnite = Carbonate-Fluorapatite
Delatorreite = Todorokite
Delessite = Mg-Chamosite
Delorenzite = Tanteuxenite

Deltaite = Crandallite + Hydroxy-apatite
Deltamooreite = Torreyite
Demantoide = Andradite
Dennisonite = Davisonite (Apatite + Crandallite)
Desmine = Stilbite
Destinezite = Diadochite
Dewalquite = Ardennite
Deweylite = Clinochrysotile-Lizardite
Diabantite = Fe-Clinochlore
Diallage = Diopside
Dialogite = Rhodochrosite
Diatomite =Tripolite (Opaline silica)
Dipyre = Scapolite
Disthene = Kyanite
Djalmaite = Uranmicrolite
Donatite = Chromite + Magnetite
Dornbergite (Doernbergite) = Bottinoite
Doverite = Synchysite
Droogmansite = Kasolite
Dubuissonite = Montmorillonite
Duporthite =Talc + Chlorite
Durdenite = Emmonsite
Dysanalyte = Nb-Perovskite
Dysodile = Resin
Eardleyite = Takovite
Eastonite = Phlogopite + Serpentine
Ekbergite = Wernerite
Elaterite = Mineral Rubber
Electrum = Au-Ag alloy
Eleonorite = Beraunite
Ellestadite = Fluorellestadite-Hydroxyellestadite
Ellsworthite = Uranpyrochlore
Embolite = Br-Chlorargyrite or Cl-Bromargyrite
Emerald = Beryl
Endellite (Hydrohalloysite) = Halloysite
Endlichite = As-Vanadinite
Enigmatite = Aenigmatite
Epidesmine = Stilbite
Epiianthinite = Schoepite
Eschynite = Aeschynite
Eucolite = Eudialyte
Fahlore = Tetrahedrite-Tennantite
Fassaite = Diopside or Augite
Femolite = Fe-Molybdenite
Fengluanite = Isomertieite
Ferchevkinite = Fe-Chevkinite
Fernandinite = Bariandite + Roscoelite + Gypsum
Ferridravite = Povondraite
Ferrifayalite = Laihunite
Ferrithorite = Thorite + Fe Hydroxide
Hematoide = Quartz + Goethite-Hematite
Ferutite = Davidite
Fibrolite = Sillimanite
Flint (Silex) = Quartz
Fluorichterite = Richterite
Fluorspar = Fluorite
Forbesite = Annabergite + Arsenolite

Forcherite = Opal
Fowlerite = Zn-Rhodonite
Francolite = Carbonated fluoroapatite
Freirinite = Lavendulan
Fuchsite = Cr-Muscovite
Fuggerite = Melilite
Genevite = Vesuvianite (Idocrase)
Genthite = Garnierite
Geyserite = Opal
Gilpinite = Johannite
Ginzburgite = Roggianite
Giobertite = Magnesite
Girasol = Opaline Quartz
Glagerite = Halloysite
Glaserite = Aphthitalite
Glauber's Salt = Mirabilite
Glaukolite (Glavcolite) = Scapolite
Glockerite = Lepidocrocite
Goongarrite = Heyrovskyite
Gorgyite = Goergeyite
Goshenite = Beryl
Grammatite = Tremolite
Grandite = Grossular-Andradite
Griffithite = Fe-Saponite
Grunerite = Cummingtonite, Amosite
Grunlingite (Gruenlingite) = Joseite + Bismuthinite
Gummite = Secondary uranium oxides
Hackmanite = Sodalite
Hatchettite = Hydrocarbons Mixture
Hatchettolite = Uranpyrochlore
Heliodor = Beryl
Heliotrope = Chalcedony or Plasma = Quartz
Hemafibrite = Synadelphite
Hessonite = Grossular
Heubachite = Ni-Heterogenite
Hexagonite = Mn-Tremolite
Hexastannite = Stannoidite
Hiddenite = Spodumene
Hjelmite = Tapiolite + Pyrochlore
Hokutolite = Pb-Barite
Hortonolite = Mg-Mn-Fayalite
Hoshiite = Ni-Magnesite
Huehnerkobelite = Alluaudite or Ferroalluaudite
Humboldtilite = Melilite
Hyacinth = Orange Zircon
Hyacinthe de Compostelle = Amethyste (Quartz)
Hyalite = Opal
Hyaloallophane = Allophane + Hyalite
Hyalosiderite = Fayalite
Hydrargillite = Gibbsite
Hydrated Halloysite = Endellite
Hydrogrossular = Hibschite-Katoite
Hydrohalloysite = Endellite
Hydromica = Brammallite, Hydrobiotite, Illite
Hydrophilite = Antarcticite or Sinjarite
Hydrotroilite = Colloidal Hydrous Ferrous Sulfide
Idocrase = Vesuvianite

Iglesiasite = Cerussite + Smithsonite
Indicolite = Indigolite = Elbaite
Iodobromite = I-Bromargyrite
Iodyrite = Iodargyrite
Iolite = Cordierite
Iozite = Wuestite
Iridosmine = Iridium osmium alloy
Fe-Cordierite = Sekaninaite
Iserine (Nigrine) = Ilmenite + Rutile
Isoplatinocopper = Hongshiite
Isostannite = Kesterite-Ferrokesterite
Jade = Jadeite (Nephrite)
Jasper = Quartz
Jefferisite = Vermiculite
Jeffersonite = Mn Zn Acmite or Augite
Jelletite = Andradite
Jenkinsite = Fe-Antigorite
Johnstrupite = Mosandrite
Josephinite = Awaruite, Kamacite, Taenite, Tetrataenite
Kalllilite = Ullmannite
Kamarezite = Brochantite
Kammererite (Kaemmererite) = Cr-Clinochlore
Karafveite = Monazite
Karpinskyite = Leifite + Clay
Kasoite = Celsian
Katayamalite = Baratovite
Keeleyite = Zinkenite
Keilhauite = Yttrian Titanite
Kellerite = Cu-Pentahydrite
Kennedyite = Armalcolite or Pseudobrookite
Kerchenite = Metavivianite
Kerolite = Talc
Kertschenite = Oxidation Product of Vivianite
Khlopinite = Ta-Samarskite
Klaprothite = Lazulite
Kleberite = Pseudorutile
Klipsteinite = Altered Rhodonite
Knebelite = Mn-Fayalite
Knipovichite = Cr-Alumohydrocalcite
Knopite = Perovskite
Kolskite = Lizardite + Sepiolite
Koppite = Pyrochlore
Kotschubeite = Cr-Clinochlore
Kramerite = Probertite
Kularite = Ce-Monazite
Kunzite = Spodumene
Kurskite = Carbonated fluorapatite
Lapis Lazuli = Lazurite
Lapparentite = Khademite (Rostite)
Laubmannite = Dufrenite + Kidwellite + Beraunite
Lavrovite = Diopside
Lazarevicite = As-sulvanite
Lehiite = Apatite + Crandallite
Leonhardtite = Starkeyite
Lepidomelane = Fe-Biotite
Lesserite = Inderite
Lettsomite = Cyanotrichite

Leuchtenbergite = Clinochlore
Leucochalcite = Olivenite
Leucoxene = Alteration of Ilmenite, pseudorutile, arizonite
Leverrierite = Kaolinite + Illite
Lewistonite = Carbonated fluorapatite
Lievrite = Ilvaite
Lingaitukuang = Brabantite
Liujinyinite = Uytenbogaardtite
Lotrite = Pumpellyite
Lovchorrite = Mosandrite
Lunijianlaite = Cookeite + Pyrophyllite
Lunnite = Pseudomalachite
Lusakite = Co-Staurolite
Lusungite = Goyazite
Lydian Stone (Basanite, Touchstone) = Quartz
Macconnellite = Mcconnellite
Mackintoshite = Thorogummite
Magnophorite = Ti-K-Richterite
Maitlandite = Thorogummite
Malacon = Zircon
Mangan Neptunite = Manganneptunite
Manganocalcite = Calcite
Manganomelane = Manganese oxides
Manganophyllite = Mn-Biotite
Mannacanite = Ilmenite
Marignacite = Ce-pyrochlore
Mariposite = Cr-Phengite
Marmatite = Fe-Sphalerite
Martite = Hematite Pseudomorph on Magnetite
Maskelynite = Glass of Plagioclase composition
Mauzeliite = Pb-Romeite
Medmontite = Chrysocolla + Mica
Melaconite = Tenorite
Melanite = Ti-Andradite
Melanochalcite = Tenorite (Chrysocolla, Malachite)
Melinose = Wulfenite
Melnikovite = Greigite
Menilite = Opal
Meroxene = Biotite
Merrilite = Whitlockite
Mesitite = Fe-Magnesite
Mesotype = Natrolite (Mesolite, Scolecite)
Metahalloysite = Halloysite
Metastrengite = Phosphosiderite
Metauranopilite = Meta-uranopilite
Minette = Iron Hydroxides And Oxides
Miomirite = Pb-Davidite
Mispickel = Arsenopyrite
Mizzonite = Marialite-Meionite
Moganite = Fine Crystalline Quartz
Mohsite = Pb-Crichtonite
Monheimite = Smithsonite
Monsmedite = Voltaite
Montdorite = Biotite
Montesite = Pb-Herzenbergite
Morencite = Nontronite
Morganite = Beryl

Morion = Quartz
Mossite = Tantalite-Tapiolite
Muchuanite = Altered Molybdenite
Mushketovite = Magnetite Pseudomorph on Hematite
Nanekevite = Ba-orthojoaquinite
Nasturan = Pitchblende
Nemalite = Fe-Brucite
Nenadkevite = Uraninite + Boltwoodite
Neotype = Barytocalcite
Nephrite = Actinolite
Nevyanskite = Iridosmine
Niccolite = Nickeline
Nickeliron = Kamacite (Taenite, Tetrataenite)
Nigrine (Iserine) = Ilmenite + Rutile
Nimesite = Brindleyite
Niobite = Ferrocolumbite
Niobozirconolite = Nb-Zirkelite
Nitroglauberite = Darapskite + Nitratine
Nitrokalit = Niter (Salpeter, Nitre, Salpetre)
Nitronatrite = Nitratine (Soda Niter)
Nocerite = Fluoborite
Nuevite = Samarskite
Nuttalite = Wernerite
O'danielite = Odanielite
Obruchevite = Y-pyrochlore
Yellow Ochre = Limonite
Octahedrite = Anatase
Oellacherite = Ba-Muscovite
Oligiste = Hematite
Oligonite = Mn-Siderite
Olivine = Peridot
Onofrite = Se-Metacinnabar
Onyx = Layered Chalcedony (Quartz)
Orthite = Allanite
Orthose = Orthoclase
Osmiridium = Iridium-osmium alloy
Outremer = Ultramarine (Lazurite)
Ozocerite = Hydrocarbons Mixture
Pageite = Vonsenite
Paigeite = Hulsite
Panabase = Tetrahedrite
Pandaite = Ba-pyrochlore
Pandermite = Priceite
Paranthine = Wernerite
Partridgeite = Bixbyite
Paternoite = Kaliborite
Paulite = Hypersthene
Pennine (Penninite) = Clinochlore
Pericline = Albite
Peridot = Forsterite
Peristerite = Albite
Perthite = Intergrowth Orthoclase + Plagioclase
Phacolite = Chabazite
Pharaonite = Microsommite
Phengite = Muscovite
Piazolite = Hydrogrossular
Picotite = Cr-Spinel

Picrochromite = Magnesiochromite
Pinite = Altered Cordierite
Pisanite = Cu-Melanterite
Pisekite = Monazite
Pistacite = Epidote
Pitchblende = Uraninite
Plasma = Green Quartz
Platiniridium = Iridium-platinium alloy
Pleonaste = Fe-Spinel
Plessite = Kamacite-Taenite
Plumbago = Graphite
Plumosite = Boulangerite
Polianite = Pyrolusite
Polyadelphite = Andradite
Porcelainite = Mullite
Prase = Green Quartz
Priorite = Aeschynite
Pseudowavellite = Crandallite
Psilomelane = Romanechite
Ptilolite = Mordenite
Pycnite = Topaz
Pyralspite = Garnet Subgroup
Pyrophyllite = Soapstone
Quercyite = Carbonate Apatite
Rashleighite = Fe-Turquoise
Resinite = Opal
Rhodusite = Mg-riebeckite
Rijkeboerite = Ba-microlite
Ripidolite = Fe-Clinochlore
Risorite = Fergusonite
Rock Salt = Halite
Roepperite = Fayalite or Tephroite
Rostite = Khademite
Rozhkovite = Pd-Auricupride
Rubellane = Altered Biotite
Rubellite = Elbaite
Ruby = Corundum
Ruby Silver = Proustite, Pyrargyrite
Ruthenosmiridium = Iridium-Osmium-Ruthenium alloy
Sagenite = Rutile
Sal Ammoniac = Salmiac
Salite = Sahlite = Diopside
Salmiac = Salammoniac (Sal Ammoniac)
Salpeter = Niter (Nitre, Salpetre, Nitrokalit)
Samiresite = Pb-Uranpyrochlore
Sapphire = Corundum
Sard = Brown Chalcedony
Saukovite = Cd-Metacinnabar
Saussurite = Zoisite (Scapolite)
Schefferite = Mn-Aegirine
Scheibeite = Phoenicochroite
Schizolite = Mn-Pectolite
Schoenite = Picromerite
Schuchardtite = Clinochlore (Vermiculite)
Schwatzite (Schwazite) = Hg-Tetrahedrite
Schweizerite = Serpentine
Rock salt = Halite

Selenite = Gypsum
Sericite = Muscovite
Seybertite = Clintonite
Sheridanite = Clinochlore
Sideretine = Pitticite
Siderochrome = Chromite
Siserskite (Syserskite) = Iridosmine
Smaltite = Skutterudite
Smoky Quartz = Brown Quartz
Soapstone = Pyrophyllite
Sobotkite = Al-Saponite
Soda Feldspar = Albite
Soda Niter = Nitratine (Nitronatrite)
Sophiite = Sofiite
Spartalite = Zincite
Specularite = Hematite
Sphene = Titanite
Staffelite = Carbonated fluorapatite
Staringite = Cassiterite + Tapiolite
Stassfurtite = Boracite
Steatite = Talc
Steinsalz = Halite
Stibine = Stibnite (Antimonite)
Strahlstein = Actinolite
Succinite = Amber
Sukulaite = Sn-microlite
Sylvinite = Halite + Sylvite
Syssertskite = Osmium
Taaffeite = Musgravite
Tagilite = Pseudomalachite
Tanzanite = Zoisite
Tarasovite = Mica-Smectite M
Tarnowitzite (Tarnowskite) = Pb-Aragonite
Tavistockite = Apatite
Tellurbismuth = Te-bismuthite
Ternovskite = Mg-riebeckite
Teruelite = Dolomite
Thulite = Zoisite
Thuringite = Fe-Chamosite
Tibiscumite = Allophane
Tiger Eye = Quartz + Crocidolite
Tincal = Borax
Toddite = Columbite + Samarskite
Topazolite = Andradite
Treanorite = Allanite
Triphane = Spodumene
Troostite = Mn-Willemite
Trudellite = Chloraluminite + Natroalunite
Tsavolite = Tsavorite = Grossular
Turgite = Turjite (Hematite)
Turnerite = Monazite
Ufertite = Davidite
Ugrandite = Garnet subgroup
Ultramarine = Lazurite
Ulvite = Ulvospinel
Uralite = Amphibole
Uranite = Autunite

Uranotile = Uranophane
Uranotile Beta = Uranophane Beta
Vegasite = Pb-jarosite
Verdelite = Tourmaline
Vernadskite = Antlerite
Vibertite = Bassanite
Viridine = Mn-Andalusite
Voltzite = Wurtzite
Vorobievite = Beryl
Vredenburgite = Jacobsite + Hausmannite
Vulpinite = Anhydrite
Wad = Mangnese Oxides
Walchowite = Resinoid
Warrenite = Owyheeite (Jamesonite)
Westgrenite = Bi-microlite
Wiikite = Y-pyrochlore + Euxenite
Wilkeite = Apatite (Fluorellestadite)
Williamsite = Antigorite
Withamite = Piemontite
Wolframite = Huebnerite-Ferberite
Wood Tin = Cassiterite
Yttroorthite = Y-Allanite
Zeiringite = Aragonite + Aurichalcite
Zigueline = Chalcopyrite + Cuprite + Limonite + Cinnabar
Zinconine = Hydrozincite
Zinkblende = Sphalerite

12.9 Further Reading

12.9.1 Crystallography

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