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REVISED BY

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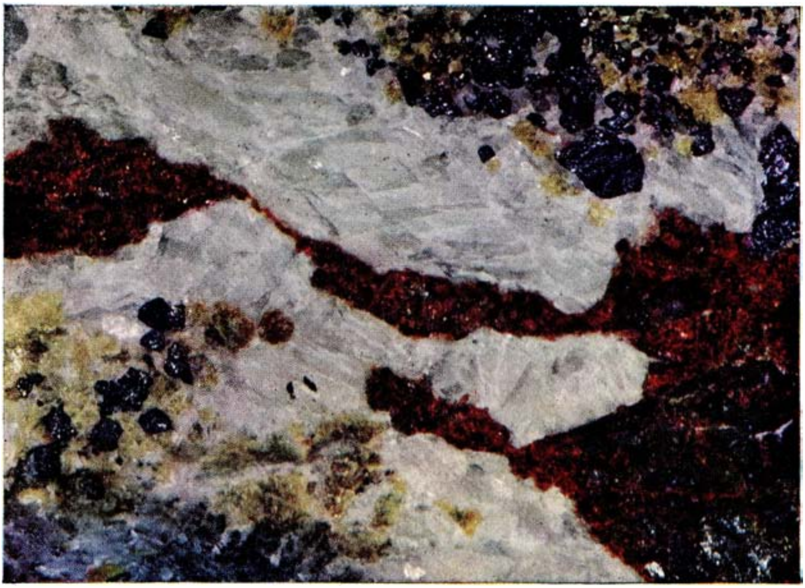

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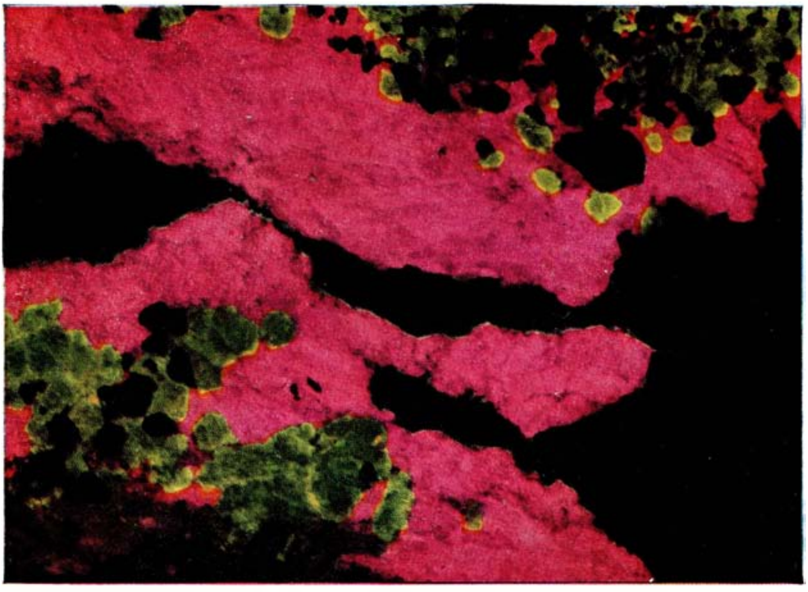

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Fluorescent Specimen from Franklin, New Jersey.
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Grateful acknowledgment is given to Professors Charles Palache and Harry Berman and their co-workers engaged in the preparation of the seventh edition of *Dana's System of Mineralogy.* As much of the manuscript as had been completed was made available, and material was drawn freely from it. The author is also indebted to Professor B. M. Shaub for the photographs.

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INTRODUCTION

A mineral may be defined as any naturally occurring chemical element or compound formed as a product of inorganic processes. This eliminates all artificial products of the laboratory as well as all natural products formed by organic agencies. The above definition is brief; and, though it embraces most of the substances considered as minerals in this book, it should be considerably expanded to be all-inclusive.

Minerals are the materials of which most of the rocks of the earth's crust consist and are, therefore, among the common objects of daily observation. The great majority of rocks are not made up of single minerals, but are more or less heterogeneous aggregates of several different species. A few rocks, like limestone and quartzite, consist of but one mineral in a more or less pure state. In addition to occurring as essential and integral parts of rocks, minerals are found distributed through them in a scattered way, or in veins and cavities.

Divisions of Mineralogy

Mineralogy is the science which describes, classifies, and correlates the different mineral species. The treatment on the following pages divides the science into five branches:

1. **Chemical Mineralogy.** The chemical composition, as determined by analysis, is the most important character of minerals, for it serves largely to define and distinguish the species. Moreover, it is upon chemical composition that the classification of minerals rests. Owing to difference in composition, minerals exhibit great differences when subjected to the action of various chemical reagents, and these reactions may be an important means of determining any given mineral.

2. **Crystallography.** Most minerals that have grown without outside interference assume definite and characteristic shapes by which they may be known. Such minerals, bounded by plane surfaces arranged according to the laws of symmetry, are called crystals. Crystallography deals not only with the study of these external faces and the laws that govern their arrangement but also with the internal structure which is characteristic for each species.

3. **Physical Mineralogy.** This branch of the science deals with the various physical properties of minerals such as hardness, specific gravity,

color, and luster. The physical properties, being usually easily and quickly obtained, are important in mineral determination.

4. **Descriptive Mineralogy.** The detailed descriptions of individual mineral species, including chemical, crystallographic, and general physical characters, together with occurrence, associations, and uses, are included in this section.

5. **Determinative Mineralogy.** This division includes the methods used for mineral identification.

These different branches of the subject are taken up in this book in the following order: I. *Crystallography.* II. *Physical Mineralogy.* III. *Chemical Mineralogy.* IV. *Descriptive Mineralogy.* V. *Determinative Mineralogy.*

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MANUAL OF MINERALOGY

I. *CRYSTALLOGRAPHY*

A. INTRODUCTION

Definition. The great majority of minerals, when the conditions of formation are favorable, occur in definite and characteristic geometrical forms known as crystals. The study of these bodies and the laws which govern their growth, shape, and geometric character is called *crystallography.* Although crystallography was developed as a branch of mineralogy, it has now reached such proportions that it has become a separate science in itself. An exhaustive discussion of it would, therefore, require a volume much larger than the present one. In the following section the elements of crystallography are presented in a brief and simple manner to introduce to the reader the more essential facts and principles of the subject.

A crystal is a homogeneous body bounded by smooth plane surfaces that are the external expression of an orderly internal atomic arrangement. This is a compact definition that will be elaborated upon in the following paragraphs.

There is a growing tendency, especially by physicists, to use the term *crystal* in reference to any solid that has a definite atomic structure whether or not it possesses external faces. Since such usage is contrary to that of most mineralogists, and since it requires the use of modifiers, it seems advisable to use the term crystal in the restricted sense as defined above. The term *crystalline* is a general one denoting the ordered arrangement of atoms in the structure, and crystal refers specifically to the external expression of that order as faces on the crystalline substance. *Cryptocrystalline* is applied to crystalline substances that are so fine-grained that the crystalline nature can be determined only with the aid of the microscope. The term *amorphous* is applied to those substances in which the orderly atomic structure is entirely wanting.

Crystallization. A better idea of the fundamental laws of crystallography will be obtained by first considering the three prominent modes of crystallization. Crystals are formed from (1) solution, (2) fusion, or (3) vapor.

The first, crystallization from solution, is the most familiar to our ordinary experience. Consider, for example, a solution of sodium chloride (common salt) in water. Suppose that by evaporation the water is slowly driven off. Under these conditions the solution will gradually contain more and more salt per unit volume. Ultimately the point will be reached where the amount of water present can no longer retain all the salt in solution, and the salt must begin to precipitate out. In other words, part of the sodium chloride, which up to this point has been held in a state of solution by the water, now assumes a solid form. If the conditions are so arranged that the evaporation of the water goes on very slowly, the separation of the salt in solid form will progress equally slowly and definite crystals will result. The particles of sodium chloride as they separate from the solution will by the laws of molecular attraction group themselves together and gradually build up a definitely shaped solid which we call a crystal. Crystals can also be formed from solution by lowering the temperature or pressure of the solution. Hot water will dissolve slightly more salt, for instance, than cold; and, if a hot solution is allowed to cool, a point will be reached where the solution becomes supersaturated for its temperature and salt will crystallize out. Again, the higher the pressure to which water is subjected the more salt it can hold in solution. So with the lowering of the pressure of a saturated solution supersaturation will result and crystals form. Therefore, in general, crystals may form from a solution by the evaporation of the solvent, by the lowering of the temperature, or by a decrease in pressure.

A crystal is formed from a fused mass in much the same way as from a solution. The most familiar example of crystallization from fusion is the formation of ice crystals when water freezes. Though it is not ordinarily considered in this way, water is fused ice. When the temperature is sufficiently lowered the water can no longer remain liquid, and it becomes solid by crystallization into ice. The particles of water which were free to move in any direction in the liquid now become fixed in their position and by the laws of molecular attraction arrange themselves in a definite order to build up a solid crystalline mass. The formation of igneous rocks from molten magmas, though more complicated, is similar to the freezing of water. In the fluid magma there are many elements in a dissociated state. As the magma cools these elements gradually group themselves into different mineral molecules, which gather together and slowly crystallize to form the mineral particles of the resulting solid rock.

The third mode of crystal formation, that in which the crystals are produced from a vapor, is less common than the other two described above. The principles that underlie the crystallization are much the same. The dissociated chemical atoms, through the cooling of the gas, are brought closer together until at last they form a solid with a definite crystal structure. The most familiar example of this mode of crystallization is the formation of snowflakes: air laden with water vapor cools and snow crystals form directly from the vapor. Another example of this type of crystallization is seen in the formation of sulfur crystals about the mouths of fumaroles in volcanic regions, where crystals have been deposited from sulfur-bearing vapors.

Properties of Crystals. *Structure.* The most fundamental and important fact concerning crystals is that the atoms of which they are composed are arranged in an orderly manner. A crystal, therefore, must be pictured as built up of an almost infinite number of exceedingly minute particles arranged in a three-dimensional pattern called a *lattice.* The term *structure* is applied to this configuration within a crystal. It is possible in many crystals to determine not only the kind of lattice but also its dimensions and to place in the lattice the positions of the various kinds of atoms present. The unit of structure must be considered as the smallest portion of the crystal that still possesses the characteristic properties of the crystal. This unit, called the *unit cell,* can be thought of as being repeated over and over in space to build up the crystal. The unit cell can never be as small as the individual atom, since the relations of the atoms to each other are important factors in determining the properties of the substance. For instance, in quartz the structural unit has been shown to consist of three molecules of SiO_2. Any smaller subdivision would not have the properties of the mineral. The proof that a crystal does possess a definite internal structure is found in consideration of its other properties, of which the following are the most important.

X-ray diffraction. Because of various physical and optical properties, it has long been known that crystals must possess some sort of orderly internal structure. It is only within comparatively recent years with the use of x-rays that the true nature of this structure has been recognized. The beginning of x-ray crystallography was in 1912 when, at the suggestion of Laue, Friedrich and Knipping of the University of Munich carried out the original experiment. Earlier attempts to diffract x-rays had been unsuccessful. Laue conceived the idea of using the ordered arrangement of atoms in a crystal as a diffraction grating. He argued that, if the spacing between parallel atomic planes of the crystal lattice were of the same order of magnitude as the wave length of the x-rays, diffraction should result. Therefore, a narrow beam of x-rays was passed through a crystal and permitted to fall on a photographic plate. The developed plate showed a large number of small spots arranged in a geometrical pattern around the larger spot caused by the direct beam. The pattern was shown to be the result of diffraction of x-rays by a regular arrangement of scattering points within the crystal. In addition to a new method of studying x-rays, this experiment pointed the way to a most important means of studying the internal structure of crystals. Figure 1, Plate I, is an example of a typical *Laue photograph.* The dark spots indicate the relative position in the crystal lattice of atomic planes, and their arrangement indicates the symmetry of the crystal. The Laue method is still used, but, since " white " x-radiation (radiation containing all wave lengths within certain limits) is necessary, quantitative interpretation of the photographs is difficult. Its chief use today is as an aid in the determination of the symmetry of crystals.

Shortly after the original experiment, W. H. Bragg, by an ingenious method, was able to determine in a single experiment on rock salt both the wave length of the x-rays and the spacing of the atomic planes of the salt crystal. He used " monochromatic " x-radiation (radiation of essentially one wave length) and an ionization chamber with which he could measure the relative intensities of diffracted radiation for different positions of a single crystal. This method of Bragg's is little used because of the complexity of the apparatus and the time required to make the readings. Nevertheless, it was a major step forward in the development of x-ray crystallography, since it provided a means of determining the wave length of x-rays. Once the wave length of x-rays was known, it became possible to measure the structural constants of all crystals.

The powder method is today more widely used than any other to study crystal structure by means of x-rays. " Monochromatic " radiation is used, and the crystalline material to be investigated is ground to an extremely fine powder. The powder is either packed into a capillary tube or held together by a binder and shaped into a needlelike aggregate. This mount is then placed at the axis of a cylindrical camera, and the x-ray beam is permitted to fall on it. The diffracted radiation is recorded on a film wrapped around the inside of a cylindrical camera (Fig. 2, Plate I). Since the particles of the powder are randomly oriented, all the atomic planes will be in position to " reflect " simultaneously. From the position of the lines on the film, the struc-

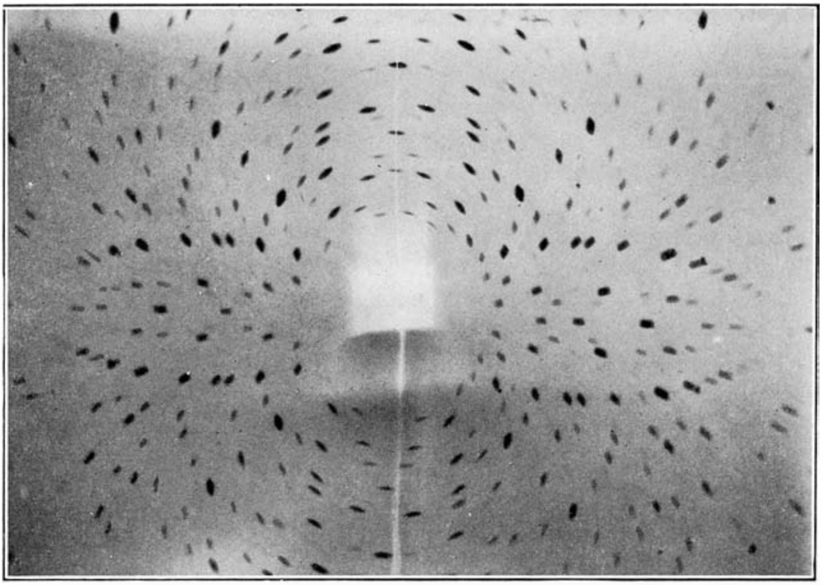

FIG. 1. Laue Photograph of Apophyllite.

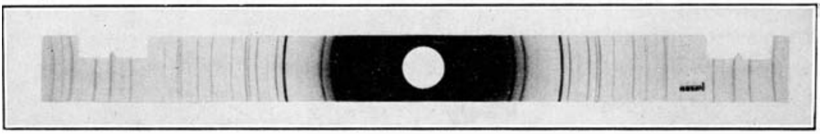

FIG. 2. Powder Photograph of Cassiterite.

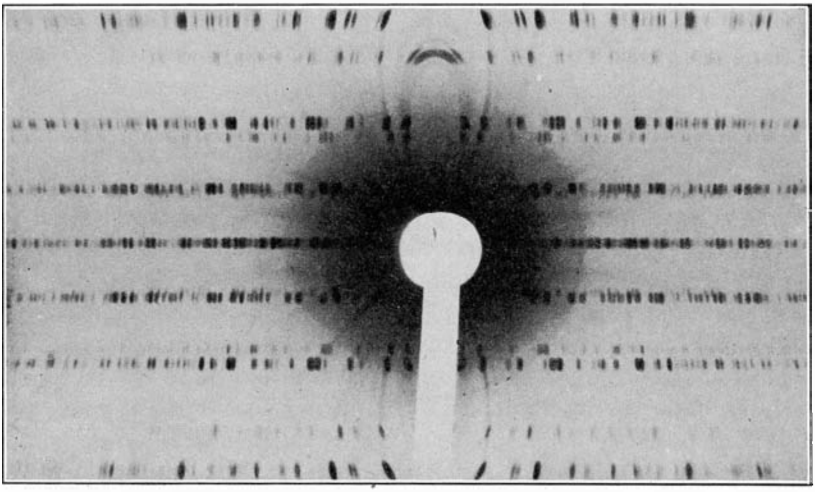

FIG. 3. Rotation Photograph of Scolecite.

PLATE I

tures of crystals belonging to the systems of higher symmetry can be calculated. The powder method is also used as a means of mineral identification, for, if a photograph of an unknown mineral corresponds exactly to the photograph of a known species, the two minerals are identical.

For the purpose of determining the structural constants of crystals the rotation method is the most powerful. This method employs " monochromatic " radiation and a single crystal that is rotated about a major axis. Either a flat photographic plate or a cylindrical film with the axis of rotation of the crystal coinciding with the axis of the film may be used. When a pencil of x-rays strikes the rotating crystal, the resulting diffraction is recorded on the plate or film (Fig. 3, Plate I). By this method one can calculate the atomic spacing along the axis of rotation. Thus, in the general case, one can determine the dimensions of the unit cell by taking three rotation photographs, using the three principal crystallographic axes as axes of rotation. More accurate measurements can be made on photographs taken by the Weissenberg method, a refinement of the rotation method.

Cleavage. Many crystals when fractured break along smooth plane surfaces known as cleavage planes. Common salt, halite, for example, cleaves equally well in three different directions at right angles to each other. These planes of cleavage are always parallel to the external crystal faces most commonly found on halite. If the internal structure were heterogeneous, the cleavage would be inexplicable. It can be explained only by assuming some definite internal structure which permits and controls such a cleavage.

Optical properties. All nonopaque substances refract the light which passes through them. In addition to this, many crystals produce changes in the nature of the light which cannot be accounted for except through the constraining influence of the internal structure of the crystal. Consider calcite as an example. In general, a double image will be seen if one observes an object through a clear block of calcite (Plate V). Thus the mineral has the power of doubly refracting light. It can be proved, in addition, that each of the two rays emerging from the calcite has a definite plane of vibration, i.e., each ray is polarized. A block of glass similar in shape will not produce these effects, because it lacks the definite internal structure possessed by the calcite.

Outward form. If crystals are considered to be made up by the repetition in three dimensions of a unit of structure, the unit cell, the limiting surfaces depend both on the shape of the units and on the environment in which they are brought together. Environment as used here includes all the external influences such as temperature, pressure, nature of solution, speed of crystal growth, surface tension, and direction of the movement of the solution. As a simple illustration, consider a pile of ordinary bricks of identical size and shape. If they are stacked together according to a regular plan, the form of the resulting mass will depend upon the shape of the individual bricks and the conditions which governed their arrangement. A cubic mass might result from one method of stacking, and a pyramidal mass might result from another. In any event, if a law of arrangement has been followed, the resulting pile will, as a whole, appear as a regular and definitely shaped solid. On the other hand, if bricks of different sizes and shapes were stacked together in a haphazard fashion, the external appearance of the whole would be totally lacking in regularity. Since crystals do have a regular external form, it must follow that they have an orderly internal structure.

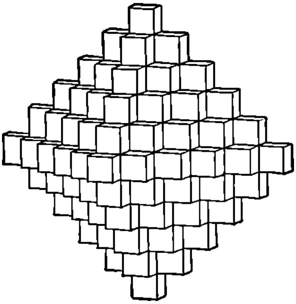

FIG. 1. Octahedron Built of Small Cubes.

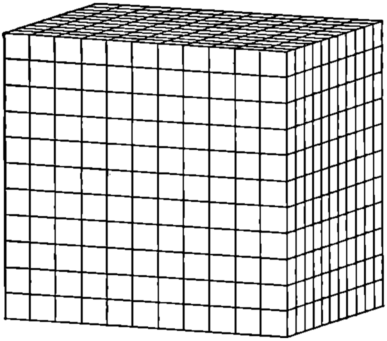

FIG. 2. Large Cube Built of Small Cubes.

The fluorite illustrated in Figs. 1 and 2 shows how it is possible for crystals of a given mineral to have different external forms as the outward expression of the same internal structure. As in the example of the bricks, the building units are identical in both the cube and octahedron, but the rate of growth in different directions varies.

With a given internal structure there are, however, only a certain number of probable planes which serve to limit a crystal. It is to be noted, moreover, that only comparatively few occur commonly. The positions of the faces of a crystal are determined by those directions through the internal structure along which the greatest number of crystal units lie. Those planes which include the greatest number of units are the ones most commonly found as faces upon the crystals. Consider Fig. 3, which represents one layer of units in a certain crystal lattice. The units are equally spaced from one another and have a rectilinear arrangement. It will be noted that there are several possible lines through this network that include a greater or lesser number of units. These lines would represent the trace on this section of possible crystal planes; and it would be found that of these possible planes those which include the larger number of units, those cutting along *A–B* and *A–C*, would be most common. Observation generally confirms this rule.

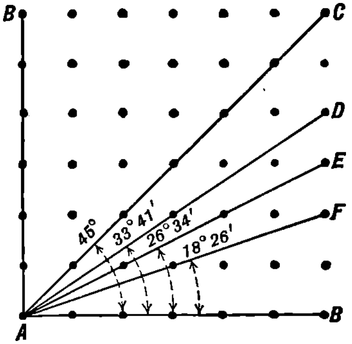

Fig. 3. Net of Crystal Points.

Since the internal structure of any crystalline substance is constant and since the crystal faces have a definite relationship to that structure, it follows that the faces must also have a definite relationship to each other. This fact is known as the **law of the constancy of interfacial angles,** which may be stated as follows: The angles between corresponding faces on crystals of the same substance are constant. Figure 3 will also illustrate this point. Since it is a square network, the face which cuts along the line *A–C* must make an angle of 45° with the face which cuts along the line *A–B*, etc. This law is fundamental and the most important in the science of crystallography. It frequently enables one to identify a mineral by the measurement of the interfacial angles on its crystals. A mineral may be found in crystals of widely varying shapes and sizes, but the angles between pairs of corresponding faces are always the same.

An important part of the study of crystallography consists in measuring the interfacial crystal angles. These measurements are accomplished by means of instruments known as goniometers. For accurate work, particularly with small crystals, a type of instrument known as a reflection goniometer is used. This is an instrument upon which the crystal to be measured is mounted so as to reflect beams of light from its faces through a telescope to the eye. The angle through which a crystal must be turned in order to throw successive beams of light from two adjacent faces into the telescope determines the angle between the faces. A simpler instrument used for approximate work and with larger crystals is known as a contact goniometer. Its appearance and use are illustrated by Fig. 4.

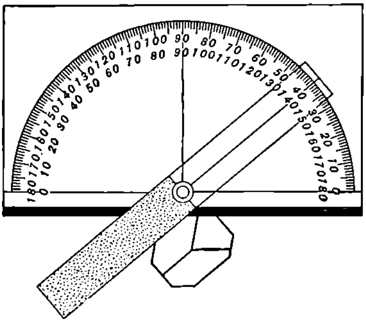

FIG. 4. Contact Goniometer.

In the preceding paragraphs x-ray diffraction, cleavage, optical properties, and external form of crystals have all been briefly presented as proof of the orderly internal structure. Since the units of repetition forming the structure are identical both physically and chemically, it can be said that a crystalline mineral is a homogeneous substance with a definite and uniform chemical composition. This is a general statement and will suffice for the present; certain modifications will be found on page 92 under isomorphism. A crystal is a guaranty of the chemical homogeneity of a mineral. From this it follows that only definite chemical compounds are capable of crystallization.

B. SYMMETRY

All crystals show by the arrangement of their faces a definite symmetry which enables one to group them into different classes. The various operations that can be performed upon a crystal which result in bringing it into coincidence with the initial position are known as the *elements of symmetry.* The fundamental symmetry operations consist of: (1) rotation about an axis, (2) reflection in a plane, (3) a combined rotation about an axis and reflection in a plane perpendicular to the axis (rotary reflection). Inversion about a center is considered by some a distinct symmetry operation. Since it is equivalent to a 2-fold axis of rotary reflection (see below), it is not here considered fundamental, although the term *center* is used for convenience.

Symmetry Plane. A symmetry plane is an imaginary plane which divides a crystal into halves, each of which, in a perfectly developed crystal, is the mirror image of the other. The shaded portion of Fig. 5 illustrates the nature and position of such a plane of symmetry. For each face, edge, or point on one side of the plane there is a corresponding face, edge, or point in a similar position on the other side of the plane.

Symmetry Axis. A symmetry axis is an imaginary line through a crystal about which the crystal may be revolved and repeat itself in appearance two or more times during a complete revolution. In Fig. 6 the line C–C' is an axis of symmetry, for the crystal represented, when revolved upon it, will have, after a revolution of 180°, the same appearance as at first; or, in other words, similar planes, edges, and solid angles will appear in the places of the corresponding planes, edges, and solid angles of the original position. Point A' will occupy the original position of A, B' that of B, etc. Since the crystal is repeated twice in appearance during a complete revolution, this axis is said to be one of 2-fold or binary symmetry. In addition to axes of 2-fold symmetry there are axes of 3-fold (trigonal), 4-fold (tetragonal), and 6-fold (hexagonal) symmetry. The nature of crystals is such that no axes other than 2-, 3-, 4-, and 6-fold can exist.

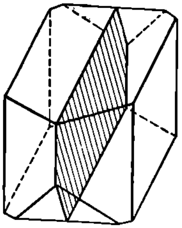

FIG. 5. Symmetry Plane.

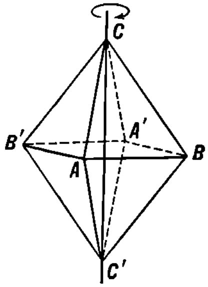

FIG. 6. Symmetry Axis.

Axis of Rotary Reflection. This composite symmetry element combines a rotation about an axis with reflection across a plane at right angles to the axis. Both operations must be completed before the new position is obtained. Figure 7 illustrates a 2-fold axis of rotary reflection. The solid point p' can be developed by rotating p 180° about the axis and then reflecting it in the plane m. Figure 8 illustrates a crystal with a 2-fold axis of rotary reflection.

Center of Symmetry. A crystal is said to have a center of symmetry if an imaginary line can be passed from any point on its surface through its center and a similar point is found on the line at an equal distance beyond the center. The crystal in Fig. 8 thus has a center of symmetry, for the point A is repeated at A' on the line passing from A through the center, C, of the crystal; the distances AC and $A'C$ are equal. It will be noted that this operation of inversion about a center is equivalent to a 2-fold axis of rotary reflection; and consequently, in the following discussions, the term *center* is used rather than *axis of 2-fold rotary reflection.*

Symmetry Notation. In describing the symmetry of a crystal, it is convenient to use a kind of shorthand notation of the symmetry elements. A rotation axis is indicated by A_n, an axis of rotary reflection by AP_n, where n is 2, 3, 4 or 6, depending on the symmetry; a plane by P, and a center by C. In this way the symmetry of a crystal with a center, four axes of 2-fold symmetry, one axis of 4-fold symmetry, and five planes would be written: C; $4A_2$, $1A_4$; $5P$.

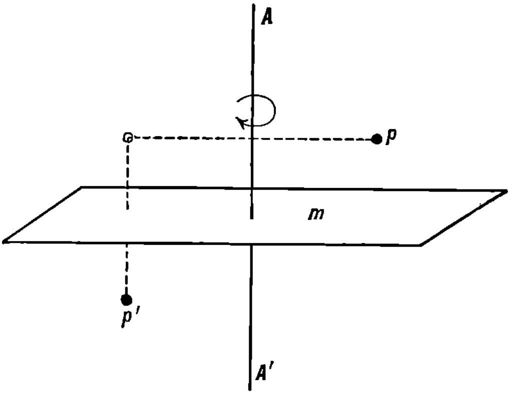

FIG. 7. Axis of Rotary-Reflection.

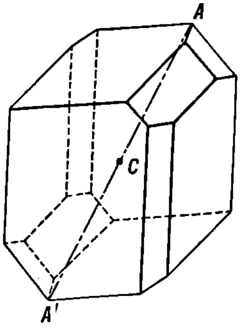

FIG. 8. Symmetry Center.

Classes of Symmetry. Different combinations of the various symmetry elements just described give rise to thirty-two distinct crystal classes. From theoretical considerations it has been shown that these comprise all the possible symmetry classes of crystals. These thirty-two classes may be grouped further into six systems, the classes of each system having certain close relations to one another. Of the thirty-two possible crystal classes the majority are of little interest to the mineralogist, since practically all known mineral species can be placed in one of ten or twelve classes. In the table on page 12 are listed all the crystal classes with their symmetry elements. The most important classes for the mineralogist, those considered in some detail on the following pages, are indicated in bold-face type.

Many different names have been used to designate each of the crystal classes. The names used here were proposed by Groth and are derived from the name of the general form in each crystal class, i.e., the form whose faces intersect all the crystallographic axes at different lengths.

The Thirty-Two Crystal Classes

Crystal System	Crystal Class	Symmetry
Isometric	**Hexoctahedral**	$C, 3A_4, 4A_3, 6A_2, 9P$
	Gyroidal	$3A_4, 4A_3, 6A_2$
	Hextetrahedral	$3A_2, 4A_3, 6P$
	Diploidal	$C, 3A_2, 4A_3, 3P$
	Tetartoidal	$3A_2, 4A_3$
Hexagonal Hexagonal division	**Dihexagonal-dipyramidal**	$C, 1A_6, 6A_2, 7P$
	Hexagonal-trapezohedral	$1A_6, 6A_2$
	Dihexagonal-pyramidal	$1A_6, 6P$
	Ditrigonal-dipyramidal	$1A_3, 3A_2, 4P$
	Hexagonal-dipyramidal	$C, 1A_6, 1P$
	Hexagonal-pyramidal	$1A_6$
	Trigonal-dipyramidal	$1A_3, 1P$
Hexagonal Rhombohedral division	**Hexagonal-scalenohedral**	$C, 1A_3, 3A_2, 3P$
	Trigonal-trapezohedral	$1A_3, 3A_2$
	Ditrigonal-pyramidal	$1A_3, 3P$
	Rhombohedral	$C, 1A_3$
	Trigonal-pyramidal	$1A_3$
Tetragonal	**Ditetragonal-dipyramidal**	$C, 1A_4, 4A_2, 5P$
	Tetragonal-trapezohedral	$1A_4, 4A_2$
	Ditetragonal-pyramidal	$1A_4, 4P$
	Tetragonal-scalenohedral	$3A_2, 2P$
	Tetragonal-dipyramidal	$C, 1A_4, 1P$
	Tetragonal-pyramidal	$1A_4$
	Tetragonal-disphenoidal	$1A\!\!\!P_4$
Orthorhombic	**Rhombic-dipyramidal**	$C, 3A_2, 3P$
	Rhombic-disphenoidal	$3A_2$
	Rhombic-pyramidal	$1A_2, 2P$
Monoclinic	**Prismatic**	$C, 1A_2, 1P$
	Sphenoidal	$1A_2$
	Domatic	$1P$
Triclinic	**Pinacoidal**	C
	Pedial	No symmetry

C. CRYSTAL NOTATION

Crystallographic Axes. It is found convenient in describing crystals to assume, after the methods of analytic geometry, certain lines passing through the center of the ideal crystal as axes of reference. These imaginary lines are called the *crystallographic axes.* The positions of the crystallographic axes are more or less fixed by the symmetry of the crystals, for in most crystals they are symmetry axes or normals to symmetry planes.

All crystals, with the exception of those belonging to the hexagonal system (see page 33), are referred to three crystallographic axes. In the general case (triclinic system), all the axes are of different lengths and at oblique angles to one another; but for simplicity in describing their conventional orientation consider those illustrated in Fig. 9. Here the three axes are mutually perpendicular and when placed in the proper position for description are oriented as follows: One axis, called *a*, is horizontal and perpendicular to the observer; another axis, called *b*, is horizontal and parallel to the observer; the third axis, called *c*, is vertical. The ends of each axis are designated by either a plus or a minus sign; the front end of *a*, the right-hand end of *b*, and the upper end of *c* are positive; the opposite ends, negative.

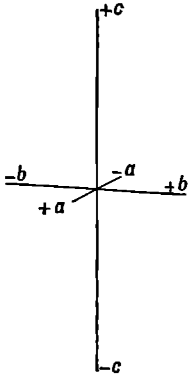

FIG. 9. Orthorhombic Crystal Axes.

Crystal Systems. Certain of the thirty-two crystal classes mentioned above have properties in common with others which permit their assignment to larger groups called *crystal systems.* There are six crystal systems that are defined in terms of the crystallographic axes.

The **isometric system** includes all those crystals which can be referred to three mutually perpendicular axes of equal lengths.

The **hexagonal system** includes all those crystals which are referred to four axes. Three equal horizontal axes intersect at angles of 60°, while the fourth is of different length and perpendicular to the plane of the other three.

The **tetragonal system** includes all those crystals which can be referred to three mutually perpendicular axes; the two horizontal axes are of equal length, but the vertical axis is either shorter or longer than the other two.

The **orthorhombic system** includes all those crystals which are referred to three mutually perpendicular axes, all of different lengths.

The **monoclinic system** includes all those crystals which are referred to three unequal axes, two of which are inclined to one another at an oblique angle and the third is perpendicular to the plane of the other two.

The **triclinic system** includes all those crystals which are referred to three unequal axes all intersecting at oblique angles.

Axial Ratio. In all the crystal systems, with the exception of the isometric, there are crystallographic axes differing in length. In these systems the length of one of the horizontal axes is taken as unity, and the others are expressed in terms of it. An *axial ratio* is thus obtained which expresses the relative, not the absolute, lengths of the crystallographic axes. Thus the axial ratio of orthorhombic sulfur, $a : b : c = 0.813 : 1 : 1.903$, is just as accurate for a crystal of microscopic size as it is for one several inches across.

The elementary student cannot be expected to calculate an axial ratio, but its meaning will be clearer if he understands the manner in which it is done. Take for example the orthorhombic mineral sulfur, whose axial ratio is given above. The crystal is oriented, and a dominant face or form (see page 17) is selected that cuts all three crystallographic axes at unit lengths (Fig. 10). This unit form is selected arbitrarily, and it is assumed that it cuts the axes at unit lengths. The length along the b axis is taken as unity. By reference to Fig. 11 it can be seen that, expressed in terms of $b = 1$, $a = \tan 39° 7' = 0.813$. Similarly, from Fig. 12, it can be seen that $c = \tan 62° 17' = 1.903$. Since the unit lengths of a and c must always be expressed as the tangents of angles, it follows that they will be irrational numbers. The angles used in the calculation of an axial ratio, as those shown in Figs. 11 and 12, are found by determining the interfacial angles on the crystals, the accurate measurement of which must be left to the advanced crystallographer.

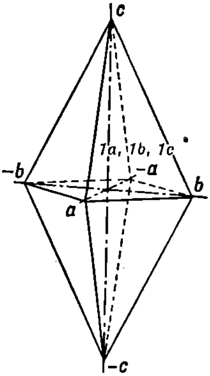

Fig. 10. Dipyramid of Sulfur.

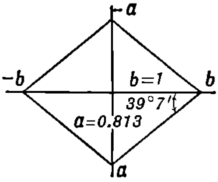

Fig. 11.

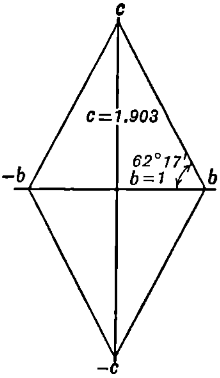

Fig. 12.

Sections through Sulfur Dipyramid.

Parameters. Crystal faces are described according to their relations to the crystallographic axes. A series of numbers which indicate the relative distances at which a face intercepts the different axes are called its parameters. A face which cuts all three axes at distances (from the point of their intersection) which are relatively the same as the unit lengths of the axes is said to have the following parameters: 1*a*, 1*b*, 1*c* (see Fig. 10). A face which cuts the two horizontal axes at distances which are proportional to their unit lengths and cuts the vertical axis at a distance twice its relative unit length will have for parameters 1*a*, 1*b*, 2*c*. It is to be emphasized that these parameters are strictly relative in their values and do not indicate any actual cutting lengths. To illustrate this further, consider Fig. 13, which represents a possible sulfur crystal. The forms present upon it are two dipyramids of different slope but each intersecting all three of the crystal axes when properly extended. The lower dipyramid intersects the two horizontal axes at distances which are proportional to their unit lengths. The parameters of the face of this dipyramid which cuts the positive ends of the three axes would be 1*a*, 1*b*, 1*c*. The upper dipyramid would cut the two horizontal axes, as shown by the dotted lines, also at distances which, although greater than in the lower dipyramid, are still proportional to their unit lengths. It cuts the vertical axis, however, at a distance which, when considered in respect to its intersections with the horizontal axes, is proportional to one-half of the unit length of *c*. The parameters of a face of this form would therefore be 1*a*, 1*b*, $\frac{1}{2}c$. From this it will be seen that the parameters 1*a*, 1*b*, do not in the two examples represent the same actual cutting distances but express only relative values. The parameters of a face do not in any way determine its size, for a face may be moved parallel to itself for any distance without changing the relative values of its intersections with the crystallographic axes.

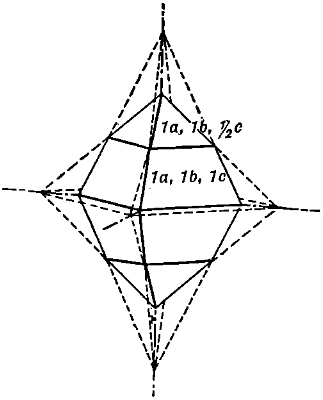

FIG. 13. Sulfur.

Indices. Various methods of notation have been devised to express the intercepts of any crystal face upon the crystal axes, and several different ones are in common use. The most universally employed is the system of indices of Miller. Though not so simple for a beginner, perhaps, as some one of the systems in which the parameters of the crystal faces are used, it adapts itself so much more readily to crystallographic calculations, and consequently has so wide an application, that it seems wise to introduce it here.

The Miller indices of a face consist of a series of whole numbers which have been derived from the parameters by their inversion and, if necessary, the subsequent clearing of fractions. The indices of a face are always given so that the three numbers (four in the hexagonal system) refer to the *a*, *b*, and *c* axes respectively, and therefore the letters which indicate the different axes are usually omitted. Like the parameters, the indices express a ratio, but for the sake of brevity the ratio sign is also omitted. The face of the dipyramid illustrated in Fig. 13, which has 1*a*, 1*b*, 1*c* for parameters, would have (111) (read: one, one, one) for indices. The face, Fig. 14, which has 1*a*, 1*b*, ∞*c* for parameters and on inversion $\frac{1}{1}, \frac{1}{1}, \frac{1}{\infty}$ would have (110) for indices. Faces which have respectively the parameters 1*a*, 1*b*, ½*c* and 1*a*, 1*b*, 2*c* would on inversion yield: $\frac{1}{1}, \frac{1}{1}, \frac{2}{1}$ and $\frac{1}{1}, \frac{1}{1}, \frac{1}{2}$. Thus on clearing of fractions the resulting indices would be respectively (112) and (221)

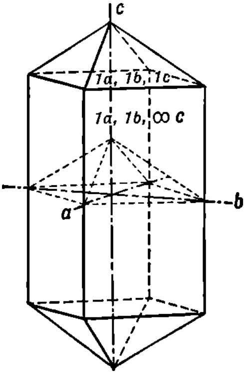

FIG. 14. Prism and Dipyramid.

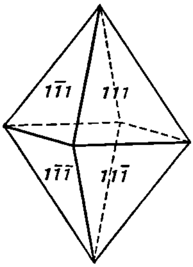

FIG. 15. Dipyramid.

It is sometimes convenient when the exact intercepts are unknown to use a general symbol (*hkl*) for the Miller indices; here *h*, *k*, and *l* each represents a simple whole number. In this symbol *h*, *k*, and *l* are respectively the reciprocals of rational but undefined intercepts along the *a*, *b*, and *c* axes. The symbol (*hkl*) would indicate that a face cuts all three of the crystallographic axes. If a face is parallel to one of the crystallographic axes and intersects the other two, the general symbols would be written as (0*kl*), (*h*0*l*), and (*hk*0). A face parallel to two of the axes is considered to intersect the third at unity, and the symbols would, therefore, be: (100), (010), and (001).

In the above discussion only those faces that intercept the positive ends of the crystallographic axes have been considered. To denote the interception at the negative end of an axis, a line is placed over the appropriate letter or number, as shown in Fig. 15.

Early in the study of crystals it was discovered that for given faces the indices would always be expressed by rational numbers. The ratios between them may be 1:2, 2:1, 2:3, 1:∞, etc., but never 1: $\sqrt{2}$, etc. Thus the Miller indices must be made up of simple whole numbers. This is known as the **law of rational indices.**

D. DEFINITIONS OF CRYSTALLOGRAPHIC TERMS

Form. Although the term *form* is sometimes used to indicate the general outward appearance of a crystal, it should be reserved for use in a special and restricted sense. Thus, a *form* in crystallography includes all those faces which have a like position with respect to the elements of symmetry. Usually all the faces of a form will have a similar appearance even though they are of different sizes and shapes because of crystal distortion. This similarity is frequently evidenced by natural striations, etchings, or growths as shown in Figs. 16 and 17. On some crystals the similarity of faces of a form can be seen only after etching with acid.

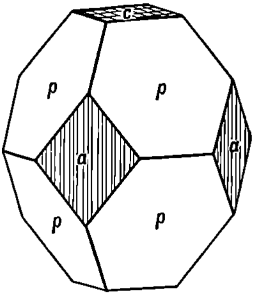

FIG. 16. Apophyllite.

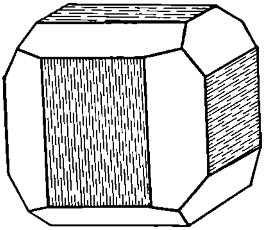

FIG. 17. Pyrite.

In Fig. 15 is illustrated a single crystal form known as a dipyramid. In the particular symmetry class to which it belongs the three crystal axes are axes of 2-fold symmetry and the axial planes are planes of symmetry. Under these conditions, if the presence of face (111) is assumed, there must be the seven other faces, for they all bear similar relations to the elements of symmetry. These eight faces constitute a form, and since they inclose space it is called a **closed form.** The forms illustrated in Figs. 18–23 do not inclose space and, therefore, are called **open forms.**

Since crystal forms depend upon the symmetry, there are many kinds. They will be discussed in some detail under the symmetry class or classes in which they are found. The forms of the isometric system have special individual names. The same general names are used for the forms of the other systems, and they will be mentioned here. **Pinacoid** is the name given to a form composed of two faces which are parallel to two (in the hexagonal system to three) of the crystallographic axes (Figs. 18–20). **Prism** is the name given to a form whose faces parallel the vertical axis and intersect the other two (Fig. 21). **Dome** is the name given to a form whose faces intersect the vertical axis and one other, and parallel the third (Figs. 22 and 23). **Pyramid** is the name given to a form whose faces intersect all the axes (Fig. 15).

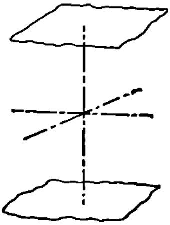

FIG. 18.

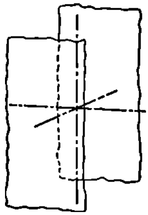

FIG. 19.

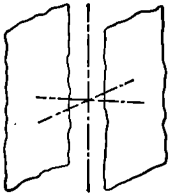

FIG. 20.

Pinacoids.

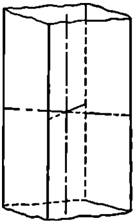

FIG. 21.

Prism.

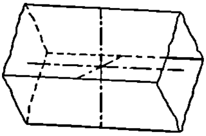

FIG. 22.

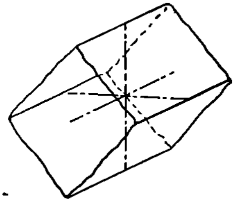

FIG. 23.

Domes.

Miller indices are frequently used as the symbol of a form. Such a symbol consists of the indices of the face having the simplest expression, and embraces all the faces of the form. When used in this manner, the symbol should be inclosed in braces, as $\{hkl\}$, to distinguish it from indices in parentheses, as (hkl), which refer to an individual face.

In crystal drawings it is found convenient to indicate the faces of a form by the same letter. The choice of which letter shall be assigned to a given form rests largely with the one first to describe the crystal. However, there are certain simple forms which, owing to convention, usually receive the same letter. Thus the three pinacoids are lettered *a*, *b*, and *c* (Fig. 24), since they cut respectively the *a*, *b*, and *c* axes. The letter *m* is usually given to the unit prism, and *p* to the unit dipyramid (Fig. 25).

Zones. One of the conspicuous features on many crystals is the arrangement of a group of faces in such a manner that their intersection lines are mutually parallel. Considered collectively, these faces comprise a *zone*. A line through the center of the crystal that parallels the lines of face intersections is called the *zone axis*. In Fig. 26 the faces *m′*, *a*, *m*, and *b* are in one zone, and *b*, *r*, *c*, and *r′* in another. In advanced crystallographic work Miller indices are sometimes used to express a zone axis. When this is done, the symbols are inclosed in brackets, as [*hkl*], to distinguish them from face and form symbols. Thus, in Fig. 26, [001] is the zone axis of *m′*, *a*, *m*, *b*; and [100] is the zone axis of *b*, *r*, *c*, *r′*.

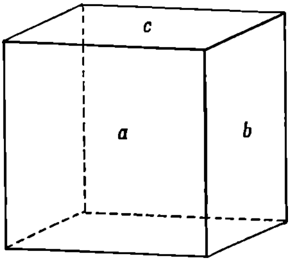

FIG. 24.

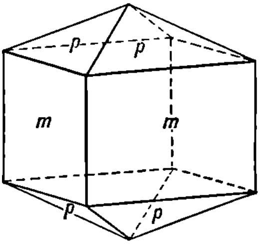

FIG. 25.

Conventional Letters on Crystal Faces.

Crystal Habit. By crystal habit is meant the common and characteristic form or combination of forms in which a mineral crystallizes. It also includes the general shape and irregularities of crystal growth if such irregularities are of common occurrence. Galena, for example, has a cubic, magnetite an octahedral, and malachite a fibrous habit. This means that, although these minerals are found in crystals which show other forms, such occurrences are comparatively rare, and their "habit" is to crystallize as indicated. Little is known regarding the factors that determine habit; but the kind of solution, the rate of crystal growth, temperature, and pressure are all thought to play a part.

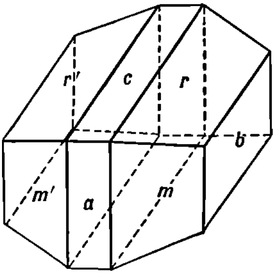

FIG. 26. Crystal Zones.

Crystal Distortion. Crystals may grow more rapidly in one direction than in another; other, surrounding crystals may interfere, and in various ways symmetrical growth may be prevented. Such crystals are said to show distortion. Ordinarily the amount of distortion is not so great as to prevent one from readily imagining what the ideally developed crystal would be like and so determining its symmetry. It is to be noted that the real symmetry of a crystal does not depend upon the symmetrical shape and size of its faces, but rather on the physical appearance of the faces and the symmetrical arrangement of the interfacial angles. In Figs. 27 to 32 are given various crystal forms, first ideally developed, and then distorted.

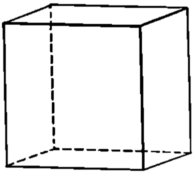
FIG. 27. Cube.

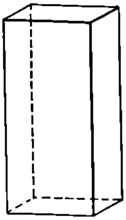
FIG. 28. Distorted Cube.

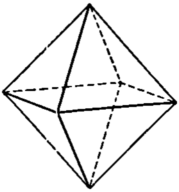
FIG. 29. Octahedron.

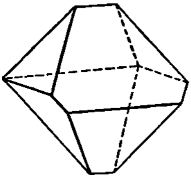
FIG. 30. Distorted Octahedron.

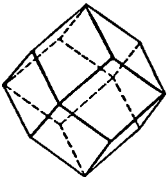
FIG. 31. Dodecahedron.

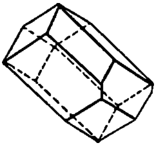
FIG. 32. Distorted Dodecahedron.

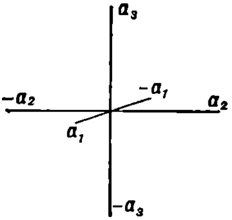

FIG. 33. Isometric Crystal Axes.

E. ISOMETRIC SYSTEM

Crystallographic Axes. The crystals of all classes of the isometric system are referred to three axes of equal length that make right angles with each other. Since the axes are identical, they are interchangeable and all are designated by the letter *a*. When properly oriented, one axis, a_1, is horizontal and perpendicular to the observer, a_2 is horizontal and parallel to the observer, and a_3 is vertical (see Fig. 33). In giving the indices of a face of an isometric form, the axes a_1, a_2, a_3 are considered in that order.

Hexoctahedral (Galena) Class

Symmetry — C, $3A_4$, $4A_3$, $6A_2$, $9P$. The symmetry of the crystals of the hexoctahedral class of the isometric system is as follows: There is a center of symmetry. The three crystallographic axes are axes of

4-fold symmetry (see Fig. 34). There are also four diagonal axes of 3-fold symmetry. These axes emerge in the middle of each of the octants formed by the intersection of the crystallographic axes (see Fig. 35). Further, there are six diagonal axes of 2-fold symmetry, each of which bisects one of the angles between two of the crystallographic axes, as illustrated in Fig. 36.

This class has nine planes of symmetry: three of them are known as the axial planes, since each includes two crystallographic axes (see Fig. 37); and six are called diagonal planes, since each bisects the angle between two of the axial planes (see Fig. 38).

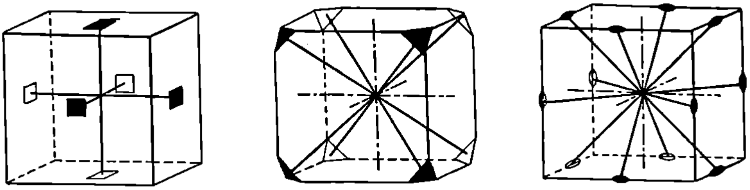

Fig. 34. Fig. 35. Fig. 36.

Isometric Symmetry Axes, Hexoctahedral Class.

This symmetry, the highest degree possible in crystals, defines the hexoctahedral class of the isometric system. Every crystal form and every combination of forms that belong to this class must show its complete symmetry. It is important to remember that in this class the three crystallographic axes are axes of 4-fold symmetry, since this fact distinguishes the class from all others* and by means of it the crystallographic axes can be easily located and a crystal properly oriented.

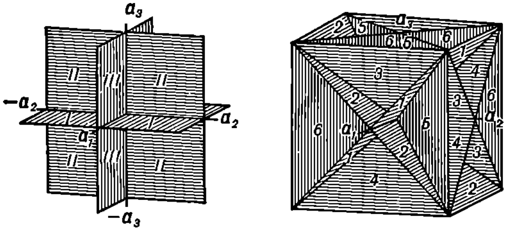

Fig. 37. Fig. 38.

Isometric Symmetry Planes, Hexoctahedral Class.

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*The gyroidal class of the isometric system also has three 4-fold symmetry axes, but no substance is known to crystallize in this class.

Forms. The forms of the isometric system, hexoctahedral class, are as follows:

1. *Cube* or *hexahedron* {100}. The cube is a form composed of six square faces which make 90° angles with each other.* Each face intersects one of the crystallographic axes and is parallel to the other two. Figure 39 represents a simple cube.

2. *Octahedron* {111}. The octahedron is a form composed of eight equilateral triangular faces, each of which intersects all three of the crystallographic axes equally. Figure 40 represents a simple octahedron, and Figs. 41 and 42 show combinations of a cube and an octahedron. When in combination the octahedron can be recognized by its eight similar faces, each of which is equally inclined to the three crystallographic axes. It is to be noted that the faces of an octahedron truncate symmetrically the corners of a cube.

3. *Dodecahedron* or *rhombic dodecahedron* {011}. The dodecahedron is a form composed of twelve rhomb-shaped faces. Each face intersects two of the crystallographic axes equally and is parallel to the third. Figure 43 shows a simple dodecahedron; Fig. 44 shows a combination of dodecahedron and cube; Figs. 45 and 46, combinations of dodecahedron and octahedron; and Fig. 47, a combination of cube, octahedron, and dodecahedron. It is to be noted that the faces of a dodecahedron truncate the edges of both the cube and the octahedron. The dodecahedron is sometimes called the rhombic dodecahedron to distinguish it from the pentagonal dodecahedron and the regular geometrical dodecahedron.

4. *Tetrahexahedron* {0*kl*}. The tetrahexahedron is a form composed of twenty-four isosceles triangular faces, each of which intersects one axis at unity and the second at some multiple, and is parallel to the third. There are a number of tetrahexahedrons which differ from each other in respect to the inclination of their faces. The commonest has the parameter relations ∞a_1, $2a_2$, $1a_3$, the symbol of which would be {012}. The indices of other forms are {013}, {014}, {023}, etc., or, in general, {0*kl*}. It is helpful to note that the tetrahexahedron, as its name indicates, is like a cube the faces of which have been replaced by four others. Figure 48 shows a simple tetrahexahedron, and Fig. 49 a cube with its edges beveled by the faces of a tetrahexahedron.

5. *Trapezohedron* or *tetragonal trisoctahedron* {*hhl*}. The trapezohedron is a form composed of twenty-four trapezium-shaped faces, each of which intersects one of the crystallographic axes at unity and the other

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* In the description of forms on the following pages the geometrically perfect model of the unmodified form is considered in each case. It should be kept in mind that in nature this ideal is rarely obtained, and that crystals not only are frequently distorted but also are usually bounded by a combination of forms.

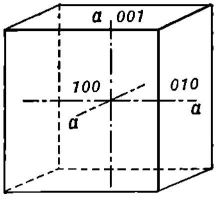


Fig. 39. Cube.

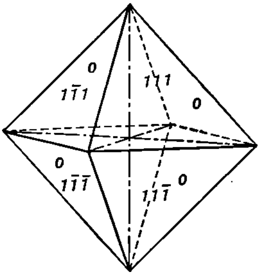


Fig. 40. Octahedron.

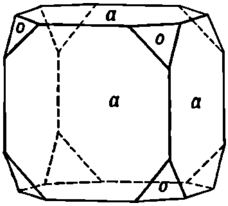


Fig. 41.

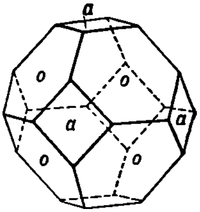


Fig. 42.

Cube and Octahedron.

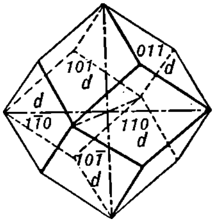


Fig. 43. Dodecahedron.

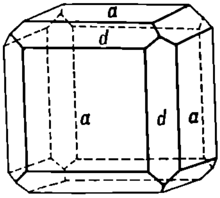


Fig. 44. Cube and Dodecahedron.

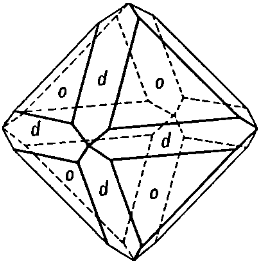


Fig. 45. Octahedron and Dodecahedron.

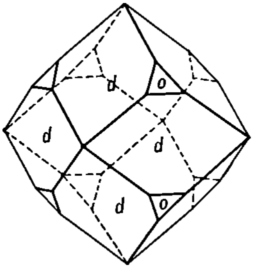


Fig. 46. Dodecahedron and Octahedron.

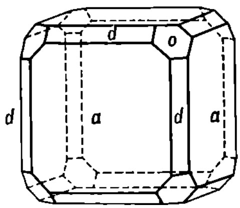


Fig. 47. Cube, Octahedron, and Dodecahedron.

two at equal multiples. There are various trapezohedrons with their faces having different angles of inclination. A common trapezohedron has for its parameters $2a_1$, $2a_2$, $1a_3$, the symbol for which would be {112}. The indices for other trapezohedrons are {113}, {114}, {223}, etc., or, in general, {*hhl*}. It will be noted that a trapezohedron is an octahedral-like form and may be conceived of as an octahedron each of the planes of which has been replaced by three faces. Consequently, it is sometimes called a tetragonal trisoctahedron. The qualifying word tetragonal is used to indicate that each of its faces has four edges and to distinguish it from the other trisoctahedral form, the description of which follows. Trapezohedron, however, is the name most commonly used.

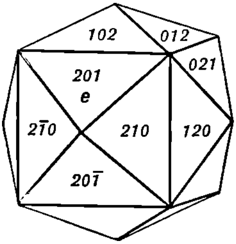


FIG. 48. Tetrahexahedron.

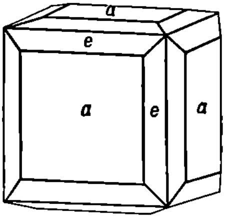


FIG. 49. Cube and Tetrahexahedron.

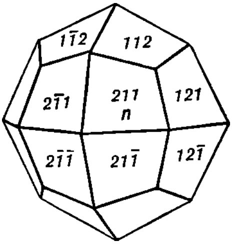


FIG. 50. Trapezohedron.

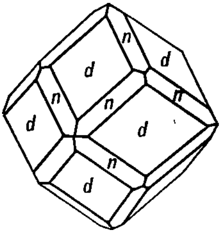


FIG. 51. Dodecahedron and Trapezohedron.

The following are aids to the recognition of the form when it occurs in combinations: the three similar faces to be found in each octant; the relations of each face to the axes; and the fact that the middle edges between the three faces in any one octant go toward points which are equidistant from the ends of the two adjacent crystallographic axes. Figure 50 shows a simple trapezohedron, and Figs. 51 and 52 each show a trapezohedron in combination with a dodecahedron. It is to be noted that the faces of the common trapezohedron {112} (Fig. 51) truncate the edges of the dodecahedron. Figure 53 shows a combination of cube and trapezohedron.

6. *Trisoctahedron* or *trigonal trisoctahedron* {*hll*}. The trisoctahedron is a form composed of twenty-four isosceles triangular faces each of

which intersects two of the crystallographic axes at unity and the third axis at some multiple. There are various trisoctahedrons the faces of which have different inclinations. A common trisoctahedron has for its parameters $2a_1 : 1a_2 : 1a_3$, its symbol being {122}. Other trisoctahedrons have the indices {133}, {144}, {233}, etc., or, in general, {*hll*}. It is to be noted that the trisoctahedron, like the trapezohedron, is a form that may be conceived of as an octahedron each face of which has been replaced by three others. Frequently it is spoken of as the trigonal trisoctahedron, the modifying word indicating that its faces have each three edges and so differ from those of the trapezohedron. But when the word "trisoctahedron" is used alone it refers to this form. The following points will aid in its identification when found in combinations: the three similar faces in each octant; their relations to the axes; and the fact that the middle edges between them go toward the ends of the crystallographic axes. Figure 54 shows the simple trisoctahedron and Fig. 55 a combination of a trisoctahedron and an octahedron. It will be noted that the faces of the trisoctahedron bevel the edges of the octahedron.

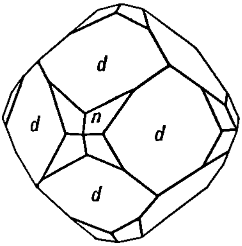


FIG. 52. Dodecahedron and Trapezohedron.

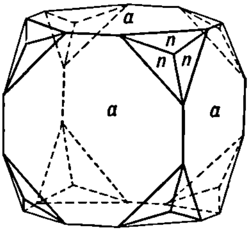


FIG. 53. Cube and Trapezohedron.

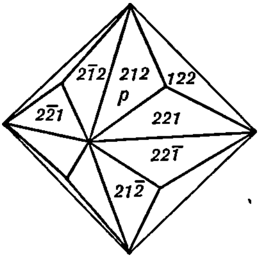


FIG. 54. Trisoctahedron.

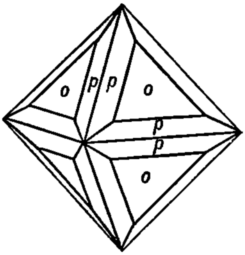


FIG. 55. Octahedron and Trisoctahedron.

7. *Hexoctahedron* {*hkl*}. The hexoctahedron is a form composed of forty-eight triangular faces, each of which cuts differently all three crystallographic axes. There are several hexoctahedrons, which have varying ratios of intersection with the axes. A common hexoctahedron has for its parameter relations $3a_1 : 2a_2 : 1a_3$, with indices {236}. Other hexoctahedrons have indices {124}, {135}, etc., or, in general, {*hkl*}. It is to be noted that the hexoctahedron is a form that may be considered as an octahedron each face of which has been replaced by six others. It can be recognized when in combination by the facts that there are six similar faces in each octant and that each face intercepts the three axes differently. Figure 56 shows a simple hexoctahedron; Fig. 57, a combination of cube and hexoctahedron; Fig. 58, a combination of dedocahedron and hexoctahedron; and Fig. 59, a combination of dodecahedron, trapezohedron, and hexoctahedron. The hexoctahedron is the general form from which this symmetry class derives its name.

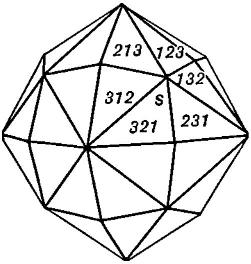


Fig. 56. Hexoctahedron.

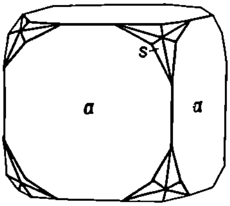


Fig. 57. Cube and Hexoctahedron.

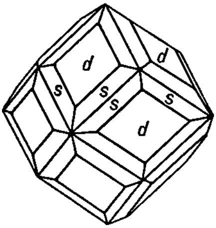


Fig. 58. Dodecahedron and Hexoctahedron.

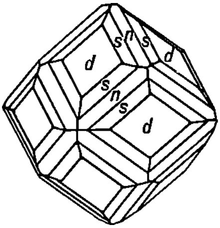


Fig. 59. Dodecahedron, Trapezohedron, and Hexoctahedron.

Determination of Indices of Isometric Forms. In determining the forms present on any isometric crystal of the hexoctahedral class, it is first necessary to locate the crystallographic axes (axes of 4-fold symmetry). Once the crystal has been oriented by these axes, the faces of the cube, dodecahedron, and octahedron are easily recognized since they intersect respectively one, two, and three axes at unit distances. The indices can be quickly obtained for faces of other forms which truncate symmetrically the edges between known faces. The algebraic sums of the *h*, *k*, and *l* indices of two faces give the indices of the face symmetrically truncating the edge between them. Thus in Fig. 60 the algebraic sum of the two dodecahedron faces (101) and (011) is (112), or the indices of a face of a trapezohedron.

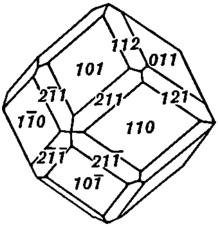


FIG. 60. Dodecahedron and Trapezohedron.

Occurrence of Isometric Forms of the Hexoctahedral Class. The cube, octahedron, and dodecahedron are the most common of the isometric forms. The trapezohedron is also frequently observed on a few minerals. The other forms, the tetrahexahedron, trisoctahedron, and hexoctahedron, are rare and are ordinarily observed only as small truncations in combinations.

In the following list, common isometric minerals are given with the forms they most frequently display well:

CUBE: Galena, halite, sylvite, fluorite, cuprite.
OCTAHEDRON: Spinel, magnetite, franklinite.
DODECAHEDRON: Magnetite, garnet.
TRAPEZOHEDRON: Leucite, garnet, analcime.

Hextetrahedral (Tetrahedrite) Class

Symmetry — $3A_2$, $4A_3$, $6P$. The three crystallographic axes are axes of 2-fold symmetry; the four diagonal axes are axes of 3-fold symmetry; and there are six diagonal planes of symmetry (see Figs. 61 and 62). It is to be noted that the hextetrahedral class lacks a center of symmetry.

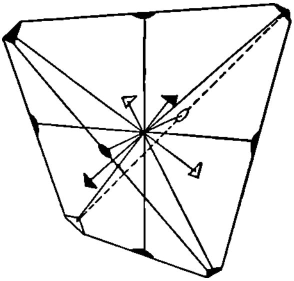


FIG. 61. Symmetry Axes.

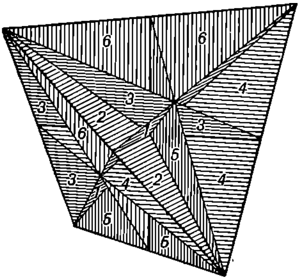


FIG. 62. Symmetry Planes.

Symmetry of Hextetrahedral Class, Isometric System.

Forms. The characteristic forms of the hextetrahedral class are as follows:

1. *Tetrahedron* $\{111\}$ *positive,* $\{1\bar{1}1\}$ *negative.* The tetrahedron is a form composed of four equilateral triangular faces, each of which intersects all of the crystallographic axes at equal lengths. It can be considered as derived from the octahedron of the hexoctahedral class by the omission of the alternate faces and the extension of the others, as shown in Fig. 63. This form, shown also in Fig. 64, is known as the positive tetrahedron $\{111\}$. If the other four faces of the octahedron had been extended, the tetrahedron resulting would have had a different orientation, as shown in Fig. 65. This is known as the negative tetrahedron $\{1\bar{1}1\}$. The positive and negative tetrahedrons when occurring alone are geometrically identical, and the only reason for recognizing the possibility of the existence of two different orientations is that they may occur truncating each other, as shown in Fig. 66. If a positive and negative tetrahedron occurred together with equal development, the resulting crystal could not be distinguished from an octahedron, unless, as often happens, the faces of the two forms showed different lusters, etchings, or striations that would serve to differentiate them.

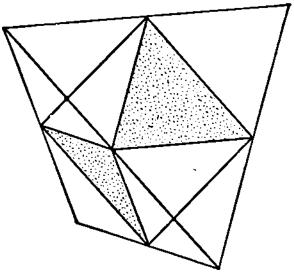


FIG. 63. Relation between the Octahedron and Tetrahedron.s

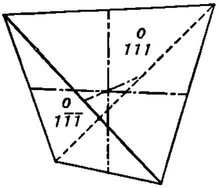


FIG. 64. Positive Tetrahedron.

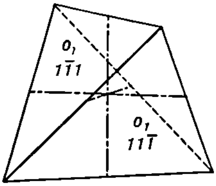


FIG. 65. Negative Tetrahedron.

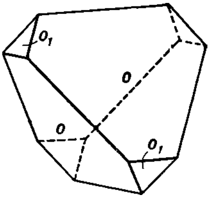


FIG. 66. Positive and Negative Tetrahedrons.

Other possible but rare tetrahedral forms are the following: The tristetrahedron $\{hll\}$ (Fig. 67) has twelve faces which correspond to one-half the faces of a trapezohedron; the deltoid dodecahedron $\{hhl\}$ (Fig. 68) has twelve faces which correspond to one-half those of the trisoctahedron; the hextetrahedron, $\{hkl\}$ (Fig. 69), has twenty-four faces which correspond to one-half the faces of the hexoctahedron. The hextetrahedron is the general form from which this class derives its name.

The cube and dodecahedron are also found on minerals of the hextetrahedral class. Figures 70 and 71 show combinations of cube and tetrahedron. It will be noted that the tetrahedron faces truncate the alternate corners of the cube, or that the cube faces truncate the edges of a tetrahedron. Figure 72 shows the combination of tetrahedron and dodecahedron. Figure 73 represents a combination of cube, dodecahedron, and tetrahedron. Figure 74 shows a combination of tetrahedron and tristetrahedron.

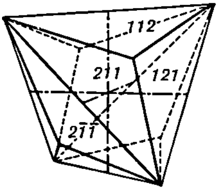


Fig. 67. Tristetrahedron.

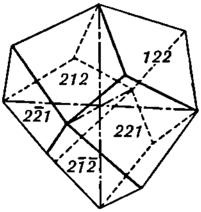


Fig. 68. Deltoid Dodecahedron.

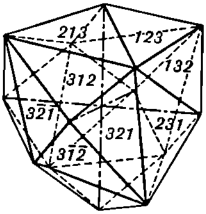


Fig. 69. Hextetrahedron.

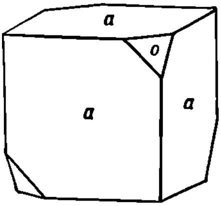


Fig. 70.

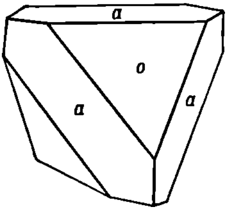


Fig. 71.

Cube and Tetrahedron.

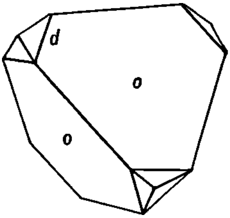


Fig. 72. Tetrahedron and Dodecahedron.

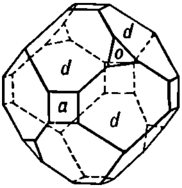


Fig. 73. Dodecahedron, Cube, and Tetrahedron.

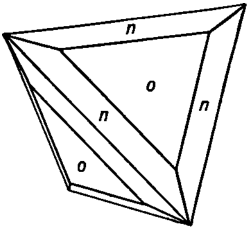


Fig. 74. Tetrahedron and Tristetrahedron.

Tetrahedrite and the related tennantite are the only common minerals that ordinarily show distinct hextetrahedral forms. Sphalerite occasionally exhibits them, but commonly its crystals are complex and distorted.

Diploidal (Pyrite) Class

Symmetry — C, $3A_2$, $4A_3$, $3P$. The symmetry of the diploidal class of the isometric system is as follows: The three crystallographic axes are axes of 2-fold symmetry; the four diagonal axes, each of which emerges in the middle of an octant, are axes of 3-fold symmetry; the three axial planes are planes of symmetry (see Figs. 75 and 76).

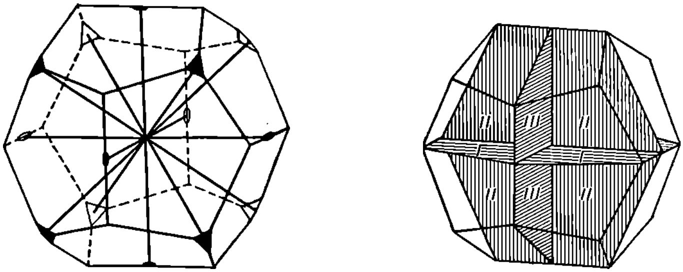


FIG. 75. Symmetry Axes. FIG. 76. Symmetry Planes.

Symmetry of Diploidal Class, Isometric System.

Forms. The characteristic forms of the diploidal class are as follows:

1. *Pyritohedron* or *pentagonal dodecahedron* $\{0kl\}$ *positive*, $\{h0l\}$ *negative*. This form consists of twelve pentagonal-shaped faces, each of which intersects one crystallographic axis at unity, the second axis at some multiple of unity, and is parallel to the third. There are a number of pyritohedrons which differ from each other in respect to the inclination of their faces. The most common positive pyritohedron has the parameter relations $1a_1$, $2a_2$, ∞a_3, the indices of which are $\{210\}$ (Fig. 77). Figure 78 shows the corresponding negative pyritohedron. It will be noted that the general symbol $\{0kl\}$ for the positive pyritohedron is the same as that for the tetrahexahedron. A pyritohedron may be considered as derived from a corresponding tetrahexahedron by the omission of alternate faces and the extension of those remaining. Figure 79 shows the relations of the two forms, the shaded faces of the tetrahexahedron being those which when extended would form the faces of the pyritohedron.

2. *Diploid* $\{hkl\}$ *positive*, $\{khl\}$ *negative*. The diploid is a rare form, but the general one from which this class derives its name. It is composed of twenty-four faces which correspond to one-half the faces of a hexoctahedron. The diploid is represented in Fig. 80.

In addition to the two forms described above, minerals of this class show also the cube, octahedron, dodecahedron, trapezohedron, and trisoctahedron. On some crystals these forms may appear alone and so perfectly developed that they cannot be told from the forms of the hexoctahedral class. This is often true of octahedrons of pyrite. Usually, however, they will show by the presence of striation lines or etching figures that they do not possess the high symmetry of the hexoctahedral class but conform rather to the symmetry of the diploidal class. This is shown in Fig. 81, which represents a cube of pyrite with characteristic striations, which are so disposed that the crystal shows the lower symmetry. Figure 82 represents a combination of cube and pyritohedron, in which it will be noted that the faces of the pyritohedron truncate unsymmetrically the edges of the cube. Figures 83, 84, and 85 represent combinations of pyritohedron and octahedron with various developments. Figure 86 shows a cube truncated by the pyritohedron and octahedron. Figure 87 represents a combi-

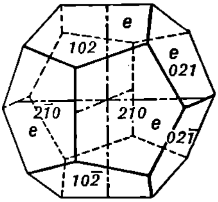


FIG. 77. Positive Pyritohedron.

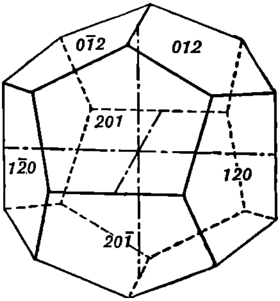


FIG. 78. Negative Pyritohedron.

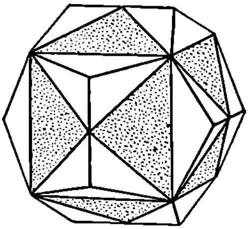


FIG. 79. Relation between Pyritohedron and Tetrahexahedron.

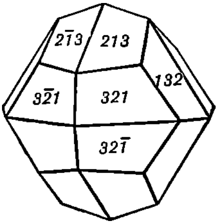


FIG. 80. Diploid.

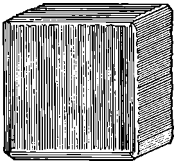


FIG. 81. Striated Cube.

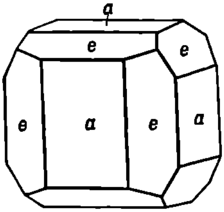


FIG. 82. Cube and Pyritohedron.

nation of cube and the diploid {124}. These figures should be studied to impress upon one the characteristic symmetry of the class.

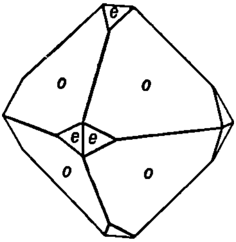


FIG. 83.

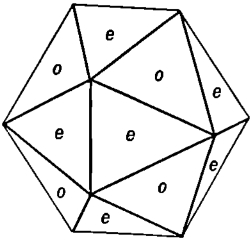


FIG. 84.

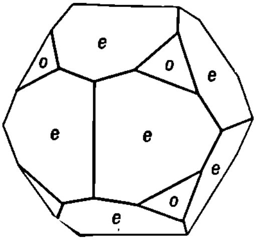


FIG. 85.

Octahedron and Pyritohedron.

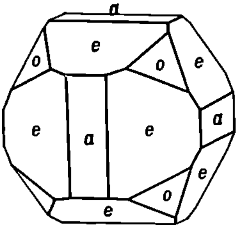


FIG. 86. Pyritohedron, Cube, and Octahedron.

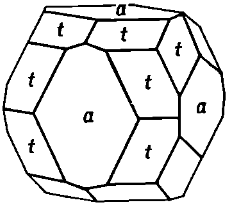


FIG. 87. Diploid and Cube.

The chief mineral of the diploidal class is pyrite; other rarer minerals of this class are cobaltite, smaltite, chloanthite, gersdorffite, and sperrylite.

Characteristics of Isometric Crystals

The striking characteristics of isometric crystals which aid in their recognition may be summarized as follows:

Undistorted crystals are equidimensional in three directions at right angles to each other. These three directions in crystals of the hexoctahedral class are axes of 4-fold symmetry; in the other two classes they are axes of 2-fold symmetry. Four 3-fold symmetry axes are common to all the classes of the isometric system. The crystals commonly show faces that are squares or equilateral triangles or these figures with truncated corners. They are characterized by the large number of similar faces; the smallest number on any form of the hexoctahedral class is six. Every form by itself would make a solid and is, thus, a *closed form*. The same indices are used for forms in the different classes, and, therefore, in referring to a form by its indices, it is necessary to give the class.

Some important *interfacial angles* of the isometric system which may aid in the recognition of the commoner forms are as follows:

Cube (100) ∧ cube (010) = 90° 00′
Octahedron (111) ∧ octahedron $(\bar{1}11)$ = 70° 32′
Dodecahedron (011) ∧ dodecahedron (101) = 60° 00′
Cube (100) ∧ octahedron (111) = 54° 44′
Cube (100) ∧ dodecahedron (110) = 45° 00′
Octahedron (111) ∧ dodecahedron (110) = 35° 16′

F. HEXAGONAL SYSTEM

Crystallographic Axes. The forms of the hexagonal system are referred to four crystallographic axes. Three of these axes lie in the horizontal plane, are of equal length, and make angles of 60° and 120° with each other; the fourth is vertical. The length of the horizontal axes is taken as unity; and the vertical axis, which varies in length in each hexagonal mineral, is expressed in terms of it. Thus for beryl, the vertical axis, designated as c, has a length which in relation to the length of the horizontal axes can be expressed as $c = 0.499$.

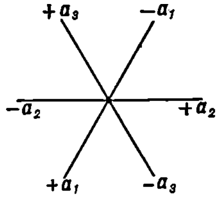


FIG. 88.

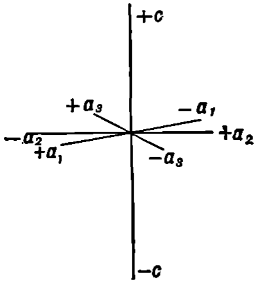


FIG. 89.

Hexagonal Crystal Axes.

When properly oriented, one of the horizontal crystallographic axes is parallel to the observer, and the other two make 30° angles on either side of a line perpendicular to him. Figure 88 shows the proper position of the horizontal axes when viewed in the direction of the vertical axis. As the three horizontal axes are interchangeable with each other, they are usually designated a_1, a_2, and a_3. Note that a_1 is to the left of the observer with its positive end at the front, that a_2 is parallel to the observer and its positive end is at the right, while a_3

is to the right of the observer and its positive end is at the back. Figure 89 shows the four axes in clinographic projection. In stating the indices for any face of a hexagonal crystal, four numbers must be given, since there are four axes. The numbers referring to the intercepts of the face with the three horizontal axes are given first in their proper order, while the number referring to the intercept on the vertical axis is given last. The third index is always equal to the sum of the first two times −1.

Hexagonal Division

Dihexagonal-Dipyramidal (Beryl) Class

Symmetry — C, $1A_6$, $6A_2$, $7P$. The symmetry of the dihexagonal-dipyramidal class of the hexagonal system is as follows: The vertical crystallographic axis is an axis of 6-fold symmetry. There are six horizontal axes of 2-fold symmetry, three of them coincident with the crystallographic axes and the other three lying midway between them (see Fig. 90). There are six vertical planes of symmetry and one horizontal plane of symmetry (Fig. 91).

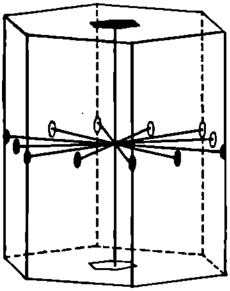


FIG. 90. Symmetry Axes.

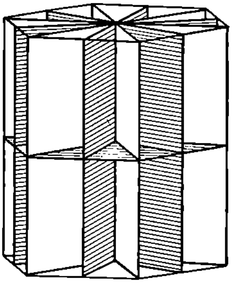


FIG. 91. Symmetry Planes.

Symmetry of Dihexagonal-Dipyramidal Class, Hexagonal System.

Forms. The forms of the dihexagonal-dipyramidal class are as follows:

1. *Basal pinacoid* {0001}. The basal pinacoid is a form composed of two horizontal faces. It is shown in combination with different prisms in Figs. 92, 93, and 94.

2. *Prism of first order* $\{10\bar{1}0\}$. This is a form consisting of six vertical faces each of which intersects two of the horizontal crystallographic axes equally and is parallel to the third. Figure 92 shows the prism of the first order.

3. *Prism of second order* $\{11\bar{2}0\}$. This is a form consisting of six vertical faces, each of which intersects two of the horizontal axes equally and the intermediate horizontal axis at one-half this distance. Figure 93 shows the prism of the second order. The prisms of the first and second order are geometrically identical forms; the distinction between them is only in their orientation.

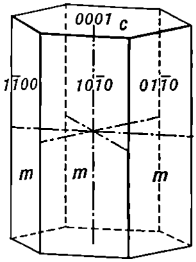


FIG. 92. First-Order Prism.

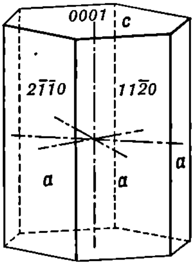


FIG. 93. Second-Order Prism.

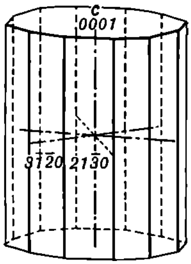


FIG. 94. Dihexagonal Prism.

Hexagonal Prisms.

4. *Dihexagonal prism* $\{hk\bar{i}0\}$. The dihexagonal prism has twelve vertical faces, each of which intersects all three of the horizontal crystallographic axes at different lengths. There are various dihexagonal prisms, depending upon their different relations to the horizontal axes. A common dihexagonal prism with indices $\{21\bar{3}0\}$ is shown in Fig. 94.

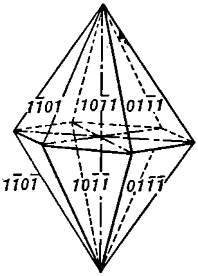


FIG. 95. First-Order Dipyramid.

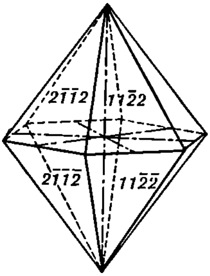


FIG. 96. Second-Order Dipyramid.

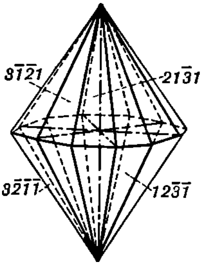


FIG. 97. Dihexagonal Dipyramid.

Hexagonal Dipyramids.

5. *Dipyramid of first order* $\{h0\bar{h}l\}$. This form consists of twelve isosceles triangular faces, each of which intersects two of the horizontal crystallographic axes equally, is parallel to the third horizontal axis, and intersects the vertical axis (see Fig. 95). Various dipyramids of the first order are possible, depending upon the inclination of the faces to c. The unit form has the indices $\{10\bar{1}1\}$.

6. *Dipyramid of second order* $\{hh\overline{2h}l\}$. This is a form composed of twelve isosceles triangular faces, each of which intersects two of the horizontal axes equally and the third and intermediate horizontal axis at one-half this distance, and also intersects the vertical axis (see Fig. 96). Various dipyramids of the second order are possible, depending upon the inclination of the faces to *c*. A common form (Fig. 96) has the indices $\{11\bar{2}2\}$. The relations between the dipyramids of the first and second order are the same as between the corresponding prisms.

If only one dipyramid is present on a crystal, it is usually set up as of the first order. If dipyramids of both orders are present, the dominant one, in the absence of other evidence, is considered the first order. If a dipyramid is combined with prismatic forms, the orientation of the crystal is usually determined by the dipyramid.

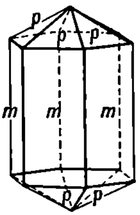


Fig. 98.

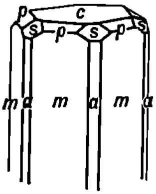


Fig. 99.

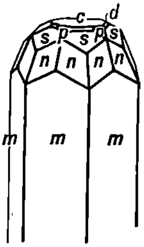


Fig. 100.

Combinations of Hexagonal Forms.

7. *Dihexagonal dipyramid* $\{hk\bar{i}l\}$. The dihexagonal dipyramid is a form composed of twenty-four triangular faces. Each face is a scalene triangle which intersects all three of the horizontal axes differently and also intersects the vertical axis. A common form, $\{21\bar{3}1\}$, is shown in Fig. 97.

Figures 98–100 show combinations of the forms of this class.

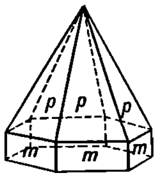


Fig. 101. Zincite.

Dihexagonal-Pyramidal (Zincite) Class

Symmetry — $1A_6$, $6P$. The dihexagonal-pyramidal class of the hexagonal system has a vertical axis of 6-fold symmetry and six vertical planes. Its symmetry differs from that of the dihexagonal-dipyramidal class in that it lacks the horizontal symmetry plane and a symmetry center.

Forms. The forms of the dihexagonal-pyramidal class are similar to the dihexagonal-dipyramidal class except that different forms appear

Forms. 1. *Rhombohedron* $\{h0\bar{h}l\}$ *positive,* $\{0h\bar{h}l\}$ *negative.* The rhombohedron is a form consisting of six rhomb-shaped faces, which correspond in their position to the alternate faces of a hexagonal dipyramid of the first order. The relation of these two forms to each other is shown in Fig. 105. The rhombohedron may also be thought of as a cube deformed in the direction of one of the axes of 3-fold symmetry. The deformation may appear either as an elongation along the symmetry axis producing an acute solid angle, or compression along the symmetry axis producing an obtuse solid angle. Depending on the angle, the rhombohedron is known as acute or obtuse.

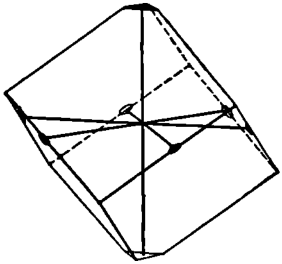


FIG. 103. Symmetry Axes.

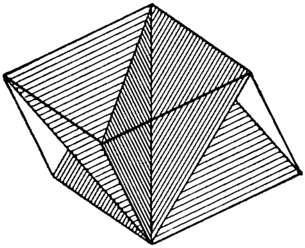


FIG. 104. Symmetry Planes.

Symmetry of Scalenohedral Class, Hexagonal System.

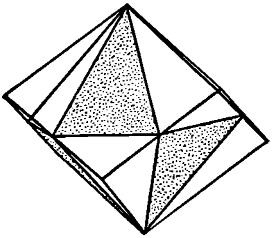


FIG. 105. Relation between First-Order Hexagonal Dipyramid and Rhombohedron.

There are two different orientations of the rhombohedron. A *positive* rhombohedron is shown in Fig. 106 and a *negative* rhombohedron in Fig. 107. It is to be noted that when properly oriented the positive rhombohedron has one of its faces, and the negative rhombohedron one of its edges, toward the observer. There are various rhombohedrons, which differ from each other in the inclination of their faces to the *c* axis. The index symbol of the unit positive rhombohedron is $\{10\bar{1}1\}$ and of the unit negative rhombohedron $\{01\bar{1}1\}$. Characteristic combinations of positive and negative rhombohedrons with each other and with other hexagonal forms are shown in Figs. 108–116. As in the tetrahedrons of the isometric system, the distinction between the positive and negative rhombohedrons is only one of orientation.

The rhombohedron is such an important form in the hexagonal system that it need not appear externally on a crystal to determine the orientation. The orientation of calcite is determined by the rhombohedral cleavage, and the orientation of corundum is determined by rhombohedral parting (see page 70). Thus in calcite the only external rhombohedral form may be negative, and in corundum the rhombohedral parting invariably necessitates orienting the crystal so that

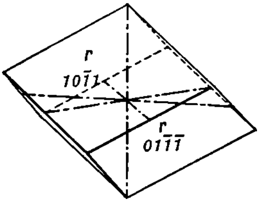


FIG. 106. Positive Rhombohedron.

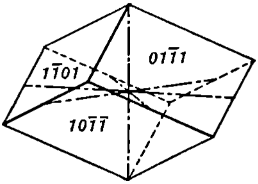


FIG. 107. Negative Rhombohedron.

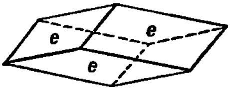


FIG. 108.

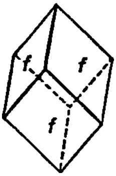


FIG. 109.

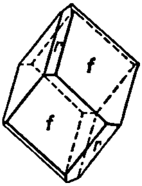


FIG. 110.

Calcite.

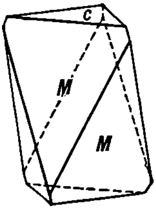


FIG. 111.

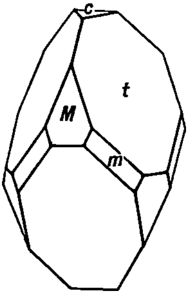


FIG. 112.

Calcite.

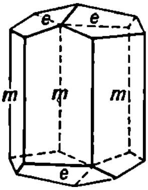


FIG. 113.

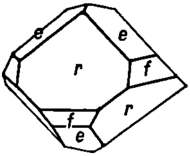


FIG. 114.

Chabazite.

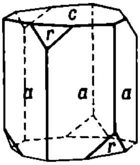


FIG. 115.

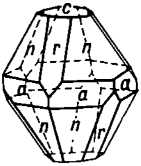


FIG. 116.

Corundum.

the prism is of the second order. However, if but one rhombohedron is present on a crystal, it is oriented, in the absence of other determining properties, in the positive position.

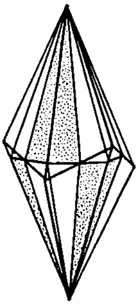


FIG. 117. Relation between Dihexagonal Dipyramid and Scalenohedron.

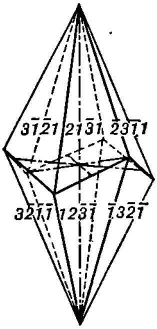


FIG. 118. Positive Scalenohedron.

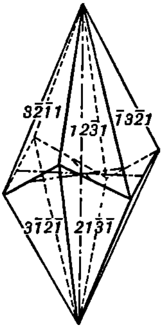


FIG. 119. Negative Scalenohedron.

2. *Scalenohedron* $\{hk\bar{i}l\}$ *positive,* $\{kh\bar{i}l\}$ *negative.* This form consists of twelve scalene triangular faces. These faces correspond in position to the alternate *pairs* of faces of a dihexagonal dipyramid as shown in Fig. 117. The striking characteristics of the scalenohedron are the zigzag appearance of the middle edges which differentiates it from the dipyramid, and the alternately more and less obtuse angles over the edges that meet at the vertices of the form. The scalenohedron is in the positive position when an edge with the greater angle is toward the observer, and in the negative position when an edge with the lesser angle is toward the observer (see Figs. 118 and 119).

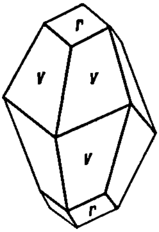


FIG. 120. Positive Scalenohedron and Positive Rhombohedron.

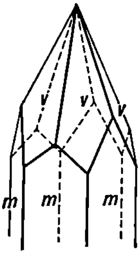


FIG. 121. Positive Scalenohedron and Prism.

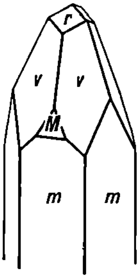


FIG. 122. Prism, Positive Scalenohedron, and Two Positive Rhombohedrons.

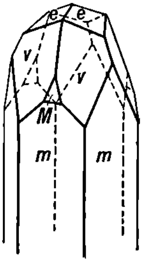


FIG. 123. Prism, Positive Scalenohedron, Positive Rhombohedron and Negative Rhombohedron.

There are many different possible scalenohedrons, depending on the varying slope of the faces. A common form in calcite is the scalenohedron $\{21\bar{3}1\}$ shown in Fig. 118.

The rhombohedron and scalenohedron of the scalenohedral class may combine with forms found in higher classes of hexagonal symmetry. Thus the first- and second-order hexagonal prisms, the second-order dipyramid, and the basal pinacoid are found in combination with the rhombohedron and scalenohedron as shown in Figs. 111-116 and 120-123.

Trigonal-Trapezohedral (Quartz) Class

Symmetry — $1A_3$, $3A_2$. The vertical crystallographic axis is an axis of 3-fold symmetry, and the three horizontal crystallographic axes are axes of 2-fold symmetry. The axes are the same as in the scalenohedral class, but planes of symmetry are lacking.

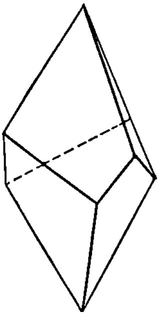


FIG. 124. Positive Left.

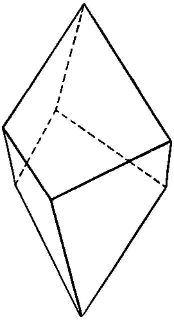


FIG. 125. Positive Right.

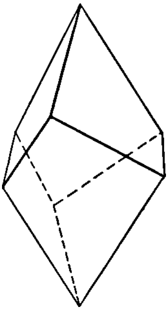


FIG. 126. Negative Left.

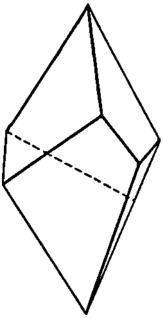


FIG. 127. Negative Right.

Trigonal Trapezohedral Forms.

Forms. The only forms peculiar to this class are trigonal trapezohedrons. There are four such forms, each made up of six trapezium shaped faces (Figs. 124-127). These faces correspond in position to one-quarter of the faces of a dihexagonal dipyramid, and thus have similar symbols, as follows: Positive right $\{hk\bar{i}l\}$, positive left $\{i\bar{k}\bar{h}l\}$, negative left $\{kh\bar{i}l\}$, negative right $\{\bar{k}i\bar{h}l\}$. Rhombohedrons, trigonal dipyramids, trigonal prisms, ditrigonal prisms, hexagonal prisms, and basal pinacoids are also found on crystals of this class.

Quartz is the most common mineral crystallizing in this class, and only rarely can faces of the trigonal trapezohedron be observed. When this form is present, the crystals can be designated as right-handed (Fig. 128) or left-handed (Fig. 129) depending on whether, with a prism face fronting the observer, the trigonal trapezohedral faces truncate the edges between prism and rhombohedron faces at the right or at the left.

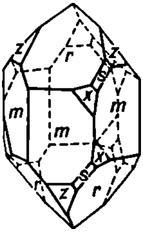


FIG. 128. Right-Handed Quartz.

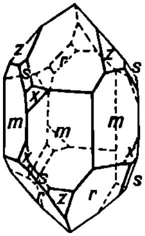


FIG. 129. Left-Handed Quartz.

Ditrigonal-Pyramidal (Tourmaline) Class

Symmetry — $1A_3$, $3P$. The vertical crystallographic axis is a 3-fold symmetry axis, and there are three symmetry planes that intersect in this axis. The symmetry of the ditrigonal pyramidal class is similar to that of the scalenohedral class but lacks a center of symmetry.

Forms. The lack of a symmetry center is evidenced in the different forms present at the top and bottom of a crystal of this class. The forms are similar to those of the scalenohedral class but with only half the number of faces. Thus the trigonal pyramid $\{h0\bar{h}l\}$ corresponds to the top three faces of the positive rhombohedron, and the trigonal pyramid $\{h0\overline{hl}\}$ corresponds to the bottom three faces of the negative rhombohedron. A trigonal prism $\{10\bar{1}0\}$ is also found in this class. Figures 130–133 represent characteristic tourmaline crystals showing the symmetry of the ditrigonal-pyramidal class.

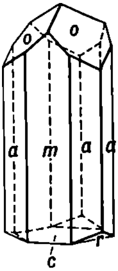


FIG. 130.

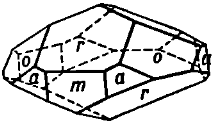


FIG. 131.

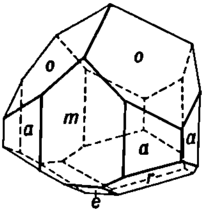


FIG. 132.

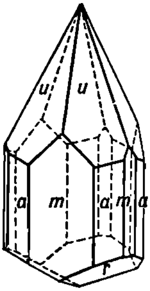


FIG. 133.

Tourmaline.

Characteristics of Hexagonal Crystals

Hexagonal crystals are most readily recognized by the following facts: The vertical crystallographic axis is one of either hexagonal or trigonal symmetry. The crystals are commonly prismatic in habit. When viewed in the direction of the vertical axis, they usually show a hexagonal cross section.

G. TETRAGONAL SYSTEM

Crystallographic Axes. The crystallographic axes of the tetragonal system are three in number and make right angles with each other. The two horizontal axes, *a*, are equal in length and interchangeable, but the vertical axis, *c*, is of a different length, characteristic for each tetragonal mineral. Figure 134 represents the crystallographic axes for the tetragonal mineral zircon where *c* is less than *a*. Figure 135 represents the crystallographic axes of the mineral octahedrite where *c* is greater than *a*. The length of the horizontal axes is taken as unity, and the relative length of the vertical axis is expressed in terms of the horizontal. This length must be determined for each tetragonal mineral by measuring the interfacial angles on a crystal and making the proper calculations (see page 16). For zircon the length of the vertical axis is expressed as $c = 0.901$, for octahedrite as $c = 1.777$. The proper orientation of the crystallographic axes and the method of their notation are similar to those of the isometric system and are shown in Figs. 134 and 135.

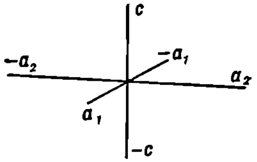


Fig. 134.

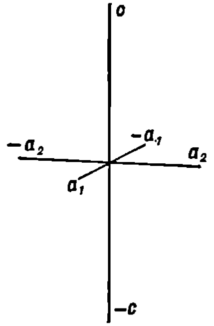


Fig. 135.

Tetragonal Crystal Axes.

Ditetragonal-Dipyramidal (Zircon) Class

Symmetry — C, $1A_4$, $4A_2$, $5P$. The symmetry of the ditetragonal-dipyramidal class of the tetragonal system is as follows: The vertical crystallographic axis is an axis of 4-fold symmetry. There are four horizontal axes of 2-fold symmetry, two of which are coincident with the crystallographic axes, while the other two bisect the angles between these. Figure 136 shows the axes of symmetry. There are five planes of symmetry, one horizontal and four vertical. Each vertical plane of symmetry passes through one of the horizontal axes of symmetry. The position of the planes of symmetry is shown in Fig. 137.

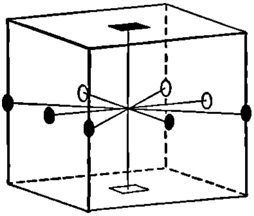


FIG. 136. Symmetry Axes.

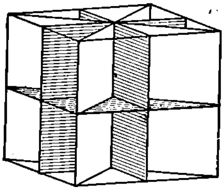


FIG. 137. Symmetry Planes.

Symmetry of Ditetragonal-Dipyramidal Class, Tetragonal System.

Forms. The forms of the normal class, tetragonal system, are as follows:

1. *Basal pinacoid* {001}. The basal pinacoid, basal plane, or base, as it is variously called, is a form composed of two horizontal faces. It is shown in combination with different prisms in Figs. 138, 139, and 140.

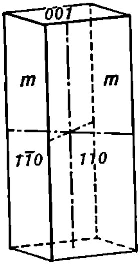


FIG. 138. First-Order Prism.

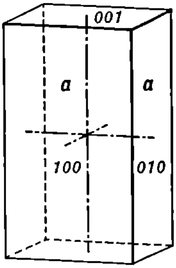


FIG. 139. Second-Order Prism.

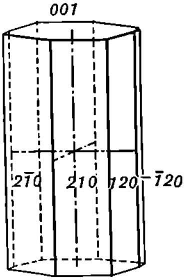


FIG. 140. Ditetragonal Prism.

Tetragonal Prisms.

2. *Prism of first order* {110}. The prism of the first order consists of four rectangular vertical faces, each of which intersects the two horizontal crystallographic axes equally. The form is represented in Fig. 138.

3. *Prism of second order* {010}. The prism of the second order consists of four rectangular vertical faces, each of which intersects one horizontal crystallographic axis and is parallel to the other two axes. The form is represented in Fig. 139. The prisms of the first and second

order are identical forms, except for their orientation. They can be converted into each other by a revolution of 45° about the vertical axis. Since both may occur together upon the same crystal, it is necessary to recognize the two forms.

4. *Ditetragonal prism* {*hk*0}. The ditetragonal prism is a form consisting of eight rectangular vertical faces, each of which intersects the two horizontal crystallographic axes unequally. There are various ditetragonal prisms, depending upon their differing relations to the horizontal axes. A common form, represented in Fig. 140, has indices {210}.

5. *Dipyramid of first order* {*hhl*}. The dipyramid of the first order is a form consisting of eight isosceles triangular faces, each of which intersects all three crystallographic axes, with equal intercepts upon the two horizontal axes. There are various dipyramids of the first order, depending upon the inclination of their faces to *c*. The unit dipyramid {111}, which intersects all the axes at their unit lengths, is the most common. Indices of other dipyramids of the first order are {221}, {331}, {112}, {113}, etc., or, in general, {*hhl*}. Figure 141 represents the unit dipyramid on zircon.

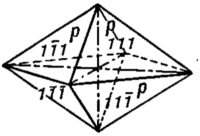


Fig. 141. First-Order Dipyramid.

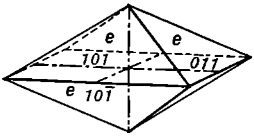


Fig. 142. Second-Order Dipyramid.

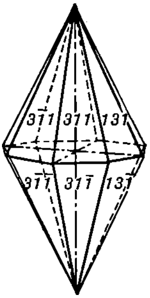
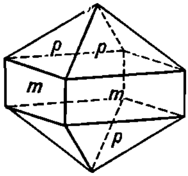


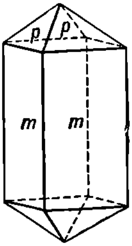
Fig. 143. Ditetragonal Dipyramid.

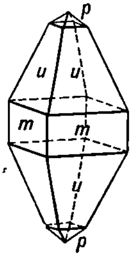
Tetragonal Dipyramids.

6. *Dipyramid of second order* {0*kl*}. The dipyramid of the second order is a form composed of eight isosceles triangular faces, each of which intersects one horizontal axis and the vertical axis and is parallel to the second horizontal axis. There are various dipyramids of the second order, with different intersections upon the vertical axis. The most common form is the unit dipyramid {011}. Other dipyramids of the second order have indices {021}, {031}, {012}, {013}, or, in general, {0*kl*}. Figure 142 represents the dipyramid {011} on zircon.

The relationship between the dipyramids of the first and second order is similar to that between the prisms of the first and second order.







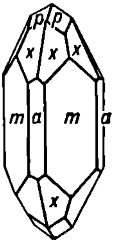


FIG. 144. FIG. 145. FIG. 146. FIG. 147.

Combinations of Tetragonal Forms Shown on Zircon Crystals.

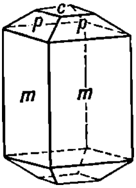


FIG. 148. Idocrase with First-Order Prism, First-Order Dipyramid, Basal Pinacoid.

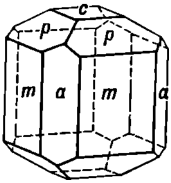


FIG. 149. Idocrase with First- and Second-Order Prisms, First-Order Dipyramid, Basal Pinacoid.

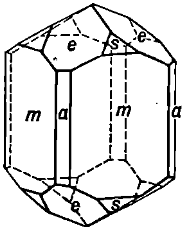


FIG. 150. Rutile with First- and Second-Order Prisms, First- and Second-Order Dipyramids.

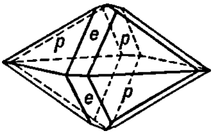


FIG. 151. Cassiterite with First- and Second-Order Dipyramids.

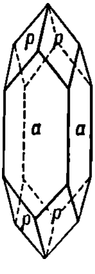


FIG. 152. Apophyllite with First-Order Dipyramid and Second-Order Prism.

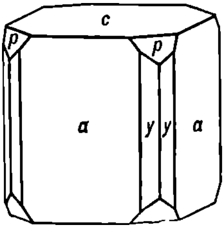


FIG. 153. Apophyllite with First-Order Dipyramid, Second-Order Prism, Ditetragonal Prism, Basal Pinacoid.

As a general rule in the absence of other evidence, if one dipyramid is present on a crystal, it is set up as the first order. If two dipyramids of different orders are present, the dominant one is usually set up as the first order. In the orientation of a crystal, the prisms are subordinate to the dipyramids. Thus, an important prism may be relegated to second order by the presence of a small dipyramid.

7. *Ditetragonal dipyramid* {*hkl*}. The ditetragonal dipyramid is a form composed of sixteen triangular faces, each of which intersects all three of the crystallographic axes, cutting the two horizontal axes at different lengths. There are various ditetragonal dipyramids, depending upon the differential axial intersections possible. One of the most common is the dipyramid {131} shown in Fig. 143 as it would appear on zircon.

Tetragonal combinations. The various dipyramids are the only closed forms in the tetragonal system and are, therefore, the only ones that can occur alone. They are ordinarily found in combination with other forms. Characteristic combinations as found on crystals of different minerals are represented in Figs. 144 to 153.

Tetragonal-Scalenohedral (Chalcopyrite) Class

Symmetry — $3A_2$, $2P$. The scalenohedral class of the tetragonal system corresponds to the hextetrahedral class of the isometric system. It is characterized by three axes of 2-fold symmetry corresponding to the crystallographic axes (see Fig. 154), and two vertical diagonal planes of symmetry (see Fig. 155).

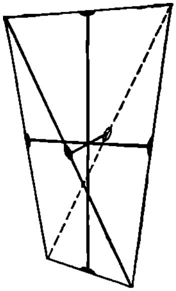


FIG. 154. Symmetry Axes.

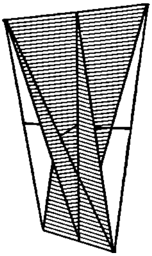
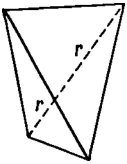


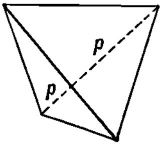
FIG. 155. Symmetry Planes.

Symmetry of Scalenohedral Class, Tetragonal System.

Forms. The *disphenoid* {*hhl*} *positive,* {$h\bar{h}l$} *negative* are the only important forms in this class. They consist of four isosceles triangular faces which intersect all three of the crystallographic axes, with equal intercepts on the two horizontal axes. The faces correspond in their position to the alternating faces of the tetragonal dipyramid of the first order. There may be different disphenoids, depending upon their varying intersections with the vertical axis. Two different disphenoids are shown in Figs. 156 and 157. There may also be a combination of a positive and a negative disphenoid as represented in Fig. 158.

The disphenoid differs from the tetrahedron in the fact that its vertical crystallographic axis is not of the same length as the horizontal axes. The only common mineral in the tetragonal scalenohedral class is chalcopyrite, crystals of which ordinarily show only the disphenoid {112}. This disphenoid closely resembles a tetrahedron, and it requires accurate measurements to prove its tetragonal character.





Figs. 156 Fig. 157. Positive Disphenoids.

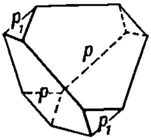


Fig. 158. Positive and Negative Disphenoids.

The *tetragonal scalenohedron* {*hkl*} is the general form from which this class derives its name. It is bounded by eight similar scalene triangles, which correspond in their position to alternate *pairs* of faces of the ditetragonal dipyramid. This is a rare form and observed only in combination with others.

Characteristics of Tetragonal Crystals

The striking characteristics of tetragonal crystals may be summarized as follows: one and only one axis of 4-fold symmetry; the length of the crystal parallel to this axis is usually greater or less than its other dimensions; the cross section of an undistorted crystal when viewed in the direction of the axis of tetragonal symmetry is a square or a truncated square. Chalcopyrite is the only common tetragonal mineral to which the above does not apply, but it can be recognized easily by its disphenoidal crystals and physical properties.

H. ORTHORHOMBIC SYSTEM

Crystallographic Axes. There are three unequal crystallographic axes in the orthorhombic system that make angles of 90° with each other. The relative lengths of the axes, or the axial ratios, must be determined for each orthorhombic mineral. Any one of the three axes may be chosen as the vertical or *c* axis. The longer of the other two is taken as the *b* axis and is called the *macro-axis*. The shorter of the horizontal axes is taken as the *a* axis and is called the *brachy-axis*. The decision as to which of the three axes shall be chosen as the vertical or *c* axis depends usually upon the crystal habit of the mineral being considered. If its crystals commonly show an elongation in one direction, this direction is conventionally chosen as the *c* axis; see Figs. 170–172, page 51. If on the other hand the crystals show a prominent pinacoid and therefore are tabular in habit, this pinacoid is usually taken as the horizontal (basal) pinacoid with the *c* axis normal to it; see Figs. 175–177, page 51. Cleavage also serves as a criterion for orienting orthorhombic crystals. If, as in topaz, there is one pinacoidal cleavage, it is taken as basal cleavage. If, as in barite, there are two equivalent cleavage directions, they are considered as prismatic rather than domatic cleavages. Of course, if a substance is well known and the orientation of its crystals is given in the literature, it is customary to conform to that orientation. The length of the axis which has been chosen as the *b* axis is taken as unity, and the relative lengths of the *a* and *c* axes are given in terms of it. Figure 159 represents the crystallographic axes for the orthorhombic mineral sulfur, whose axial ratio is $a : b : c = 0.813 : 1 : 1.903$ (see page 14).

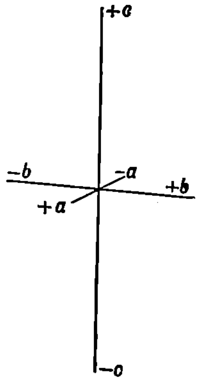


FIG. 159. Orthorhombic Crystal Axes.

Rhombic-Dipyramidal (Barite) Class

Symmetry — C, $3A_2$, $3P$. The three crystallographic axes are axes of 2-fold symmetry (Fig. 160), and the three axial planes are planes of symmetry (Fig. 161). From these symmetry elements, it follows that there is also a center of symmetry.

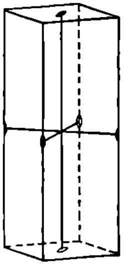


FIG. 160. Symmetry Axes.

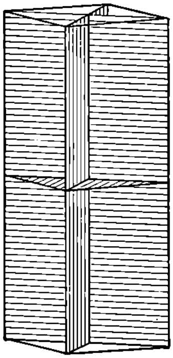


FIG. 161. Symmetry Planes.

Symmetry of Dipyramidal Class, Orthorhombic System.

Forms. The following forms are found in the orthorhombic dipyramidal class:

1. *Basal pinacoid* {001}. The basal pinacoid is a form consisting of two parallel faces, each of which intersects the *c* axis and is parallel to the *a* and *b* axes (Figs. 162 and 163).

2. *Brachypinacoid* {010}. This is a form consisting of two parallel faces, each of which intersects the *b* axis and is parallel to the *a* (brachy) and the *c* axes (Figs. 162 and 164).

3. *Macropinacoid* {100}. The macropinacoid has two parallel faces, each of which intersects the *a* axis and is parallel to the *b* and *c* axes. It derives its name from the fact that it is parallel to the *b* or macro-axis. It is represented in Fig. 162 in combination with the basal and brachypinacoids.

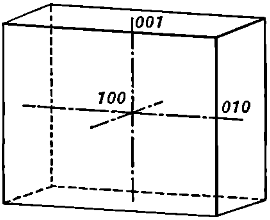


FIG. 162. Orthorhombic Pinacoids.

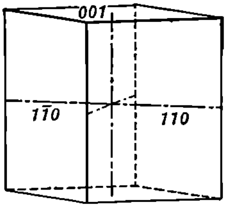


FIG. 163. Unit Prism and Basal Pinacoid.

4. *Prism* {*hk*0}. The orthorhombic prism has four vertical rectangular faces, each of which intersects the two horizontal axes. The unit prism {110} intersects the two horizontal axes at unit lengths (Fig. 163).

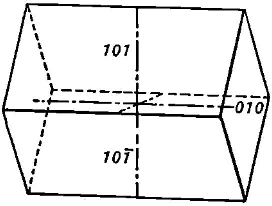


FIG. 164. Unit Macrodome and Brachypinacoid.

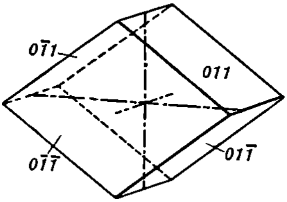


FIG. 165. Unit Brachydome and Macropinacoid.

5. *Macrodome* {*h*0*l*}. A macrodome is a form consisting of four faces, each of which intersects the *a* and *c* axes and is parallel to the *b* or macro-axis. It is named from the axis which it parallels. There are various macrodomes with different axial intercepts. The unit form {101} is shown in Fig. 164 in combination with the brachypinacoid.

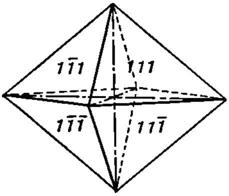


FIG. 166. Orthorhombic Dipyramid.

6. *Brachydome* {0*kl*}. The brachydome consists of four faces, each of which intersects the *b* and *c* axes and is parallel to the *a* or brachy-axis. There are various brachydomes with different axial intercepts. The unit form {011} is illustrated in Fig. 165 in combination with the macropinacoid.

Since the domes parallel a horizontal axis and like the prism are composed of four faces, they are sometimes called *horizontal prisms.* Moreover, a dome may become a prism if a different orientation of axes is chosen.

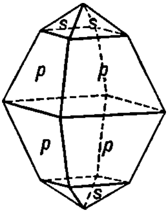


Fig. 167.

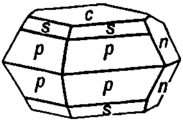


Fig. 168.

Sulfur.

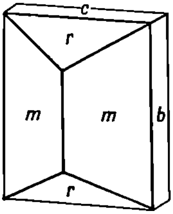


Fig. 169.

Staurolite.

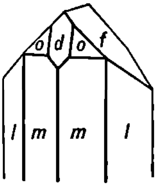


Fig 170.

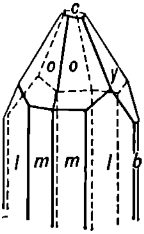


Fig. 171.

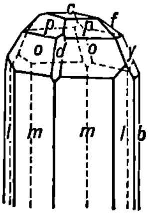


Fig. 172.

Topaz.

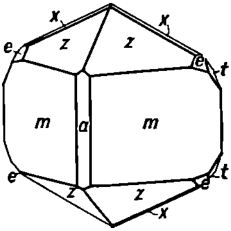


Fig. 173. Brookite.

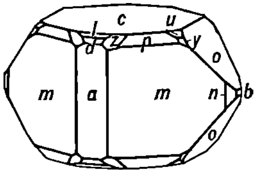


Fig. 174. Anglesite.

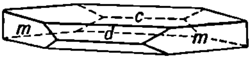


Fig. 175.

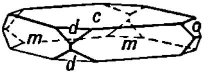


Fig. 176.

Barite.

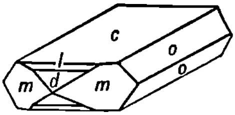


Fig. 177. Celestite

Crystals Showing Combinations of Orthorhombic Forms.

7. *Dipyramid* $\{hkl\}$. An orthorhombic dipyramid has eight triangular faces, each of which intersects all three of the crystallographic axes. It is the general form from which the orthorhombic-dipyramidal class receives its name. Figure 166 represents the unit dipyramid $\{111\}$.

Combinations. Practically all orthorhombic crystals consist of combinations of two or more forms. Characteristic combinations of the various forms are given in Figs. 167–177.

Rhombic-Pyramidal (Hemimorphite) Class

Symmetry — $1A_2$, $2P$. In the orthorhombic pyramidal class the c axis is an axis of 2-fold symmetry. The two symmetry planes intersect in the symmetry axis.

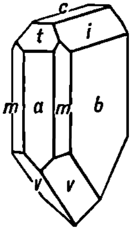


FIG. 178. Hemimorphite.

Forms. The lack of a horizontal symmetry plane in the orthorhombic pyramidal class necessitates the presence of different forms at the top and bottom of crystals. Thus the pyramid $\{111\}$ embraces only four faces at the top of the crystal, while $\{11\bar{1}\}$ embraces four faces at the bottom of the crystal. Likewise the domes are each composed of but two faces, and the basal pinacoid $\{001\}$ differs from and is independent of $\{00\bar{1}\}$. The prisms are the same as in the dipyramidal class. Hemimorphite, the best example of a mineral crystallizing in this class, is represented in Fig. 178.

Characteristics of Orthorhombic Crystals

The most distinguishing characteristics of orthorhombic crystals are as follows: The three chief directions at right angles to each other are of different lengths. These three directions are, in the dipyramidal class, axes of binary symmetry. The crystals are commonly prismatic in their development and usually show cross sections that are either rectangles or truncated rectangles.

I. MONOCLINIC SYSTEM

Crystallographic Axes. In the monoclinic system there are three crystallographic axes of unequal lengths. The axes a and b, and b and c make 90° angles with each other, but a and c make some oblique angle with each other. The relative lengths of the axes and the angle between the a and c axes vary for each monoclinic mineral and must be determined from appropriate measurements. When properly oriented, b, known as the *ortho-axis*, is horizontal and parallel to the observer; a, known as the *clino-axis*, is inclined downward toward the observer; and *c* is vertical. The length of the *b* axis is taken as unity, and the lengths of the *a* and *c* axes are expressed in terms of it. The larger of the two supplementary angles that *a* and *c* make with each other is designated as β. Figure 179 represents the crystallographic axes of the monoclinic mineral orthoclase, the axial constants of which are expressed as: $a : b : c = 0.658 : 1 : 0.555$; $\beta = 116° 03'$.

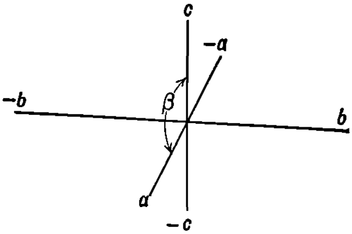


FIG. 179. Monoclinic Crystal Axes.

In any monoclinic crystal the positions of the *b* axis and of the plane in which the *a* and *c* axes lie are fixed by the symmetry (see Figs. 180 and 181). The directions which shall serve as the *a* and *c* axes, however, are matters of choice and depend upon the crystal habit and the cleavage. If the crystals of the substance show an elongated development (prismatic habit) parallel to some direction in the *a*–*c* plane, that direction often serves as the *c* axis; see Figs. 191–193, page 57. Further, if there is a prominent sloping plane or planes, such as planes *c* in Figs. 196–198, or planes *r* in Figs. 193 and 194, these may be taken as parallel to the inclined *a* axis. It is quite possible that there may be two, or even more, different choices that are equally good as to the directions of the *a* and *c* axes in a monoclinic crystal. Once established, the orientation of the crystals of a given substance is usually followed in subsequent descriptions.

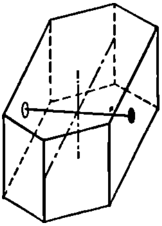


FIG. 180. Symmetry Axis.

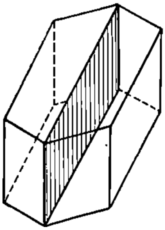


FIG. 181. Symmetry Plane.

Symmetry of Monoclinic System.

Cleavage is also an important factor in orienting a monoclinic crystal. If there is a good pinacoidal cleavage parallel to the *b* axis, as in orthoclase, Fig. 196, it is usually taken as the basal cleavage. If there are two equivalent cleavage directions, as in the amphiboles and pyroxenes, they are usually taken to be prismatic cleavages.

Prismatic (Gypsum) Class

Symmetry — ***C*, 1*A*$_2$, 1*P*.** In the prismatic class of the monoclinic system the *b* crystallographic axis is an axis of 2-fold symmetry. The *a*–*c* plane of the crystallographic axes is a symmetry plane (see Figs. 180 and 181). With a 2-fold symmetry axis at right angles to a symmetry plane, it must follow that there is also a center of symmetry.

Forms. The following forms are found in the monoclinic system:

1. *Basal pinacoid* {001}. The basal pinacoid (see Figs. 182 and 185) consists of two parallel faces each of which intersects the *c* axis and parallels the *a* and *b* axes.

2. *Clinopinacoid* {010}. The clinopinacoid (see Figs. 182 and 183) consists of two parallel faces, each of which intersects the *b* axis and is parallel to the *a* (clino) and *c* axes.

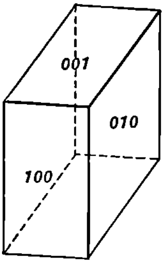


FIG. 182. Orthopinacoid, Clinopinacoid, and Basal Pinacoid.

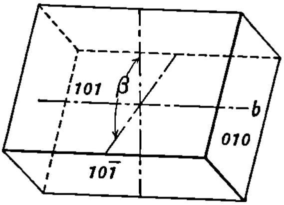


FIG. 183. Orthodomes and Clinopinacoid.

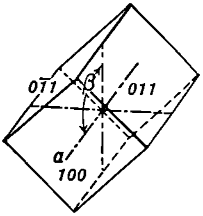


FIG. 184. Clinodome and Orthopinacoid.

3. *Orthopinacoid* {100}. The orthopinacoid (see Fig. 184) has two parallel faces, each of which intersects the *a* axis and is parallel to the *b* (ortho-) and *c* axes. Figure 182 shows a combination of the three pinacoids.

4. *Prism* {*hk*0}. The monoclinic prism has four vertical faces, each of which intersects the *a* and *b* axes and is parallel to the *c* axis. There are various prisms with different axial intercepts. A unit prism {110} is represented in Fig. 185.

5. *Clinodome* {0*kl*}. The clinodome is a form having four faces, each of which intersects the *b* and *c* axes and parallels the *a* or clinoaxis. There are various clinodomes with differing axial intercepts; the unit form {011} is represented in Fig. 184. If the *a* and *c* axes of a monoclinic crystal were to be interchanged, the clinodomes of the first setting would become prisms of the second setting; and the prisms of the first, clinodomes of the second.

6. *Orthodome* $\{h0l\}$ *positive,* $\{\bar{h}0l\}$ *negative.* The dome as a crystallographic form is considered to be made up of four faces. However, the orthodomes of the monoclinic system have only two parallel faces, and are thus designated as *hemidomes.** Each face intersects the *a* and *c* axes and parallels the *b* or ortho-axis. There are various hemi-orthodomes with different axial intercepts. Since the opposite ends of the *a* axis in the monoclinic system are not interchangeable, there are two distinct types of hemi-orthodomes depending on whether the face upon the upper end of the crystal intersects the positive or negative end of the *a* axis. If such a face intersects the positive end of the *a* axis, the form is designated as a *positive hemi-orthodome*; if it intersects the negative end of the *a* axis, it is designated as a *negative hemi-orthodome.* It should be emphasized that these two forms are entirely independent of one another, and the presence of one in no way necessitates the presence of the other. The unit positive hemi-orthodome $\{101\}$ and the unit negative hemi-orthodome $\{\bar{1}01\}$ are illustrated respectively in Figs. 186 and 187 in combination with the prism and base. The two forms are illustrated together in Fig. 188 in combination with the prism and base.

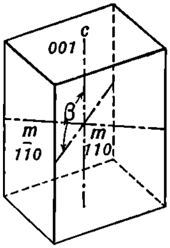


FIG. 185. Monoclinic Prism and Base.

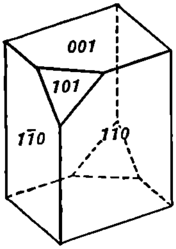


FIG. 186. Positive Hemi-orthodome, Prism, and Base.

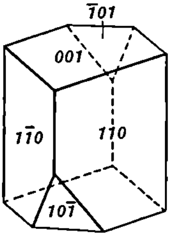


FIG. 187. Negative Hemi-orthodome, Prism, and Base.

7. *Dipyramid* $\{hkl\}$ *positive,* $\{\bar{h}kl\}$ *negative.* The dipyramid as a crystallographic form is normally considered to be made up of eight faces. Since the dipyramids of the monoclinic system have only four faces, they are called *hemi-dipyramids.* There are different dipyramids depending on the varying axial intercepts. In the monoclinic system

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* Since an orthodome has but two faces, it might be called a pinacoid. However, in an elementary treatment it seems best to reserve *pinacoid* for a form intersecting only one axis. Once the orientation is established, a hemi-orthodome intersects both the *a* and *c* axes.

there are two independent types depending on whether the two faces on the upper half of the crystal intersect the positive or negative end of the *a* axis. If two such faces intersect the positive end of the *a* axis, the form is known as a *positive hemi-dipyramid;* if they intersect the negative end of the *a* axis, the form is known as a *negative hemi-dipyramid.* These two types of dipyramids are entirely independent of each other. The unit positive hemi-dipyramid represented in Fig. 189 and the unit negative hemi-dipyramid represented in Fig. 190 are shown in combination with the prism and base.

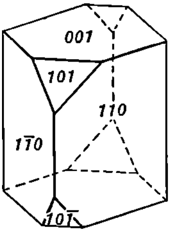


Fig. 188. Positive and Negative Hemi-orthodomes, Prism, and Base.

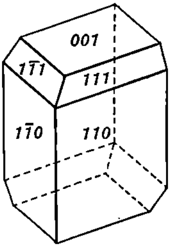


Fig. 189. Positive Hemi-dipyramid, Prism, and Base.

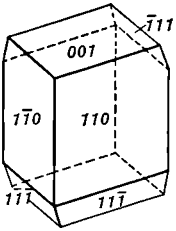


Fig. 190. Negative Hemi-dipyramid, Prism, and Base.

It should be noted that the only monoclinic form that is absolutely fixed in its designation is the clinopinacoid. The other forms may vary with a variation in the choice of the directions of the *a* and *c* axes. For instance, the orthopinacoid, basal pinacoid, and orthodome may be converted into each other by a change in orientation, and the same is true of the prism, hemi-dipyramid, and clinodome.

This, the prismatic, class of the monoclinic system derives its name from the fact that the general form has four faces, and that any four-faced form can be oriented as the prism.

Monoclinic combinations. Characteristic combinations of the forms described above are given in Figs. 191–198.

Characteristics of Monoclinic Crystals

Monoclinic crystals are to be distinguished chiefly by their low symmetry. The fact that they possess but one plane of symmetry and one axis of 2-fold symmetry at right angles to it serves to differentiate them from the crystals of all other systems. Usually the inclination of the crystal faces which are parallel to the clino-axis is marked, and only in rare instances does the angle between the *a* and *c* axes approach closely 90°.

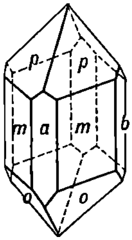


FIG. 191

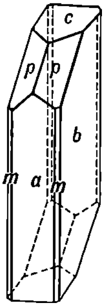


FIG. 192

Pyroxene.

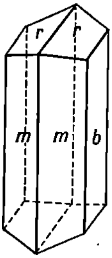


FIG. 193.

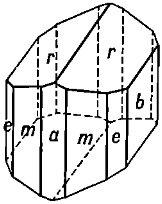


FIG. 194.

Amphibole.

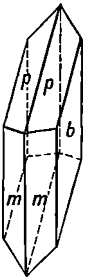


FIG. 195.

Gypsum.

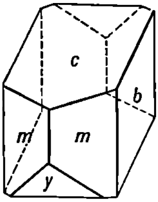


FIG. 196.

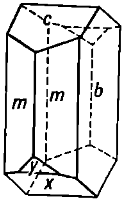


FIG. 197.

Orthoclase.

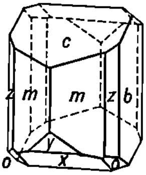


FIG. 198.

Monoclinic Crystals.

J. TRICLINIC SYSTEM

Crystallographic Axes. In the triclinic system there are three crystallographic axes of unequal length that make oblique angles with each other (see Fig. 199). The three rules that should be followed in orienting a triclinic crystal and thus in determining the positions of the crystallographic axes are: (1) The most-pronounced zone should be set vertical. The axis of this zone then becomes the *c* axis. (2) The basal pinacoid should slope forward and to the right. (3) Two forms in the vertical zone should be selected; one as the brachypinacoid, the other as the macropinacoid. The directions of the *a* and *b* axes are determined respectively by the intersections of the brachy- and macropinacoids with the basal pinacoid. The *b* (macro-) axis should be longer than the *a* (brachy-)

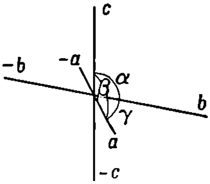


FIG. 199. Triclinic Crystal Axes.

axis. The relative lengths of the three axes and the angles between them can be established only with difficulty and must be calculated for each mineral from appropriate measurements. The angles between the positive ends of b and c, c and a, and a and b are designated respectively as α, β, and γ (see Fig. 199). For example, the crystal constants of the triclinic mineral axinite are as follows: $a : b : c = 0.492 : 1 : 0.480$; $\alpha = 82° 54'$, $\beta = 91° 52'$, $\gamma = 131° 32'$.

Pinacoidal (Anorthite) Class

Symmetry — C. The symmetry of the pinacoidal class of the triclinic system consists of only a center. There are no axes or planes of symmetry.

Forms. All forms of the pinacoidal class of the triclinic system consist of two similar and parallel faces, and in this respect they might be spoken of as pinacoids. It is because of this fact that this, the pinacoidal, class receives its name. However, the forms are usually designated as pyramids when their faces intersect all three crystallographic axes, as prisms or domes when they intersect two axes, and as pinacoids when they intersect but one axis.* It is to be noted, however, that by a change in the choice of axial directions any one of these forms could be converted into any other.

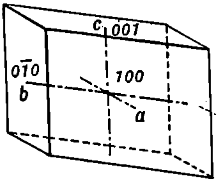


FIG. 200. Triclinic Pinacoids.

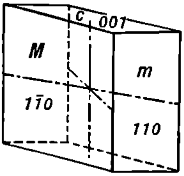


FIG. 201. Triclinic Prisms and Base.

1. *Pinacoids.* A triclinic pinacoid is a form consisting of two parallel faces, each of which intersects one crystallographic axis and is parallel to the other two. As in the orthorhombic system, they are designated as the macropinacoid {100}, as the brachypinacoid {010}, and as the basal pinacoid {001}. Figure 200 shows the three pinacoids in combination.

2. *Prisms.* The prisms are designated as *right* $\{hk0\}$, or *left* $\{h\bar{k}0\}$, depending on whether the front face intersects the right or left end of the b axis (Fig. 201).

---

* If the nomenclature used for the other systems were to be carried to its logical conclusion in the triclinic system, the prisms would be hemiprisms, the domes hemidomes, and the pyramids tetarto-dipyramids.

3. *Domes.* A triclinic dome consists of two similar parallel faces. The brachydomes are designated as *right* $\{0kl\}$, and *left* $\{0\bar{k}l\}$ (Fig. 202). The macrodomes are designated as *front* $\{h0l\}$, and *back* $\{\bar{h}0l\}$ (Fig. 203). It should be pointed out that each of these four forms may occur independently of the others.

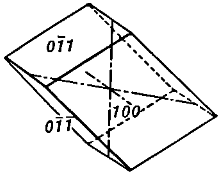


FIG. 202. Brachydomes and Macropinacoid.

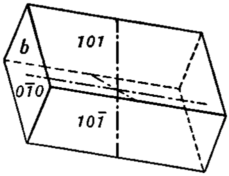


FIG. 203. Macrodomes and Brachypinacoid.

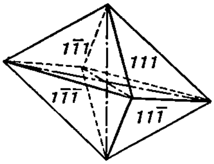


FIG. 204. Triclinic Pyramids.

4. *Pyramids.* A triclinic pyramid consists of two parallel faces, each of which intersects all three of the crystallographic axes. Four types are possible, depending on the octants in which the faces lie. The four pyramids may be designated as *front right* $\{hkl\}$, *front left* $\{h\bar{k}l\}$, *back right* $\{\bar{h}kl\}$, *back left* $\{\bar{h}\bar{k}l\}$. Figure 204 shows a combination of the four unit pyramids.

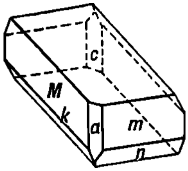


FIG. 205. Rhodonite.

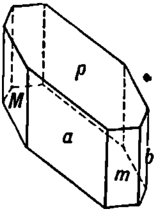


FIG. 206. Chalcanthite.

Triclinic Crystals.

Triclinic combinations. Figures 205 and 206 represent characteristic triclinic crystals.

Characteristics of Triclinic Crystals

With the exception of the plagioclase feldspars, there are few common triclinic minerals, and they rarely form distinct and well-developed crystals. When such crystals do occur, they are usually recognized by the fact that they have no plane or axis of symmetry and by the fact that each form consists of only two similar and parallel faces.

K. TWIN CRYSTALS AND CRYSTALLINE AGGREGATES

In the foregoing discussion of the various crystal systems, the character of ideally developed individual crystals has been considered. Such crystals are the exception, and minerals are more frequently found in crystals distorted from ideal symmetry or intergrown with one another. An intergrowth may result in a parallel, subparallel, or haphazard grouping of the crystalline units. More rarely two or more crystals are observed intergrown according to some definite law and are called twin crystals.

Twin Crystals. When two or more crystals intergrow according to some definite law, the resulting group is said to be a *twin crystal.* The component parts of a twin crystal are related to each other, either as if one part were derived from the other by reflection over a plane common to both, or as if one part were derived from the other by a revolution of 180° about some crystal direction common to both. The plane and axis involved in the above imaginary operations are known as the **twin plane** and the **twin axis.** If a twin plane and a twin axis are both present, they are at right angles to one another. The plane on which two individuals are united is called the **composition plane;** this plane is commonly, but not invariably, the twin plane. Both the twin plane and the composition plane are parallel to possible crystal faces, but the twin plane can never be parallel to a plane of symmetry. The twin axis is a zone axis or a direction perpendicular to a possible crystal face; it can never be an axis of even symmetry (2-, 4-, 6-fold). The twin law is expressed by indicating the twin plane or twin axis and, where possible, the composition plane.

Twin crystals are usually designated as either **contact twins** or **penetration twins.** Contact twins have a definite composition plane separating the two individuals (see Fig. 212). Penetration twins have an indefinite composition plane and are made up of interpenetrating individuals (see Fig. 213). **Repeated** or **multiple twins** are made up of three or more parts all twinned according to the same law. If the successive composition planes are all parallel, the resulting group is called a **polysynthetic twin.** If the successive composition planes are not parallel, a **cyclic twin** results. Figure 207, showing albite twinning in plagioclase feldspar, and Fig. 208, showing twinning on the negative rhombohedron in calcite, are common examples of polysynthetic twinning. When a large number of individuals in a polysynthetic twin are closely spaced, crystal faces or cleavages crossing the composition planes show striations owing to the reversed positions of adjacent individuals. Figures 209 and 210 of rutile and chrysoberyl illustrate cyclic twinning.

Twinning in the lower symmetry groups generally produces a resulting aggregate symmetry higher than that of each individual because the twin plane is an added symmetry plane.

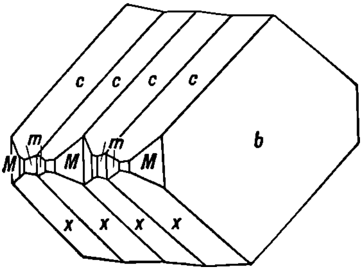


Fig. 207. Albite Twins.

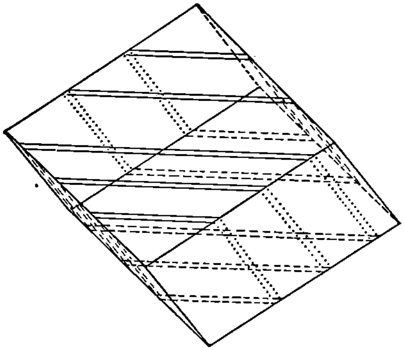


Fig. 208. Calcite Twinned on Negative Rhombohedron.

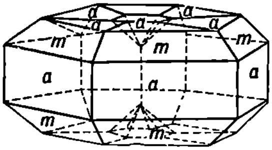


Fig. 209. Rutile

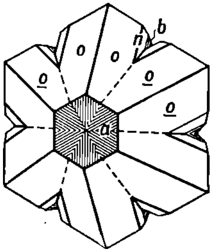


Fig. 210. Chrysoberyl.

Cyclic Twinning.

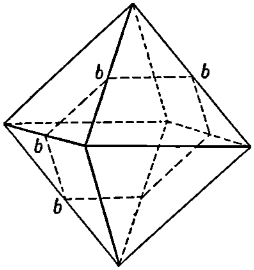


Fig. 211. Octahedron Showing Plane of Twinning.

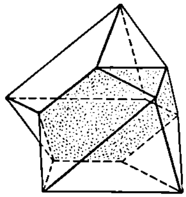


Fig. 212. Spinel Twin.

Common Twin Laws. *Isometric system.* In the hexoctahedral class of the isometric system the twin axis, with a few rare exceptions, is a 3-fold symmetry axis, and the twin plane is thus parallel to a face of the octahedron. Figure 211 shows an octahedron with plane *bb* a possible twin plane, and Fig. 212 shows an octahedron twinned according to this law, forming a contact twin. This type of twin is especially common in gem spinel and hence is called a *spinel twin.* Figure 213 shows two cubes forming a penetration twin following the same law.

In the diploidal class of the isometric system penetration twins of two pyritohedrons, as shown in Fig. 214, are common. Here a plane parallel to a face of the rhombic dodecahedron serves as the twin plane and the normal to it as the twin axis. This twin is known as the *iron cross.*

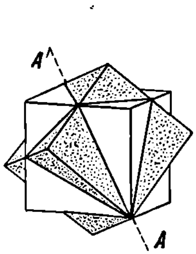


Fig. 213. Fluorite Penetration Twin.

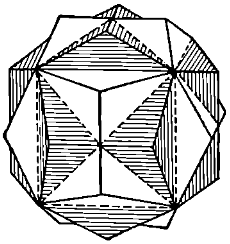


Fig. 214. Pyrite Iron Cross.

Hexagonal system. In the hexagonal division of this system twins are rare and unimportant, but in the rhombohedral division twins are common. The rhombohedral carbonates, especially calcite, serve as excellent illustrations of three of the twinning laws. The twin plane may be parallel to the basal pinacoid, with the c axis as the twin axis, as shown in Figs. 215 and 216. A plane parallel to a face of the negative rhombohedron $\{01\bar{1}2\}$ frequently serves as the twin plane (Fig. 217). Polysynthetic twinning frequently takes place according to this law,

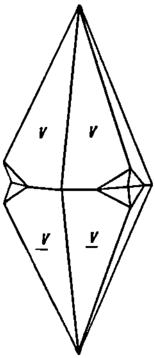


Fig. 215.

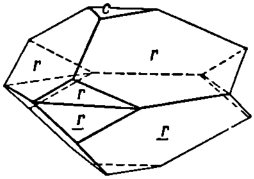


Fig. 216.

Calcite Twinned on the Base.

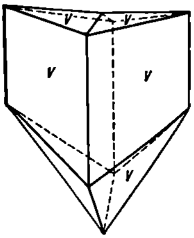


Fig. 217. Calcite Twinned on the Negative Rhombohedron.

and may form as the result of pressure (Fig. 208). A cleavage fragment of Iceland spar may be twinned artificially by the pressure of a knife blade according to the same law, as shown in Fig. 218. In Fig. 219 a plane parallel to a face of the positive rhombohedron $\{10\bar{1}1\}$ serves as a twin plane.

In the trigonal trapezohedral class the mineral quartz shows several types of twinning. In Fig. 220 the *Brazil law* is illustrated with the twin plane parallel to a face of the second-order prism $\{11\bar{2}0\}$. Here, right- and left-hand individuals have formed a penetration twin. In Fig. 221 is illustrated a penetration twin with the *c* axis the twin axis. Such twins are composed either of two right- or two left-hand individuals. In Fig. 222 is illustrated the *Japanese law* with the twin plane parallel to a face of the dipyramid.

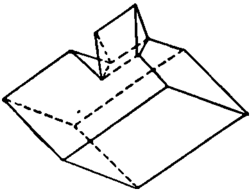


FIG. 218. Artificial Twinning in Calcite.

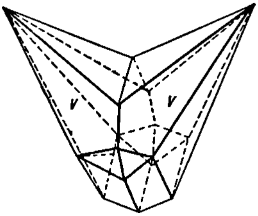


FIG. 219. Calcite Twinned on the Positive Rhombohedron.

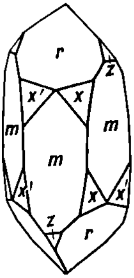


FIG. 220. Brazilian Twin.

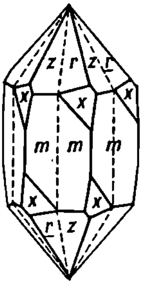


FIG. 221. Penetration Twin.

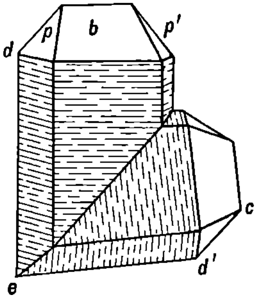


FIG. 222. Japanese Twin.

Twinning in Quartz.

Tetragonal system. The most common type of twin in the tetragonal system has a plane parallel to a face of the dipyramid of the second order {011} as the twin plane. Figures 223–226 represent crystals of cassiterite, rutile, and zircon twinned according to this law.

Orthorhombic system. In the orthorhombic system a plane parallel to a prism face most frequently serves as the twin plane. Figure 227

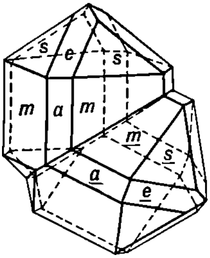


FIG. 223. Cassiterite.

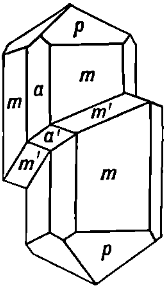


FIG. 224. Rutile.

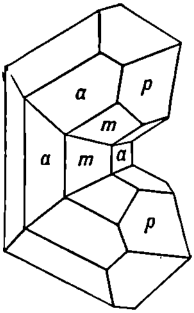


FIG. 225. Rutile.

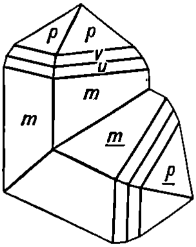


FIG. 226. Zircon.

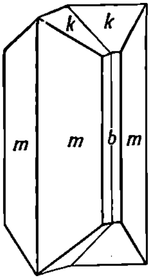


FIG. 227. Aragonite.

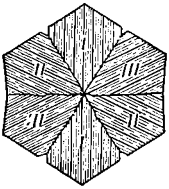


FIG. 228. Cross Section of Cyclic Aragonite Twin.

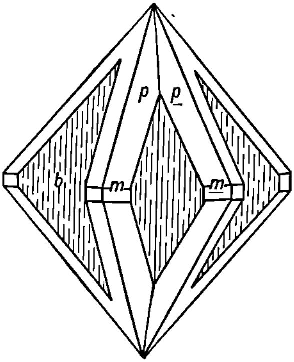


FIG. 229. Cerussite.

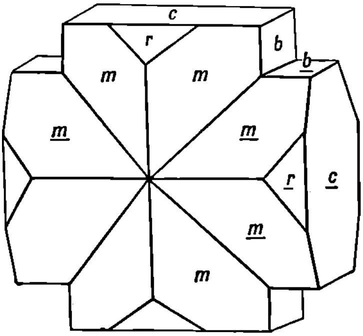


FIG. 230.

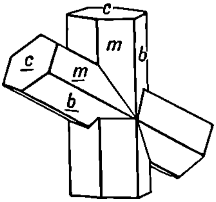


FIG. 231.

Staurolite Twins.

represents a contact twin of aragonite and Fig. 228 a cross section of a cyclic twin of the same mineral formed in this manner. Figure 229 shows a similar cyclic twin of cerussite. The pseudohexagonal appearance of Figs. 228 and 229 results from the fact that the prism angles are nearly 60°. Two types of twinning common in the mineral staurolite are shown in Fig. 230, where a plane parallel to a face of the brachydome {032} is the twin plane; and in Fig. 231, where a plane parallel to a face of the dipyramid {232} is the twin plane.

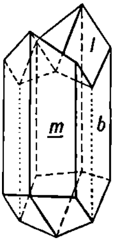


FIG. 232. Gypsum Twin.

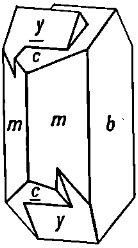


FIG. 233. Carlsbad Twin.

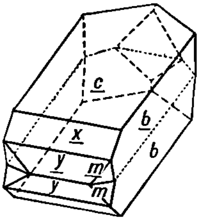


FIG. 234. Manebach Twin.

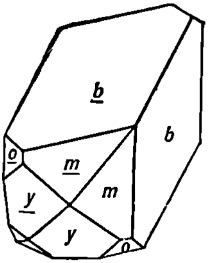


FIG. 235. Baveno Twin.

Monoclinic system. In the monoclinic system twinning on a pinacoid {100} or {001} is most common. Figure 232 of gypsum and Fig. 233 of orthoclase illustrate twinning with the orthopinacoid {100} the twin plane. In the latter species these twins are called *Carlsbad twins*, and the composition plane {010} differs from the twin plane. The Carlsbad twin may also be considered as having the *c* axis the twin axis, but in this case there is no crystallographic plane as twin plane. Orthoclase also forms twins according to the *Manebach law* with a plane parallel to the basal pinacoid {001} the twin plane (Fig. 234), and according to the *Baveno law* with a plane parallel to a face of the clinodome {021} the twin plane (Fig. 235).

Triclinic system. The feldspars illustrate best the twinning of the triclinic system. They are almost universally twinned according to the *albite law* with the brachypinacoid {010} the twin plane, as shown in Fig. 236. Another important type in feldspar is twinning according to the *pericline law* with the crystallographic *b* axis the twin axis.

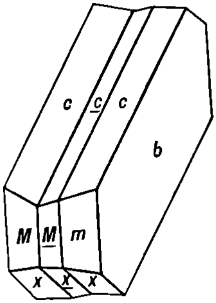


FIG. 236. Albite Twinning.

Crystal Habit and Crystalline Aggregates. Certain terms used to express the appearance or habit of individual crystals, or of aggregates of crystals, are given below:

1. When a mineral consists of isolated and distinct crystals, the following terms may be used:

   a. *Acicular.* In slender needlelike crystals.
   b. *Capillary.* In hairlike crystals.
   c. *Filiform.* In threadlike crystals.
   d. *Bladed.* Elongated crystals flattened like a knife blade.

2. When a mineral consists of a group of distinct crystals the following terms are used:

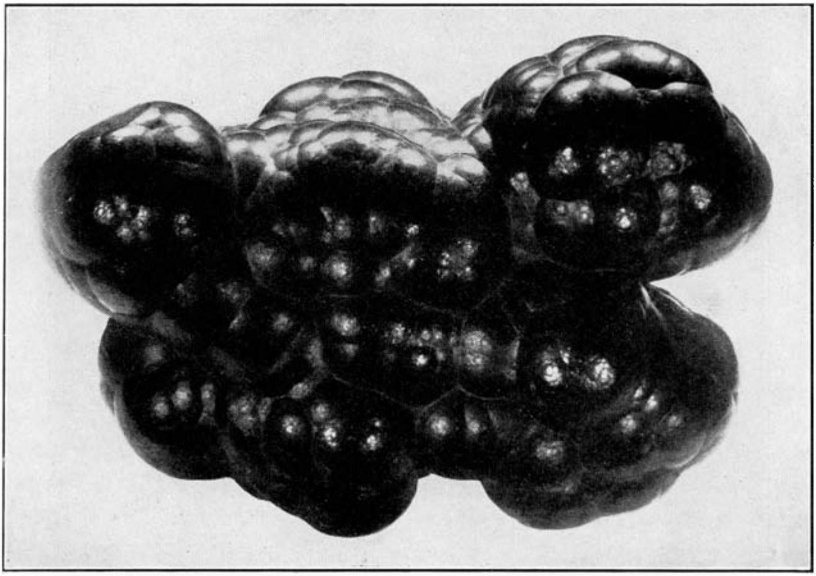
   a. *Dendritic.* Arborescent, in slender divergent branches, somewhat plantlike, made up of more or less distinct crystals.
   b. *Reticulated.* Latticelike groups of slender crystals.
   c. *Divergent* or *radiated.* Radiating crystal groups.
   d. *Drusy.* A surface is drusy when covered with a layer of small crystals.

3. When a mineral consists of parallel or radiating groups of individuals, the following terms are used:

   a. *Columnar.* In stout columnlike individuals.
   b. *Bladed.* An aggregate of many flattened blades.
   c. *Fibrous.* In slender fibrous aggregates.
   d. *Stellated.* Radiating individuals forming starlike or circular groups.
   e. *Globular.* Radiating individuals forming spherical or hemispherical groups.
   f. *Botryoidal.* When the globular forms are in groups. The word is derived from the Greek for a " bunch of grapes."
   g. *Reniform.* Radiating individuals terminating in rounded masses resembling a kidney in shape (see Plate II).
   h. *Mammillary.* Large rounded masses resembling mammae formed by radiating individuals.
   i. *Colloform.* It is frequently difficult to distinguish between aggregates represented by the last three terms, and as a result the term colloform has been proposed to include all the more or less spherical forms.

4. When a mineral consists of scales or lamellae, the following terms are used:

   a. *Foliated.* When a mineral separates easily into plates or leaves.
   b. *Micaceous.* Similar to foliated, but the mineral can be split into exceedingly thin sheets, as in the micas.
   c. *Lamellar* or *tabular.* When a mineral consists of flat platelike individuals superimposed upon and adhering to each other.
   d. *Plumose.* Consisting of fine scales with divergent or featherlike structure.



Hematite with Reniform Surface, Cumberland, England.

PLATE II

5. When a mineral consists of grains.

   Granular. When a mineral consists of an aggregate of large or small grains.

6. Miscellaneous.

   a. Stalactitic. When a mineral occurs in pendent cylinders or cones. Stalactites form by deposition from mineral-bearing waters dripping from the roof of some cavity (see Plate III).

   b. Concentric. Consisting of more or less circular layers superimposed upon one another about a common center.

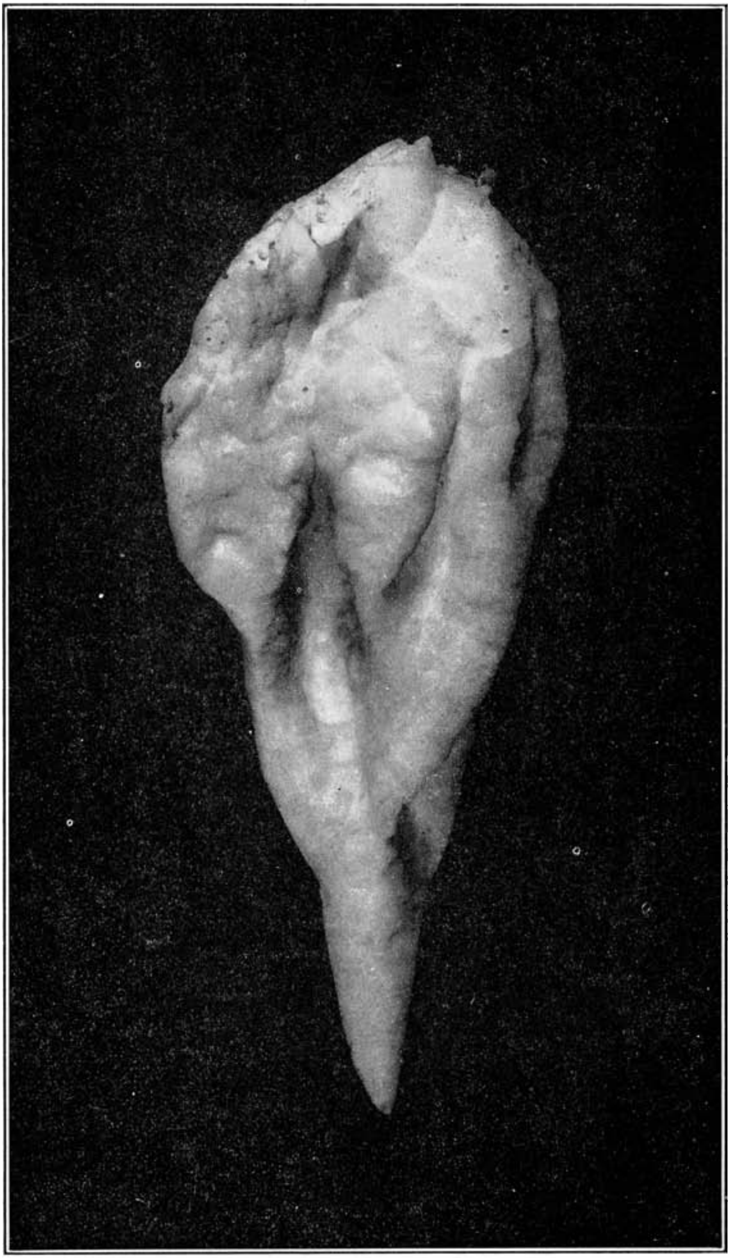
   c. Pisolitic. A mineral consisting of rounded masses about the size of peas.

   d. Oölitic. A mineral aggregate formed of small spheres resembling fish roe.

   e. Banded. When a mineral occurs in narrow bands of different color or texture.

   f. Geodes. When a cavity has been lined by the deposition of mineral material but not wholly filled, the more or less spherical mineral shell is called a geode. The mineral is often banded owing to successive depositions of the material, and the inner surface is frequently covered with projecting crystals.

   g. Massive. A mineral composed of compact material with an irregular form without any peculiar appearance like those described above.



Stalactite.

Plate III

II. PHYSICAL MINERALOGY

The physical properties are highly important in the rapid determination of minerals, since most of them can be recognized at sight or determined by simple tests.

A. CLEAVAGE, PARTING, AND FRACTURE

1. **Cleavage.** If a mineral, when the proper force is applied, breaks so that it yields definite plane surfaces, it is said to possess a *cleavage.* Cleavage surfaces are always parallel to crystal faces or possible crystal faces, and usually to those having simple relations to the crystallographic axes. They may be perfect as in the micas or more or less obscure as in beryl and apatite. Cleavage is closely related to the crystal structure and results from the fact that the internal cohesion is weaker in certain directions than in others. It should be emphasized that cleavage is a directional property, i.e., if a cleavage exists, any plane parallel to it through the crystal is a potential cleavage plane. The number of possible planes is limited theoretically only by the atomic spacing. In describing a cleavage its quality, ease of production, and crystallographic direction should all be given. The quality is expressed as perfect, good, fair, etc. The direction is expressed by the name or indices of the form which the cleavage parallels, as cubic $\{100\}$ (see Fig. 237), octahedral $\{111\}$, rhombohedral $\{10\bar{1}1\}$, prismatic $\{110\}$, pinacoidal $\{001\}$, etc. Cleavage is always consistent with the symmetry; thus, if one octahedral cleavage direction is developed, it implies that there must be three other directions similar to it. If one dodecahedral cleavage direction is present, it likewise implies five other, similar directions. Not all minerals show cleavage, and only a comparatively few show it in an eminent degree, but in these it serves as an outstanding diagnostic criterion.

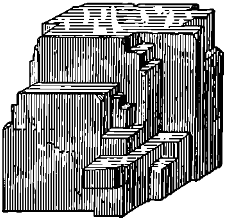


FIG. 237. Cleavage of Galena.

2. **Parting.** Certain minerals when subjected to stress or pressure develop planes of structural weakness along which they may subsequently be broken. Twin crystals, especially polysynthetic twins, may separate easily along the composition planes. When plane surfaces are

produced on a mineral by its breaking along some such predetermined plane, it is said to have a *parting*. This phenomenon resembles cleavage but is to be distinguished from it by the fact that not every specimen of a certain mineral will exhibit it, but only those specimens which are twinned or have been subjected to the proper pressure. Even in these specimens there are only a certain number of planes in a given direction along which the mineral will break. If a mineral possesses cleavage, every specimen will, in general, show it, and it can be produced in a given direction in all parts of a crystal. Familiar examples of parting are found in the octahedral parting of magnetite, the basal parting of pyroxene, and the rhombohedral parting of corundum (see Figs. 238 and 239).

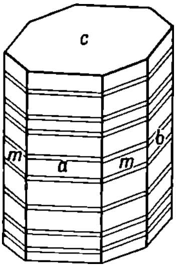


Fig. 238. Basal Parting of Pyroxene.

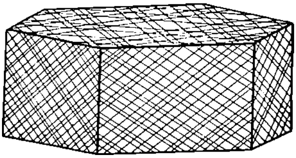


Fig. 239. Rhombohedral Parting of Corundum.

3. Fracture. By the fracture of a mineral is meant the way in which it breaks when it does not yield along cleavage or parting surfaces.

The following terms are commonly used to designate different kinds of fracture:

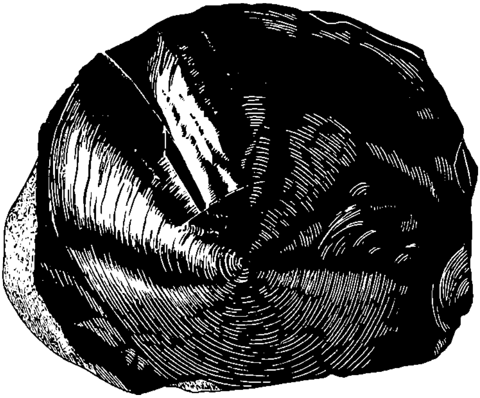


Fig. 240. Conchoidal Fracture in Obsidian (Volcanic Glass).

a. Conchoidal. When the fracture has smooth, curved surfaces like the interior surface of a shell (see Fig. 240). This is most commonly observed in such substances as glass and quartz.

b. Fibrous or *splintery*. When the mineral breaks showing splinters or fibers.

c. Hackly. When the mineral breaks with a jagged, irregular surface with sharp edges.

d. Uneven or *irregular.* When the mineral breaks into rough and irregular surfaces.

B. HARDNESS

The resistance that a smooth surface of a mineral offers to scratching is its *hardness* (designated by **H**). The degree of hardness is determined by observing the comparative ease or difficulty with which one mineral is scratched by another, or by a file or knife. The hardness of a mineral might then be said to be its " scratchability." A series of ten common minerals has been chosen as a scale, by comparison with which the relative hardness of any mineral can be told. The following minerals arranged in order of increasing hardness comprise what is known as the *Mohs scale of hardness:*

Scale of Hardness

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluorite.
5. Apatite.
6. Orthoclase.
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

In order to determine the relative hardness of any mineral in terms of this scale, it is necessary to find which of these minerals it can and which it cannot scratch. In making the determination, the following should be observed: Sometimes when a mineral is softer than another, portions of the first will leave a mark on the second which may be mistaken for a scratch. It can be rubbed off, however, whereas a true scratch will be permanent. Some minerals are frequently altered on the surface to material which is much softer than the original mineral. A fresh surface of the specimen to be tested should therefore be used. The physical nature of a mineral may prevent a correct determination of its hardness. For instance, if a mineral is pulverulent, granular, or splintery, it may be broken down and apparently scratched by a mineral much softer than itself. It is always advisable when making the hardness test to confirm it by reversing the order of procedure.

The following materials may serve in addition to the above scale: The hardness of the finger nail is a little over 2, a copper coin about 3, the steel of a pocket knife a little over 5, window glass $5\frac{1}{2}$, and the steel of a file $6\frac{1}{2}$. With a little practice, the hardness of minerals under 5 can be quickly estimated by the ease with which they can be scratched with a pocket knife.

Crystals may show different degrees of hardness, depending on the direction in which they are scratched. With the exception of the mineral kyanite, a directional hardness difference in common minerals can be detected only by means of delicate instruments.

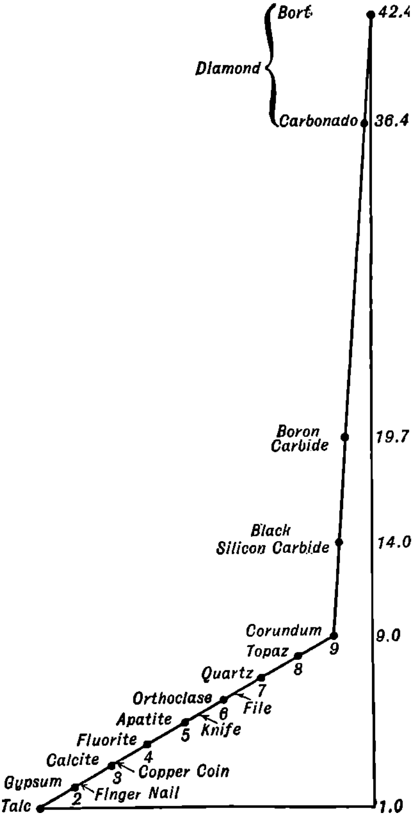


FIG. 241. Relative Hardness of Minerals in the Scale of Hardness (after Wooddell).

It can be seen that only within relatively wide limits can one be quantitative in the determination of hardness. Moreover, the interval of hardness between different pairs of minerals in the scale varies. For instance, the hardness difference between corundum and diamond is many times greater than that between topaz and corundum. Figure 241 is based on quantitative data obtained by one investigator, who determined that, if quartz is 7 and corundum is 9 in hardness on an absolute scale, diamond would be 42.4.

C. TENACITY

The resistance which a mineral offers to breaking, crushing, bending, or tearing — in short, its cohesiveness — is known as tenacity. The following terms are used to describe various kinds of tenacity in minerals:

1. *Brittle.* When a mineral breaks or powders easily.
2. *Malleable.* When a mineral can be hammered out into thin sheets.
3. *Sectile.* When a mineral can be cut into thin shavings with a knife.
4. *Ductile.* When a mineral can be drawn into wire.
5. *Flexible.* When a mineral bends but does not resume its original shape when the pressure is released.
6. *Elastic.* When, after being bent, the mineral will resume its original position upon the release of the pressure.

D. SPECIFIC GRAVITY

The specific gravity of a mineral is a number which expresses the ratio between its weight and the weight of an equal volume of water at 4° C. If a mineral has a specific gravity of 2, it means that a given specimen of that mineral weighs twice as much as the same volume of water. The specific gravity of a mineral of fixed composition is constant, and its determination is frequently an important aid in identification of the mineral. In this book specific gravity is frequently denoted by **G.**

Most people in handling objects of everyday experience acquire a sense of relative weight. With but little experience a similar sense is developed in regard to minerals. For example, ulexite (**G.** 1.65) seems light, while barite (**G.** 4.5) seems heavy for nonmetallic minerals. This means that one has developed an idea of an average specific gravity or a feeling of what a nonmetallic mineral of a given size should weigh. This average specific gravity can be considered to be between 2.65 and 2.75. The reason for this is that quartz (**G.** 2.65), feldspar (**G.** 2.60–2.75) and calcite (**G.** 2.71), the most common and abundant nonmetallic minerals, fall mostly within this range. The same sense may be developed in regard to metallic minerals. Graphite (**G.** 2.1) seems light, while silver (**G.** 10.5) seems heavy. The average specific gravity for metallic minerals can be considered about 5.0, that of pyrite. Thus, with a little practice, one can become expert enough to distinguish from each other minerals that have comparatively small differences in specific gravity, by merely lifting a specimen.

In order to determine accurately the specific gravity of a mineral several conditions must be observed. The mineral must be pure, a requirement frequently difficult to fulfill. It must also be compact with no cracks or cavities within which bubbles or films of air could be imprisoned. For normal mineralogical work, the specimen should have a volume of about one-eighth of a cubic inch; this would be a cube one-half an inch on a side. If these conditions cannot be met, a specific-gravity determination by any rapid and simple method means little.

The necessary steps in making an ordinary specific-gravity determination are briefly as follows: The mineral is first weighed in air. Let this weight be represented by W_a. It is then immersed in water and weighed again. Under these conditions it weighs less, since any object immersed in water is buoyed up by a force equivalent to the weight of the water displaced. Let the weight in water be represented by W_w. Then $W_a - W_w$ equals the loss of weight caused by immersion in water, or the weight of an equal volume of water. The expression $\dfrac{W_a}{W_a - W_w}$

will therefore yield a number which is the specific gravity of the mineral. Since specific gravity is merely a ratio, it is not necessary to determine the absolute weight of the specimen but merely some value that is proportional to the weight.

Jolly Balance. One of the best methods of obtaining the specific gravity of a mineral is by means of a *Jolly balance*, Fig. 242, in which the data for making the calculations are obtained by measuring the stretching of a spiral spring. From the spring are suspended two small pans, *c* and *d*, one above the other. The apparatus is so arranged that the lower pan, *d*, is always immersed in a beaker of water which, resting upon the adjustable platform *B*, can be placed at the required height. In all types of Jolly balances it is necessary to adjust the apparatus so that the index on the spring is at zero with the lower pan immersed in water. The mineral is then placed in the upper pan, and the stretching of the spring, W_a, necessary to bring the indicator to zero again, is determined by means of an affixed scale. The specimen is then placed in the lower pan and another adjustment and W_w reading taken. The specific gravity is then calculated by:

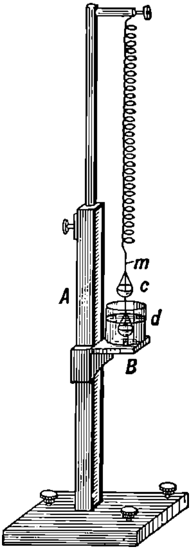


Fig. 242. Jolly Balance.

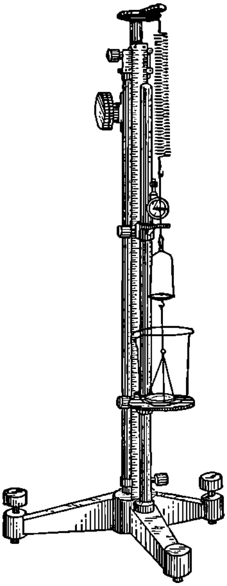


Fig. 243. Improved Jolly Balance.

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

Figure 243 represents an improved type of Jolly balance devised by Kraus. The description of it by its manufacturer* is as follows:

"The balance consists of an upright tube to which the inner, fixed vernier and the movable, double graduated scale are attached. This tube contains a round tube which can be moved by a large milled head. To this second tube, the outer, movable vernier is fastened. A movement of the round tube upward carries the second vernier and the graduated scale with it. Within the round tube there is a rod of adjustable length, which carries the spiral spring, index, and scale pans. With this form of balance only two readings and a simple division are necessary to determine the specific gravity.

"In using the balance it is necessary that the graduated scale, the two verniers, and the index, which is attached to the spiral spring, all be at zero, the lower scale pan being immersed in water. This is accomplished by adjusting approximately by hand the length of the rod carrying the spring and then introducing the necessary correction by means of the micrometer screw. A fragment is then placed on the upper scale pan, and by the turning of the large milled head, the round tube, graduated scale, and outer vernier are all driven upward until the index on the spring is again at zero. The fixed inner vernier, W, now records the elongation of the spring due to the weight of the fragment in the air. The scale is then clamped by means of the screw at the lower end of it. The fragment is now transferred to the lower scale pan and immersed in water, and the round tube is lowered by the large milled head until the index again reads at zero. During this operation the outer vernier moves downward on the graduated scale and its position may now be indicated by L. This is obviously the decrease in the elongation of spring due to the immersion of the fragment in water. The readings at W and L are all the data necessary for the calculation of the specific gravity.

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Loss of weight in water}} = \frac{W}{L}$$

It is also obvious that these readings are recorded so that they may be checked, if necessary, after the operation and calculation are completed."

A refined balance of similar operation, capable of determining the specific gravity of small single particles under 25 milligrams, has recently been made available. To the advanced worker in mineralogy interested in accurate determination of specific gravity this balance is particularly helpful, since frequently it is possible to obtain only a tiny mineral fragment free from impurities.

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* Manufactured by Eberbach and Son, Ann Arbor, Michigan.

Beam Balance. The beam balance is a very convenient and accurate method of determining specific gravity. Moreover, owing to its simplicity, it can be easily and inexpensively constructed at home. The balance illustrated in Fig. 244 was devised by S. L. Penfield, whose description of its operation, slightly modified, is as follows: The beam made of wood or brass is supported at *b* on a fine wire or needle, which permits it to swing freely. The long arm *bc* is divided into a decimal scale; the short arm carries a double arrangement of pans so suspended that one of them is in air and the other in water. A piece of lead on the short arm serves to almost counterbalance the long arm. When the pans are empty, the beam is brought to a horizontal position, marked upon the upright near *c*, by means of a rider *d*. A number of counterpoises are needed; but, since it is their position on the beam and not their actual weight that is recorded, they need not be of any specific denomination. After the beam is adjusted by means of the rider *d*, a mineral fragment is placed in the upper pan and a counterpoise is chosen which, when placed near the end of the long arm, will bring it into a horizontal position. A value, W_a, proportional to the weight of the mineral in air, is given by the position of the counterpoise on the scale. The mineral is next transferred to the lower pan, and the same counterpoise is brought nearer the fulcrum *b* until the beam becomes horizontal again. The position of the counterpoise now gives a value, W_w, proportional to the weight of the mineral in water. The specific gravity can then be determined as follows:

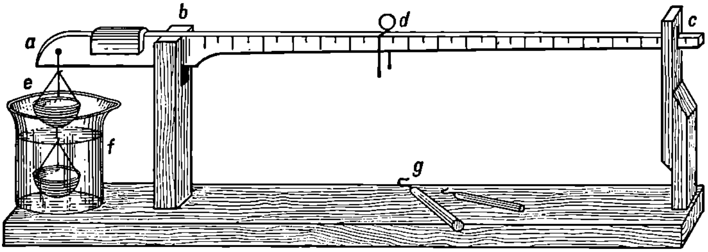

FIG. 244. Beam Balance.

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

Pycnometer. When a mineral cannot be obtained in a homogeneous mass large enough to permit use of one of the balance methods, the specific gravity of a powder or an aggregate of mineral fragments can be accurately obtained by means of the *pycnometer*. The pycnometer is a small bottle (Fig. 245) fitted with a ground-glass stopper through which a capillary opening has been drilled.

In making a specific-gravity determination, the dry bottle with stopper is first weighed empty (P). The mineral fragments are then introduced into the bottle and a second weighing (M) is made. The bottle is partially filled with distilled water and boiled for a few minutes to drive off any air bubbles. After cooling, the pycnometer is filled with distilled water and weighed (S), care being taken that the water rises to the top of the capillary opening but that no excess water is present. The last weighing (W) is made after emptying the bottle and refilling with distilled water alone. The specific gravity can thus be determined:

$$G = \frac{M - P}{W + M - P - S}$$

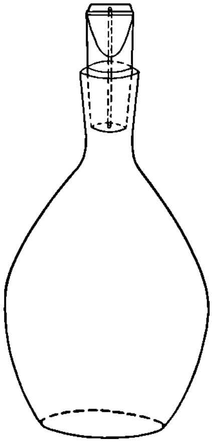

FIG. 245. Pycnometer.

Heavy Liquids. Several liquids with relatively high specific gravities are sometimes used in the determination of the specific gravity of minerals. The two liquids most easily used are bromoform (**G.** 2.89) and methylene iodide (**G.** 3.33). These liquids are miscible with one another and also with acetone (**G.** 0.79), and thus, by mixing, a solution of any intermediate specific gravity may be obtained. A mineral grain is introduced into the heavy liquid, and the solution is diluted with a liquid of lesser specific gravity until the mineral neither rises nor sinks. The specific gravity of the liquid and the mineral are then the same, and that of the liquid may be quickly determined by means of a Westphal balance.

Heavy liquids are frequently used in the separation of mineral grains and powders composed of several constituents.

E. PROPERTIES DEPENDING UPON LIGHT

Luster. The general appearance of the surface of a mineral in reflected light is called *luster*. The luster of minerals can be divided into two types, *metallic* and *nonmetallic*. There is no sharp line dividing these two groups, and those minerals lying between are sometimes said to be *submetallic*.

A mineral having the brilliant appearance of a metal has a metallic luster. Moreover, such minerals are quite opaque to light and, as a result, give a black or very dark streak (see p. 79). Galena, pyrite, and chalcopyrite are common minerals with metallic luster.

All minerals without a metallic appearance have, as the term implies, a nonmetallic luster. They are, in general, light colored and will transmit light through thin edges. The streak of a nonmetallic mineral is either colorless or very light in color. The following terms are used to describe further the appearance of nonmetallic minerals:

Vitreous. Having the luster of glass. Example, quartz.

Resinous. Having the appearance of resin. Example, sphalerite.

Pearly. Having the iridescent appearance of a pearl. This is usually observed in minerals on surfaces that are parallel to cleavage planes. Example, basal plane on apophyllite.

Greasy. Looking as if covered with a thin layer of oil. Examples, nepheline and some specimens of sphalerite and massive quartz.

Silky. Like silk. It is the result of a fine fibrous parallel aggregate. Examples, fibrous gypsum, malachite, and serpentine.

Adamantine. Having a hard, brilliant luster like that of a diamond. It is due to the mineral's high index of refraction (see page 83). The transparent lead minerals, like cerussite and anglesite, show it.

Color. The color of minerals is one of their most important physical properties. For many minerals, especially those showing a metallic luster, color is a definite and constant property and will serve as an important means of identification. The brass-yellow of chalcopyrite, the blue-gray of galena, the black of magnetite, and the green of malachite are examples in which color is a striking property of the mineral. It is to be noted, however, that surface alterations may change the color even in minerals whose color is otherwise constant. This is shown in the yellow tarnish frequently observed on pyrite and marcasite, the purple tarnish on bornite, etc. In noting the color of a mineral, therefore, a fresh surface should be examined. Many minerals, however, do not show a constant color in their different specimens. This variation in color in the same species may be due to different causes. A change in color is often produced by a change in composition. The progressive replacement of zinc by iron in sphalerite (see page 92) will change its color from white through yellow and brown to black. The minerals of the *amphibole group* show a similar variation in color. The amphibole tremolite, which is a silicate with only calcium and magnesium as bases, is very light in color, while actinolite and hornblende, which are amphiboles that contain increasing amounts of iron, range in color from green to black. Again, a mineral may show a wide range of color without any apparent change in composition. Fluorite is a striking example of this, for it is found in crystals that are colorless, white, pink, yellow, blue, green. Such wide variations in color are rare, however. Minerals are also frequently colored by various impurities. The red cryptocrystalline variety of quartz, known as jasper, is colored by small amounts of hematite. From the above it is seen that, though the color of a mineral is one of its important physical properties, it is not always constant and must, therefore, be used with caution in the identification of some species.

Streak. The color of the fine powder of a mineral is known as its *streak.* The streak is frequently used in the identification of minerals, for, although the color of a mineral may vary between wide limits, the streak is usually constant. This property can be conveniently determined in the laboratory by rubbing the mineral on a piece of unglazed porcelain, known as a *streak plate.* The streak plate has a hardness of about 7, and thus it cannot be used with minerals of a greater hardness.

Play of Colors. A mineral is said to show a *play of colors* when on turning it several spectral colors are seen in rapid succession. This is seen especially well in diamond and precious opal. A mineral is said to show a *change of color* when on turning it the colors change slowly with position. This is observed in some labradorite.

Iridescence. A mineral is *iridescent* when it shows a series of spectral colors in its interior or on its surface. An internal iridescence is usually caused by the presence of small fractures or cleavage planes, while an external iridescence is caused by the presence of a thin surface film or coating.

Opalescence. A milky or pearly reflection from the interior of a specimen is known as *opalescence.* It is observed in some opal, moonstone, and cat's-eye.

Tarnish. A mineral is said to show a *tarnish* when the color of the surface differs from that of the interior. Tarnish is frequently shown by the copper minerals, chalcocite, bornite, and chalcopyrite, after fresh surfaces have been exposed to the air.

Asterism. Some crystals, especially those of the hexagonal system, when viewed in the direction of the vertical axis, show starlike rays of light. This phenomenon arises from peculiarities of structure along the axial directions, or from inclusions arranged along these directions. The outstanding example is the star sapphire.

Pleochroism. Some minerals possess a selective absorption of light in different crystallographic directions, and may thus appear variously colored when viewed in different directions in transmitted light. This property is known as *pleochroism.* If a mineral has only two such absorption directions, the property is called *dichroism.*

Luminescence. Any emission of light by a mineral that is not the direct result of incandescence is known as *luminescence.* The phenomenon may be brought about in several ways, apparently quite independent of one another. Most luminescence is faint and can be observed only in the dark.

Triboluminescence is a property possessed by some minerals of becoming luminous on being crushed, scratched, or rubbed. Most minerals showing this property are nonmetallic, anhydrous, and possess a good cleavage. Fluorite, sphalerite, and lepidolite may be triboluminescent and, less commonly, pectolite, amblygonite, feldspar, and calcite.

Thermoluminescence is the property possessed by some minerals of emitting visible light when heated to a temperature below that of red heat. Like triboluminescence, this phenomenon is best shown in nonmetallic, anhydrous minerals. When a thermoluminescent mineral is heated, the initial visible light, usually faint, is given off at a temperature between 50° and 100° C., and light ceases to be emitted at temperatures between 125° and 475° C.* Fluorite for a long time has been known to possess this property; the variety *chlorophane* was named because of the green light emitted. Other minerals which are commonly thermoluminescent are calcite, apatite, scapolite, lepidolite, and feldspar.

Fluorescence and Phosphorescence. Minerals which become luminescent during exposure to ultra-violet light, x-rays, or cathode rays are *fluorescent.* If the luminescence continues after the exciting rays are shut off, the mineral is said to be *phosphorescent.* Phosphorescence was early observed on some minerals which, after exposure to the sun, would glow on removal to a dark room. There is no sharp distinction between fluorescence and phosphorescence, for some minerals which appear only to fluoresce can be shown by refined methods to continue to glow for a small fraction of a second after the removal of the exciting rays. Consequently, both phenomena are considered by some to be the same.

More minerals show fluorescence than other types of luminescence, and, since it is easier to produce, much work has been done on it. Fluorescence is shown by some fluorite, the mineral from which the property receives its name. Other minerals which frequently, but by no means invariably, fluoresce are willemite, scheelite, calcite, scapolite, diamond, hyalite, autunite. Fluorescence is a property that cannot be predicted, for some specimens of a given mineral will show it, while other, apparently similar, specimens will not. Not only do the fluorescent colors of different minerals and different specimens of the same mineral vary greatly, but also they bear no relation to the natural color of the minerals. A well-arranged display of fluorescent minerals makes a beautiful and striking exhibit. (See frontispiece.)

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* Temperatures by M. Allen Northup and O. Ivan Lee in *Jour. Optical Soc. Am.*, Vol. 30, pp. 206–223, 1940

Fluorescence is most commonly produced by excitation with ultra-violet light, and each year sees improvements in the methods of producing such light. It is best to have a source of ultra-violet light with a minimum of accompanying visible light so that the fluorescent effects will not be lessened by reflection. The iron spark, the mercury-vapor lamp, and the argon tube, or some variation of these, are most commonly used. The wave length or color of the light emitted during fluorescence varies considerably with the wave length or source of the ultra-violet light.

Fluorescence is having an increasing commercial and industrial significance, and much work is being done on synthetic material. In connection with minerals, the property has a practical use at Franklin, New Jersey, where the iron spark gap is used to determine the amount of willemite which goes into the tailings. Also, since most scheelite fluoresces, prospecting for that mineral is frequently carried out at night with the aid of ultra-violet light.

Apparently no simple relation exists between luminescence of various kinds, for any kind may exist alone or with any of the others. Moreover, the color of the different types of luminescence may vary in the same specimen. Luminescence is rarely shown by pure compounds, and therefore one factor that may be common to all minerals showing luminescence is a small amount of impurity.

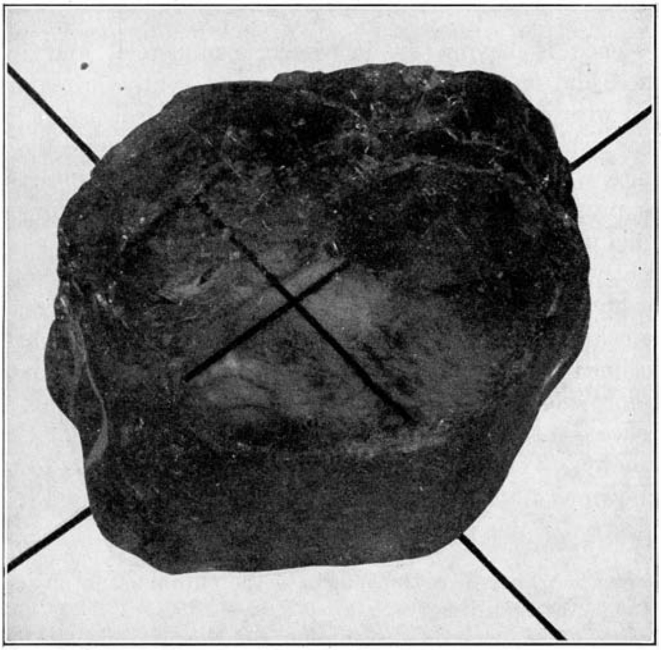
Diaphaneity. The property possessed by some minerals to transmit light is known as *diaphaneity.* The following terms are used to express varying degrees of this property:

Transparent. A mineral is transparent if the outline of an object viewed through it is perfectly distinct.

Translucent. A mineral is translucent which will transmit light, but through which objects cannot be seen.

Opaque. A mineral is opaque if, even on its thinnest edges, it will transmit no light.

Refraction of Light. When light comes into contact with a non-opaque mineral, part of it is reflected from the surface and part enters the mineral. The light which enters the mineral is in general refracted. When light passes from a rarer into a denser medium, as in passing from air into a mineral, its velocity is retarded. This change in velocity is accompanied by a corresponding change in the direction in which the light travels, and it is this change in direction of propagation that is known as refraction of light. (See Plate IV.) The amount of refraction of a given light ray is directly proportional to the ratio existing between the velocity of light in air and that in the mineral. The ratio between these two velocities is known as n, the index of refraction. The ratio is equal to V/v, where V represents the velocity of light in air and v the velocity of light in the mineral. The velocity of light in air may be considered as equal to 1, and therefore $n = 1/v$, or the index of refraction is equal to the reciprocal of the light velocity. Thus, if the index of refraction of a mineral is 2.0, light will travel in the mineral with one-half the velocity it has in air.



Refraction of Light Shown by a Large Cleavage Fragment of Topaz.

PLATE IV

In Fig. 246 let *M–M* represent the surface of a crystal of fluorite. Let *N–O* be normal to that surface. Let *A–O* be one of a number of parallel light rays striking the surface *M–M* in such a way as to make the angle i (angle of incidence) with the normal *N–O*. Let *O–P* be at right angles to the rays and representing the wave front of the light in air. Since the crystal is the denser medium, the light will travel in it more slowly. Therefore, as each ray in turn strikes the surface *M–M*, it will be retarded and the direction of its path will be changed proportionately. In going from a rarer into a denser medium, the ray will be bent toward the normal *N–O*. To find the direction of the rays and line of wave front in the crystal, proceed as follows: Since the index of refraction of fluorite is 1.43, ray *A* will travel in the crystal, in the time it takes ray *C* to travel from *P* to *R*, $\frac{1}{1.43}$ of that distance, or to some point on the circular arc the length of whose radius *OA′* is $\frac{1}{1.43}$ the distance *P–R*. Similarly, ray *B* will travel in the mineral during the period of time in which ray *C* travels from *S* to *R* a distance equal to $\frac{1}{1.43}$ of the distance *S–R*, or the radius *TB′*. The same reasoning will hold true for all other rays. The wave front in the crystal can then be determined by drawing a tangent — the line *A′B′R* — to these various circular arcs; and lines perpendicular to this wave front will represent the direction in which the light travels in the mineral, and the angle *NOA′* or *r* will be the angle of refraction. Figure 247 shows the same construction as that of Fig. 246, but the mineral in question is here assumed to be diamond. Since the index of refraction of diamond ($n = 2.42$) is much greater than that of fluorite, light will travel in it with a still slower velocity. Consequently, in diamond refraction will be greater. This is shown in the two figures, in both of which the angle of incidence is the same.

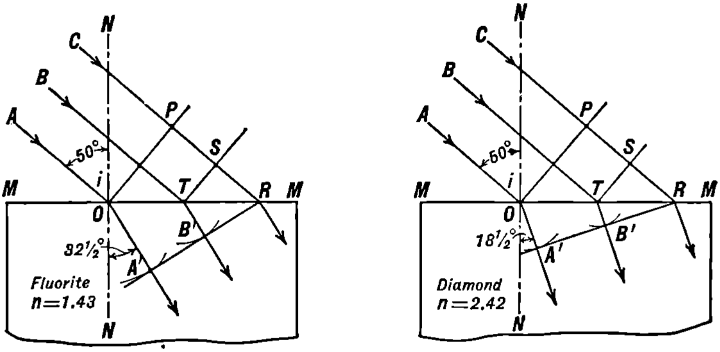


Fig. 246. Fig. 247.

Refraction of Light.

The refractive power toward light which a mineral possesses has often a distinct effect upon the appearance of the mineral. For example, a mass of cryolite may almost always be identified at sight, though, as is generally true, there are no crystal forms to aid in the identification. The mass has a peculiar appearance, somewhat like that of wet snow, and quite different from that of ordinary white substances; this is due to the fact that the index of refraction of cryolite is unusually low for a mineral.

An instructive experiment may be tried by finely pulverizing some pure white cryolite and throwing the powder into water, when it will apparently disappear, as if it had instantly gone into solution. The powder, however, is insoluble, and may be seen indistinctly as it settles to the bottom of the vessel. The reason for this disappearance of the cryolite is that its index of refraction (about 1.34) is near that of water (1.335); hence the light travels almost as readily through the mineral as through water, and consequently it undergoes little reflection or refraction.

Substances with an unusually high index of refraction have an appearance which it is hard to define, and which is generally spoken of as adamantine luster. This kind of luster may be comprehended best by examining specimens of diamond (n = 2.419) or of cerussite (n = about 2.1). They have a flash and quality, some diamonds almost a steel-like appearance, which is not possessed by minerals of low index of refraction; compare, for example, cerussite and fluorite (n = 1.434). It is their high index of refraction that gives to many gem minerals their great brilliancy and charm.

Many nonopaque minerals have a refractive index not far from 1.5, which gives to the minerals the luster of glass, designated as vitreous. Quartz and feldspar are good examples.

Double Refraction. All crystalline minerals except those belonging to the isometric system show, in general, a double refraction of light. That is, when a ray of light enters such a mineral it is broken up into two rays, each of which travels through the mineral with a characteristic velocity and has its own refractive index. Thus, the angle of refraction will be different for the two rays and they will diverge. In other words, the light undergoes double refraction. In the majority of minerals, the amount of this double refraction is small, and the fact that it exists can be demonstrated only by special instruments. Calcite, however, shows such a strong double refraction that it can be easily observed. This is shown in Plate V, Fig. 1, where a double image may be seen through a block of clear calcite (Iceland spar).

The divergence of the two rays in a given mineral depends, first, on its birefringence (the difference between the greatest and least refractive index); second, on the thickness of the mineral block; and, lastly, on the crystallographic direction in which the light is traveling. In tetragonal and hexagonal minerals, there is one direction (that of the vertical crystallographic axis) in which no double refraction takes place (Plate V, Fig. 2). As soon as a ray of light in the mineral deviates from this direction it is doubly refracted, and the amount of double refraction increases as the path of the light becomes more oblique, and attains its maximum when it is at right angles to the vertical axis. Such minerals

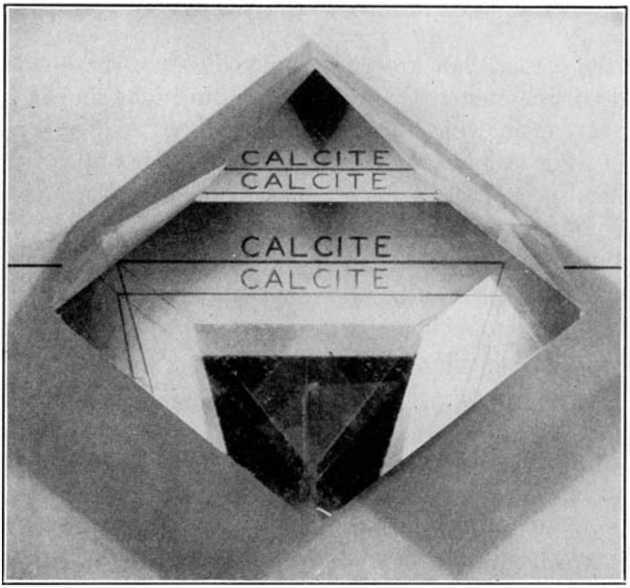


FIG. 1. Calcite, Viewed Normal to the Rhombohedron Face Showing Double Refraction. The double repetition of " calcite " at the top of the photograph is seen through a face cut on the specimen parallel to the base.

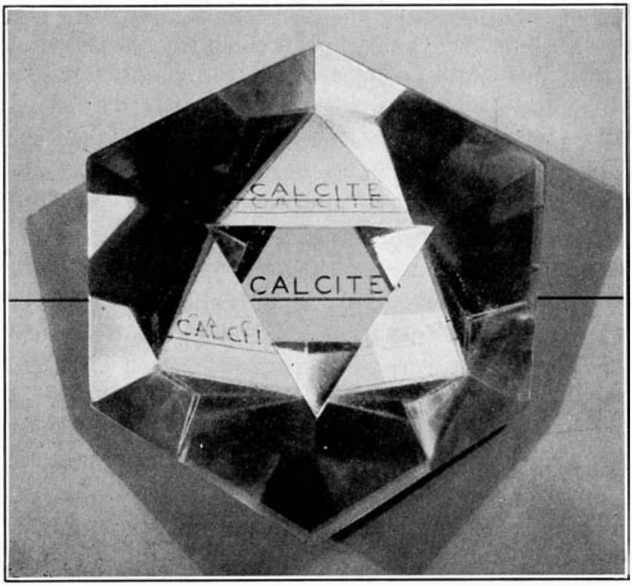


FIG. 2. Calcite Showing No Double Refraction. Viewed parallel to the *c* axis.

PLATE V

belong to the optical class known as uniaxial. In orthorhombic, monoclinic, and triclinic minerals, there are two directions similar to the one described above, in which no double refraction takes place, and the minerals of these systems are therefore spoken of as optically biaxial.

The optical properties of minerals comprise an important branch of mineralogy but are beyond the scope of this book. For an adequate consideration of optical properties the reader is referred to books of a more specialized nature.

F. ELECTRICAL AND MAGNETIC PROPERTIES

Pyroelectricity. The simultaneous development of positive and negative charges of electricity on different parts of the same crystal under the proper conditions of temperature change is called *pyroelectricity*. Only those minerals crystallizing in symmetry classes which lack a symmetry center and thus have polar axes can show this property. Quartz is a good example of such a mineral. If it is heated to about 100° C., it will develop on cooling positive electric charges at three alternate prismatic edges, and negative charges at the three remaining edges.

Piezoelectricity. If an electric charge is developed in a crystallized body by pressure, the substance is said to show *piezoelectricity*. As in the case of pyroelectric minerals, only those belonging to a crystal class which lacks a center of symmetry can show this property. Quartz is probably the most important piezoelectric mineral, for an extremely slight pressure parallel to its "electric axis" can be detected by the electric charge set up. For this reason it is used in properly oriented plates in radio apparatus and in the "sonic sounder." The property of piezoelectricity is frequently the only way of determining the absence of a symmetry center of a given crystal.

Magnetism. Those minerals which, in their natural state, will be attracted to an iron magnet are said to be magnetic. Magnetite, Fe_3O_4, and pyrrhotite $Fe_{(1-x)}S$, are the only two common magnetic minerals. Lodestone, a variety of magnetite, itself has the attracting power and polarity of a true magnet.

In the magnetic field of a powerful electromagnet many other minerals, especially those containing iron, are drawn to the magnet. Because of this, the electromagnet is an important means of separating mixtures of mineral grains having different magnetic susceptibilities.

III. CHEMICAL MINERALOGY

The chemical composition of a mineral is of fundamental importance, for upon it all its other properties are in great measure dependent. As mentioned previously, the characters of a mineral depend not alone upon the chemical nature of its constituent elements, but also upon the arrangement of the atoms of these elements in the crystalline structure. The physical characteristics of a mineral may serve as a means of its positive identification, and for most minerals they will be of material assistance. Since, however, the classification of minerals is on the basis of chemistry, the final proof of the identity of a mineral will often lie in the determination of its chemical nature by means of chemical tests. Consequently, the study of the chemistry of minerals is the most important single division of mineralogy. In this section on chemical mineralogy some general aspects of the subject will be presented first, followed by a short description of the methods of testing for the different elements most commonly found in minerals. Because of the scope and size of this book it is necessary to assume that the reader is familiar with at least the essentials of chemical fact and nomenclature.

Up to the present time the occurrence of ninety-two different elements has been established. All but the rarest of these are listed with their atomic weights in the table on page 88. Only forty-four elements are found in sufficient amount or, because of their properties, are of sufficient importance to warrant a discussion of them here. A considerable proportion of elements in this list also must be considered as rare in occurrence. The following table gives the names and the approximate percentages* in the earth's crust of the most abundant elements.

Oxygen	46.46%	Hydrogen	0.14%
Silicon	27.61	Phosphorus	0.12
Aluminum	8.07	Carbon	0.09
Iron	5.06	Manganese	0.09
Calcium	3.64	Sulfur	0.06
Magnesium	2.07	Chlorine	0.05
Sodium	2.75	Barium	0.04
Potassium	2.58	Fluorine	0.03
Titanium	0.62	Strontium	0.02

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* Percentages from *Data of Geochemistry*, U.S.G.S. Bull. 770.

INTERNATIONAL ATOMIC WEIGHTS

1940

Reprinted from the *Journal of the American Chemical Society*

	Symbol	*Atomic Number*	*Atomic Weight*		*Symbol*	*Atomic Number*	*Atomic Weight*
Aluminum...	Al	13	26.97	Molybdenum..	Mo	42	95.95
Antimony....	Sb	51	121.76	Neodymium..	Nd	60	144.27
Argon.......	A	18	39.944	Neon........	Ne	10	20.183
Arsenic......	As	33	74.91	Nickel.......	Ni	28	58.69
Barium......	Ba	56	137.36	Nitrogen.....	N	7	14.008
Beryllium....	Be	4	9.02	Osmium......	Os	76	190.2
Bismuth.....	Bi	83	209.00	Oxygen......	O	8	16.0000
Boron.......	B	5	10.82	Palladium....	Pd	46	106.7
Bromine.....	Br	35	79.916	Phosphorus...	P	15	30.98
Cadmium....	Cd	48	112.41	Platinum.....	Pt	78	195.23
Calcium.....	Ca	20	40.08	Potassium....	K	19	39.096
Carbon......	C	6	12.010	Praseodymium	Pr	59	140.92
Cerium......	Ce	58	140.13	Protactinium..	Pa	91	231
Cesium......	Cs	55	132.91	Radium......	Ra	88	226.05
Chlorine.....	Cl	17	35.457	Radon.......	Rn	86	222
Chromium...	Cr	24	52.01	Rhenium.....	Re	75	186.31
Cobalt......	Co	27	58.94	Rhodium.....	Rh	45	102.91
Columbium..	Cb	41	92.91	Rubidium....	Rb	37	85.48
Copper......	Cu	29	63.57	Ruthenium...	Ru	44	101.7
Dysprosium..	Dy	66	162.46	Samarium....	Sm	62	150.43
Erbium......	Er	68	167.2	Scandium....	Sc	21	45.10
Europium....	Eu	63	152.0	Selenium.....	Se	34	78.96
Fluorine.....	F	9	19.00	Silicon.......	Si	14	28.06
Gadolinium..	Gd	64	156.9	Silver........	Ag	47	107.880
Gallium.....	Ga	31	69.72	Sodium......	Na	11	22.997
Germanium..	Ge	32	72.60	Strontium....	Sr	38	87.63
Gold........	Au	79	197.2	Sulfur.......	S	16	32.06
Hafnium.....	Hf	72	178.6	Tantalum....	Ta	73	180.88
Helium......	He	2	4.003	Tellurium....	Te	52	127.61
Holmium....	Ho	67	163.5	Terbium.....	Tb	65	159.2
Hydrogen....	H	1	1.0080	Thallium.....	Tl	81	204.39
Indium......	In	49	114.76	Thorium.....	Th	90	232.12
Iodine.......	I	53	126.92	Thulium.....	Tm	69	169.4
Iridium......	Ir	77	193.1	Tin.........	Sn	50	118.70
Iron.........	Fe	26	55.85	Titanium.....	Ti	22	47.90
Krypton.....	Kr	36	83.7	Tungsten.....	W	74	183.92
Lanthanum..	La	57	138.92	Uranium.....	U	92	238.07
Lead........	Pb	82	207.21	Vanadium....	V	23	50.95
Lithium.....	Li	3	6.940	Xenon.......	Xe	54	131.3
Lutecium....	Lu	71	174.99	Ytterbium....	Yb	70	173.04
Magnesium..	Mg	12	24.32	Yttrium......	Y	39	88.92
Manganese...	Mn	25	54.93	Zinc.........	Zn	30	65.38
Mercury.....	Hg	80	200.61	Zirconium....	Zr	40	91.22

It is to be noted that, although the percentages given above total 99.5, the list fails to include such important elements as copper, lead, zinc, silver, gold, tin, mercury, nickel, antimony, and arsenic.

Below is given a brief discussion of the various classes of chemical compounds in which the majority of minerals occur.

A. CHEMICAL CLASSES

1. **Elements.** About twenty elements in an uncombined form are found as minerals and are said to occur in the native state. Example, gold, Au.

2. **Sulfides.** This class consists for the most part of combinations of the various metals with the element sulfur but also includes similar combinations of metals with selenium and tellurium. The majority of the metallic ore minerals are in this class. Example, galena, PbS.

3. **Sulfo Salts.** Minerals composed of lead, copper, or silver in combination with sulfur and antimony, arsenic, or bismuth are alone included in the sulfo-salt class. Example, enargite, Cu_3AsS_4.

4. **Oxides.** *a. Anhydrous oxides.* The minerals of this class contain a metal in combination with oxygen. Example, hematite, Fe_2O_3.

b. Hydrous oxides. The mineral oxides that contain water or the hydroxyl (OH) as an important radical are included in this class. Example, diaspore, $Al_2O_3 \cdot H_2O$.

5. **Halides.** This class includes the natural chlorides, fluorides, bromides, and iodides. Example, halite, NaCl.

6. **Carbonates.** The minerals whose formulas include the carbonate radical, CO_3, are in this class. Example, calcite, $CaCO_3$.

7. **Phosphates.** Minerals whose formulas include the phosphate radical, PO_4, are included in this class. Example, apatite, $Ca_5(F,Cl)(PO_4)_3$.

8. **Sulfates.** Minerals whose formulas include the sulfate radical, SO_4, are in this class. Example, barite, $BaSO_4$.

9. **Tungstates.** The few minerals that are included in this class have the tungstate radical, WO_4, in their formulas. Example, scheelite, $CaWO_4$.

10. **Silicates.** The silicates form the largest chemical class among minerals. They contain various elements, the most common of which are sodium, potassium, calcium, magnesium, aluminum, and iron, in combination with silicon and oxygen, frequently forming very complex chemical structures. X-ray study has shown that the fundamental unit of structure common to all the silicates is composed of a silicon atom with four oxygen atoms arranged about it as at the corners of a tetrahedron. Different arrangements of these oxygen-silicon tetra-

hedrons with respect to one another in the crystal structure give rise to different silicate types.

B. DERIVATION OF A CHEMICAL FORMULA FROM THE ANALYSIS OF A MINERAL

All the chemical formulas which are assigned to minerals have been calculated from chemical analyses. An analysis gives the percentage composition of a mineral, or, in other words, the parts by weight in 100 parts of the different elements or radicals present. Consider the following analysis of chalcopyrite:

1 Percentages	2 Atomic Weights	3 Atomic Proportions	4 Atomic Ratio	
Cu = 34.30	63.6	= 0.539	= 1	approx.
Fe = 30.59	55.9	= 0.547	= 1	
S = 34.82	32.06	= 1.086	= 2	

In the first column the numbers given indicate the weight percentages of the different elements in the mineral; but, as these elements have different atomic weights, the numbers do not represent the ratio of the different atoms to each other in the chemical molecule. In order to derive the relative proportions of the atoms of the different elements to each other, the percentages as given are divided in each case by the atomic weight of the element. This gives a series of numbers which represents the atomic proportions in the molecule and from which the atomic ratio can be quickly derived. In the analysis of chalcopyrite, this ratio becomes S : Cu : Fe = 2 : 1 : 1. Consequently, $CuFeS_2$ will constitute the chemical formula for the mineral.

If the mineral is an oxygen compound, the results of the analysis are given by convention as percentages of the oxides present, and by a calculation similar to that outlined above the ratio of these oxides to each other in the compound is determined, the only difference in the process being that in this case the percentage numbers are divided by the sum of the atomic weights of the elements present in the different oxides. As an example consider the following analysis of gypsum:

1 Percentages	2 Molecular Weights	3 Molecular Proportions	4 Molecular Ratio	
CaO = 32.44	56.1	= 0.578	= 1	approx.
SO_3 = 46.61	83.06	= 0.583	= 1	
H_2O = 20.74	18.0	= 1.152	= 2	
99.79				

From this it is seen that the ratio of the oxides to each other in the compound is $SO_3 : CaO : H_2O = 1 : 1 : 2$, and consequently the composition of gypsum can be represented by $CaO{\cdot}SO_3{\cdot}2H_2O$ or $CaSO_4{\cdot}2H_2O$.

It is frequently desirable to determine the theoretical composition of a mineral from its chemical formula as a check on the validity of the formula. The process of calculation is the reverse of that described in the preceding division. Take, for example, the mineral chalcopyrite, $CuFeS_2$; what are the proportions by weight of the different elements in 100 parts of the mineral? The process consists in first adding up the atomic weights of the different elements present and so obtaining the molecular weight of the compound, as follows:

$$\begin{array}{lrl} & & \text{Atomic Weights} \\ \text{Cu} & = & 63.6 \\ \text{Fe} & = & 55.9 \\ S_2 = 32.06 \times 2 & = & \underline{64.12} \\ \text{Molecular weight } CuFeS_2 & = & 183.62 \end{array}$$

It is obvious from the above that in 183.62 parts by weight of chalcopyrite there are 63.6 parts of copper, etc. In order to find the parts of copper in 100 parts of the mineral, or in other words, the percentage, the following proportion is made:

$$183.62 : 63.6 = 100 : x$$

When this equation is solved, x becomes 34.64, or the theoretical percentage of copper in chalcopyrite. The percentages of the iron and sulfur are obtained in a similar manner.

C. RELATION OF CHEMISTRY TO CRYSTALLOGRAPHY

In the following paragraphs various terms used in mineralogy to express the relation of chemistry to crystal structure and form* are presented and defined.

Homeomorphism. When crystals of two unrelated and chemically dissimilar minerals have fortuitously similar morphological constants, they are said to be *homeomorphs.* Rutile, TiO_2, and zircon, $ZrSiO_4$, are an example of homeomorphism, for both of them crystallize in the tetragonal system with similar habit.

Isostructure. Distinct mineral species that have a similar structure and crystallography are *isostructural.* Such minerals likewise have an analogous chemical composition, if *analogous* be interpreted in the

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* The term *form* is used in this section, not in the restricted manner previously defined, but in its broader sense meaning external appearance and shape. It is necessary to do this because most of the terms used have the suffix *-morph* derived from the Greek word meaning form.

broad sense. For example, barite, $BaSO_4$, and celestite, $SrSO_4$. Many groups of minerals are isostructural, of which the barite group of sulfates, the calcite group of carbonates, and the aragonite group of carbonates are perhaps the best examples. The extremely close relationship that exists among the members of many groups is illustrated by the aragonite group listed below.

ARAGONITE GROUP

Mineral	Chemical Composition	Axial Ratio $a : b : c$	$110 \wedge 1\bar{1}0$	Cleavage	
Aragonite	$CaCO_3$	0.622 : 1 : 0.721	63° 48′	{110}	{010}
Witherite	$BaCO_3$	0.603 : 1 : 0.730	62° 12′	{110}	{010}
Strontianite	$SrCO_3$	0.609 : 1 : 0.724	62° 41′	{110}	
Cerussite	$PbCO_3$	0.610 : 1 : 0.723	62° 46′	{110}	{021}

When the term isostructural is used unmodified it refers only to those minerals of like structure that do not combine to form mixed crystals. (See below.)

Isomorphism. Those isostructural minerals that can crystallize together in different proportions to form mixed crystals are said to be *isomorphous*. Isomorphous minerals may be divided into two groups: (1) those possessing limited isomorphism; (2) those possessing complete isomorphism.

Limited isomorphism. If two chemical substances can combine with each other to form mixtures but cannot combine in all proportions, they show limited isomorphism. For example, suppose that A and B unite to form a mixture and that they are capable of combining in all proportions until B makes up 40 per cent of the mineral. However, because of the atomic structure it is impossible for more than 40 per cent of B to enter into the mixed crystal. Sphalerite offers a good example of limited isomorphism. It is a mineral which shows a variation of color in its different specimens that ranges from white through brown to black with a corresponding variation in composition. This is brought out by a comparison of the chemical analyses listed below.

Chemical Analyses of Differently Colored Sphalerite

	Colorless		Brown			Black		
		Atomic ratio		Atomic propor.	Atomic ratio		Atomic propor.	Atomic ratio
S	32.22	1.00	33.36	1.04	1.04	33.25	1.04	1.04
Zn	67.46	1.03	63.36	0.96	1.02	50.02	0.76	1.03
Fe			3.60	0.06		15.44	0.27	
Total	99.68		100.32			98.71		

It will be noted that in the three analyses there is a progressive increase in the percentage of iron and a corresponding decrease in the amount of zinc while the sulfur remains constant. The iron has replaced a portion of the zinc in the mineral, and the iron atoms occupy positions in the molecule normally held by zinc. From the atomic proportions of the last two analyses, it can be seen that there is no definite ratio between the amounts of iron and zinc; but the atomic ratios show that there is a constant 1 : 1 relation between the sum of the atoms of the metals and the atoms of sulfur. This means that, although the composition may vary, the atomic ratios and the crystalline structure remain constant. Only a limited percentage of iron can enter into the sphalerite molecule, the maximum being about 18.

A compound having little or no zinc, in this series, would not be similar to sphalerite in its physical properties. (The natural FeS, troilite, is hexagonal.)

Complete isomorphism. When two isostructural minerals can combine with each other in all proportions so as to form an unbroken series from one to the other, they are said to show complete isomorphism. A close chemical and structural relationship exists between such minerals, since atoms of one can replace in all proportions the atoms of the other without appreciably altering the structure. A continuous gradation is shown both in crystallographic and physical properties. The plagioclase feldspars furnish a good example of complete isomorphism. They form a continuous series from albite, $NaAlSi_3O_8$, to anorthite, $CaAl_2Si_2O_8$. The albite and anorthite are called end members, and the divisions between these end members to which other names are given are arbitrary.

COMPARISON OF DIMORPHOUS MINERALS

Chemical Substance	Mineral	Crystal System	Hardness	Specific Gravity
C	Diamond Graphite	Isometric Hexagonal	10 1	3.5 2.2
FeS_2	Pyrite Marcasite	Isometric Orthorhombic	6 6	5.0 4.85
$CaCO_3$	Calcite Aragonite	Rhombohedral Orthorhombic	3 3½	2.71 2.95

Polymorphism. A number of examples are found among minerals in which the same chemical substance exists in two or more distinct structural types. Such compounds are said to be *dimorphous* if they exist in two modifications, *trimorphous* if they exist in three modifications, or in general *polymorphous* (existing in many forms). Since the crystal structures of polymorphous substances differ from one another, the physical properties are in general different. Carbon is one of the best examples, existing in nature as diamond and graphite with strikingly dissimilar properties. The properties of these two minerals as well as those of two other dimorphous compounds, FeS_2 and $CaCO_3$, are listed in the table, page 93.

Gel Minerals or Mineraloids. There are a number of mineral substances whose analyses do not yield definite chemical formulas and further show no signs of crystallinity. These have been called "gel minerals" or "mineraloids." A mineral may exist in a crystalline phase with a definite composition and molecular structure, or, formed under different conditions, practically the same substance may occur as a mineral gel. The mineral gels are formed under conditions of low pressure and temperature and are commonly substances of secondary origin formed during the process of weathering of the materials of the earth's crust. They characteristically occur in mammillary, botryoidal, stalactitic, and similar-shaped masses. The power of these minerals to absorb other substances to a considerable extent accounts for their often wide variations in chemical composition. Limonite and opal are familiar examples of gel minerals.

Pseudomorphs. If a crystal of a mineral is altered so that the internal structure is changed but the external form is preserved, it is called a *pseudomorph*, or *false form.* The chemical composition and structure of a pseudomorph belong to one mineral species, while the crystal outline corresponds to another. For example, pyrite may change to limonite but preserve all the external features of the pyrite. In describing such a crystal it is said to be a pseudomorph of *limonite after pyrite.* Pseudomorphs are usually further defined according to the manner in which they were formed, as by:

1. *Substitution.* In this type of pseudomorph there is a gradual removal of the original material and a corresponding and simultaneous replacement of it by another with no chemical reaction between the two. A common example of this is the substitution of silica for the wood fiber to form petrified wood. Another example is quartz, SiO_2, after fluorite, CaF_2.

2. *Incrustation.* In the formation of this type of pseudomorph a crust of one mineral is deposited over crystals of another. A common example is quartz incrusting cubes of fluorite. The fluorite may later be entirely carried away by solution, but its former presence is indicated by the casts left in the quartz.

3. *Alteration.* In this type of pseudomorph there has been only a partial addition of new material, or a partial removal of the original material. The change of anhydrite, $CaSO_4$, to gypsum, $CaSO_4 \cdot 2H_2O$, and galena, PbS, to anglesite, $PbSO_4$, are examples of alteration pseudomorphs. A core of the unaltered mineral may be found in such pseudomorphs.

4. *Paramorphism.* The name *paramorph* is given to a crystal whose internal structure has changed to that of a polymorphous form without producing any change in external form. Thus aragonite frequently goes over to calcite and rutile changes to brookite.

D. INSTRUMENTS, REAGENTS, AND METHODS OF TESTING

The Blowpipe and Its Use. Many of the chemical tests made on minerals are quickly and easily performed by means of an instrument known as a blowpipe. The ordinary blowpipe consists essentially of a tapering tube ending in a small opening through which air can be forced in a thin stream under high pressure. When this current of air is directed into a luminous flame, combustion takes place more rapidly and completely, producing a very hot flame.

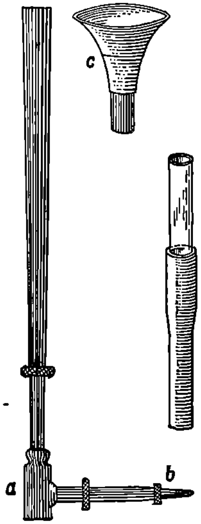

FIG. 248. Common Blowpipe.

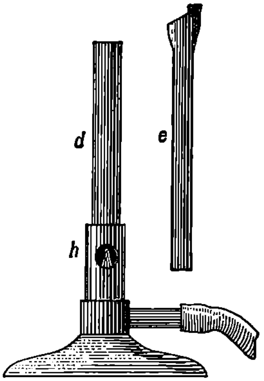

FIG. 249. Bunsen Burner.

Figure 248 represents a common type of blowpipe. The mouthpiece, either *c* or *c′*, is fitted into the upper end of the tube, and air from the lungs forced into it issues from the small opening at the other end.

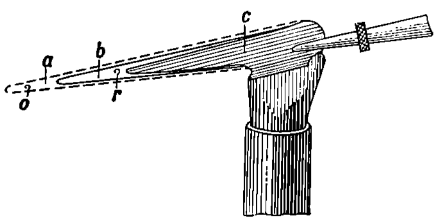

FIG. 250. Blowpipe Flame.

The tip of the blowpipe, *b*, is placed just within a flat flame rich in carbon, such as is obtained from a candle or ordinary illuminating gas. A convenient method of producing a blowpipe flame is to use illuminating gas in a Bunsen burner, in which an inner tube, *e* (Fig. 249), has been placed so as to shut off the supply of air at the base of the burner and thus yield a luminous flame. The upper end of this tube is flattened and cut at an angle, as shown in Fig. 249. The gas flame is ordinarily adjusted so that it measures about one inch in height and one-half inch in breadth. The blowpipe is introduced into this flame as shown in Fig. 250. The resulting blowpipe flame should be nonluminous, narrow, sharp-pointed, and clean-cut. If illuminating gas is not available, a candle with a flat wick or an ordinary candle can be used. The candles, however, require more skill in manipulation.

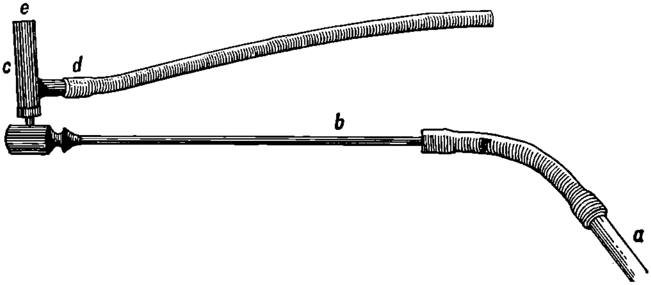

FIG. 251. Improved Blowpipe.

Figure 251 illustrates a more elaborate blowpipe, but one which can be easily and efficiently manipulated. It resembles the blowpipe described above but is constructed with a gas fitting, *c* (Fig. 251), in such a way that air, forced into the tube through the mouthpiece *a*, and gas admitted through tube *d*, issue together from the opening *e*. The chief advantage of this type of blowpipe is that one hand can hold the complete assembly and at the same time govern the direction of the flame. If compressed air is available, an air line can be connected to *b* (Fig. 251), and the operator is thus relieved of blowing. Special blowpipes are also available for use with compressed air.

The Art of Blowpiping. It usually requires some practice before one can produce a steady and continuous blowpipe flame. Some blowpipe tests can be completed before it is necessary to replenish the supply of air in the lungs. Frequently, however, an operation takes a longer time than this permits, and an interruption in order to fill the lungs afresh materially interferes with the success of the experiment. Consequently, it often becomes important to be able to maintain a steady stream of air from the blowpipe for a considerable time. This is accomplished by distending the cheeks so as to form a reservoir of air in the mouth. When the supply of air in the lungs is exhausted, the passage from the mouth into the throat is closed by lifting the root of the tongue and, while a new supply is being obtained by breathing in through the nose, a steady stream of air is also being forced out of the reservoir in the mouth. In this way a constant flame may be obtained. It requires considerable practice, however, to do this skillfully.

The Character of the Blowpipe Flame. Figure 250 represents a typical blowpipe flame. The inner cone, *c*, which is light blue in color and the most distinct part of the flame, is composed of unburned gas mixed with air from the blowpipe. No combustion takes place in this part of the flame. Around this cone is a narrow pale-violet cone, *b*, which is almost invisible and in which combustion does take place. Any gas that is used for the production of the flame will consist of some combination of carbon and hydrogen. These elements when the gas is burned are converted into their respective oxides. The hydrogen burns directly to water vapor, H_2O, and the carbon burns first to carbon monoxide, CO. Later this lower oxide is changed by the addition of another atom of oxygen to carbon dioxide, CO_2. The final products of combustion will, therefore, be the gases H_2O and CO_2. In cone *b*, where combustion is taking place, there will necessarily be considerable amounts of the lower oxide of carbon, CO. Surrounding cone *b* there will be an invisible cone, *a*, consisting of the final products of combustion CO_2 and H_2O.

Fusion by Means of the Blowpipe Flame. A good blowpipe flame may reach a temperature as high as 1,500° C., but the temperature varies somewhat depending on the type of gas used and the mixture of gas and air. The determination of the degree of fusibility of a mineral is an important aid to its identification. It should be emphasized that, although the temperature of the blowpipe flame is high, the amount of heat is small. Thus for best results small fragments of uniform size should be used. The small mineral fragment on which a blowpipe test is made is known as the *assay*.

In making the fusion test the assay, if possible a sharply pointed fragment of the mineral, should be inserted into the blowpipe flame just beyond the tip of the inner cone, where the combustion is most rapid and the temperature the highest.

The fragment should be held as illustrated in Fig. 252, so that it projects beyond the end of the forceps by which it is held in such a manner that the entire heat of the flame can be concentrated upon it. If it melts and rounds over, losing its sharp outline, it is said to be fusible in the blowpipe flame.

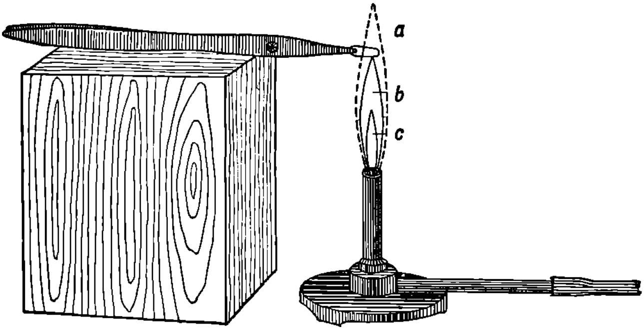

FIG. 252. Mineral Fragment Held in Flame by Forceps.

Minerals can therefore be divided into two classes, those fusible and those infusible in this flame. The minerals which are fusible can be further classified according to the ease with which they fuse. To assist in this classification, a series of six minerals which show different degrees of fusibility has been chosen as a scale to which all fusible minerals may be approximately referred. For instance, when a mineral is said to have a fusibility of 3, it means that it will fuse as easily as the mineral listed as 3 in the scale. In making such comparative tests, it is necessary to use fragments of the same size and to have the conditions of the experiments uniform. In the table, page 99, are given the minerals of the scale of fusibility with the approximate temperature at which each fuses.

Reducing and Oxidizing Flames. Reduction consists essentially in taking oxygen away from a chemical compound, and oxidation consists in adding oxygen to it. These two opposite chemical reactions can be accomplished by means of either a Bunsen burner or a blowpipe flame. Cone *b*, Figs. 250 and 252, as explained above, contains CO, carbon monoxide. This is what is known as a reducing agent, since, because of its strong tendency to take up oxygen in order to become CO_2, carbon dioxide, it will, if possible, take oxygen away from another substance in contact with it. For instance, if a small fragment of ferric oxide, Fe_2O_3, is held in this part of the blowpipe flame, it will be reduced by the removal of one atom of oxygen to ferrous oxide, FeO, according to the following equation:

$$Fe_2O_3 + CO = 2FeO + CO_2$$

SCALE OF FUSIBILITY

Number	Mineral	Approximate Fusing Point	Remarks
1	Stibnite	525° C.	Very easily fusible in the candle flame
2	Chalcopyrite	800°	A small fragment will fuse easily in the Bunsen burner flame
3	Garnet (Almandite)	1,050°	Infusible in the Bunsen burner flame but fuses easily in the blowpipe flame
4	Actinolite	1,200°	A sharp-pointed splinter fuses with little difficulty in the blowpipe flame
5	Orthoclase	1,300°	The edges of fragments are rounded with difficulty in the blowpipe flame
6	Bronzite	1,400°	Practically infusible in the blowpipe flame. Only the fine ends of splinters are rounded
7	Quartz	1,710°	Infusible in the blowpipe flame

This change can be proved by noting that the ferric oxide is red in color and nonmagnetic, whereas the ferrous oxide is black and strongly magnetic. The cone *b*, Fig. 250, is therefore known as the reducing part of the blowpipe flame, and if a reduction test is to be performed the mineral fragment is placed at *r*, as shown in Fig. 250. It is sometimes convenient to use a block to support the forceps holding the assay as shown in Fig. 252.

If oxidation is to be accomplished, the mineral must be placed entirely outside of the flame, where the oxygen of the air can have free access to it, but where it can still get in large degree the heat of the flame. Under these conditions, if the reaction is possible, oxygen will be added to the mineral and the substance will be oxidized. The oxidizing part of the blowpipe flame is at *o* (Fig. 250). Pyrite, FeS_2, for instance, if placed in the oxidizing flame, would be converted into ferric oxide, Fe_2O_3, and sulfur dioxide, SO_2, according to the following equation:

$$2FeS_2 + 11O = Fe_2O_3 + 4SO_2$$

The iron combines with oxygen to form ferric oxide, a dark red residue, while the sulfur combines with oxygen to form sulfur dioxide, a pungent-smelling gas.

Use of Charcoal in Blowpiping. Small charcoal blocks, about 4 inches long, 1 inch wide, and ½ inch thick, are employed in a number of blowpipe tests (Fig. 253). The charcoal should be of a fine and uniform grain. It should not be so soft as to soil the fingers readily, nor should it be so hard as not to be easily cut and scraped by a knife. The charcoal is used as a support upon which various reactions are accomplished. For instance, some metals, indicated in the following table, can be reduced from their minerals by means of the blowpipe flame, the experiment being performed upon the charcoal.

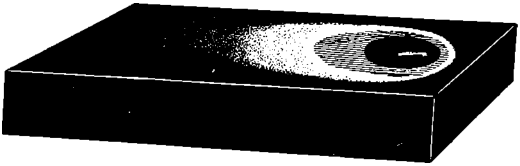

FIG. 253. Charcoal Block with Antimony Oxide Coating.

It is impossible to extract the metal from some minerals by ordinary blowpipe means. Other metals can be reduced by means of a flux, while a few can be reduced merely by heating on charcoal. A mixture of sodium carbonate and charcoal in equal proportions, called the *reducing mixture*, serves as a good flux for most reductions.

METALLIC GLOBULES REDUCED ON CHARCOAL

Element	Color and Character of Globule	Remarks
Gold Au	Yellow, soft, no coating, remains bright	Metallic gold can be easily reduced from the gold tellurides without a flux
Silver Ag	White, soft, no coating, remains bright	Usually necessary to use reducing mixture. To distinguish from other globules, dissolve in nitric acid, add hydrochloric acid to obtain white silver chloride precipitate
Tin Sn	White, soft, becomes dull on cooling. White coating of oxide film	Globules form with difficulty even with reducing mixture. The metallic globule is oxidized in nitric acid to a white hydroxide
Copper Cu	Red, soft, surface black when cold, difficultly fusible	Copper minerals should be roasted to drive off sulfur, arsenic, and antimony before mixing with reducing mixture
Lead Pb	Gray, soft, fusible. Bright in reducing flame, iridescent in oxidizing flame	The incandescent charcoal will reduce the lead. To distinguish from other globules dissolve in nitric acid, and from clear solution precipitate white lead sulfate by addition of sulfuric acid

NOTE: Easily fusible metallic beads are often obtained on heating metallic compounds containing sulfur, antimony, or arsenic. Such beads are always very brittle and often magnetic. Magnetic masses or globules are obtained when compounds of iron, nickel, and cobalt are heated on charcoal.

SUBLIMATES ON CHARCOAL

Element	Composition of Coating	Color and Character of Coating on Charcoal	Remarks
As	Arsenious oxide As_2O_3	White and volatile, depositing at some distance from the assay	Usually accompanied by garlic odor
Sb	Antimony oxides Sb_2O_3, Sb_2O_4	White and volatile, depositing close to the assay	Less volatile than arsenic oxide
Se	Selenium oxide SeO_2	Volatile white, tinged with red on outside; to gray near assay	Accompanied by a peculiar odor. Coating touched with reducing flame gives blue flame
Te	Tellurium oxide TeO_2	Dense white; volatile. On outside gray to brownish	In reducing flame coating gives bluish green flame color
Zn	Zinc oxide ZnO	If mixed with sodium carbonate on charcoal gives nonvolatile sublimate, yellow when hot, white when cold near assay	Coating moistened with cobalt nitrate and ignited turns green
Sn	Tin oxide SnO_2	Faint yellow when hot, white when cold. Nonvolatile in the oxidizing flame	Coating moistened with cobalt nitrate and ignited turns bluish green
Mo	Molybdenum oxide MoO_3	Pale yellow when hot, white when cold. May be crystalline. Volatile in the oxidizing flame. Red MoO_2 under assay	Coating touched for a moment by a reducing flame becomes dark blue
Pb	Lead oxide PbO	Yellow near the mineral and white farther away. Volatile	Coating may be composed of white sulfite and sulfate of lead in addition to the oxide
	Lead iodide PbI_2	Chrome yellow. Volatile	This reaction when lead minerals heated with iodide flux
Bi	Bismuth oxide Bi_2O_3	Yellow near the mineral and white farther away. Volatile	To be told from the lead oxide coating by iodide test
	Bismuth iodide BiI_3	Bright red with yellow ring near assay	This reaction when bismuth minerals heated with iodide flux

One of the important uses of the charcoal block is to obtain characteristic oxide coatings upon its surface. The preceding table gives a list of the elements which yield coatings when their minerals are heated in

SUBLIMATES ON CHARCOAL

Element	Composition of Coating	Color and Character of Coating on Charcoal	Remarks
As	Arsenious oxide As_2O_3	White and volatile, depositing at some distance from the assay	Usually accompanied by garlic odor
Sb	Antimony oxides Sb_2O_3, Sb_2O_4	White and volatile, depositing close to the assay	Less volatile than arsenic oxide
Se	Selenium oxide SeO_2	Volatile white, tinged with red on outside; to gray near assay	Accompanied by a peculiar odor. Coating touched with reducing flame gives blue flame
Te	Tellurium oxide TeO_2	Dense white; volatile. On outside gray to brownish	In reducing flame coating gives bluish green flame color
Zn	Zinc oxide ZnO	If mixed with sodium carbonate on charcoal gives nonvolatile sublimate, yellow when hot, white when cold near assay	Coating moistened with cobalt nitrate and ignited turns green
Sn	Tin oxide SnO_2	Faint yellow when hot, white when cold. Nonvolatile in the oxidizing flame	Coating moistened with cobalt nitrate and ignited turns bluish green
Mo	Molybdenum oxide MoO_3	Pale yellow when hot, white when cold. May be crystalline. Volatile in the oxidizing flame. Red MoO_2 under assay	Coating touched for a moment by a reducing flame becomes dark blue
Pb	Lead oxide PbO	Yellow near the mineral and white farther away. Volatile	Coating may be composed of white sulfite and sulfate of lead in addition to the oxide
	Lead iodide PbI_2	Chrome yellow. Volatile	This reaction when lead minerals heated with iodide flux
Bi	Bismuth oxide Bi_2O_3	Yellow near the mineral and white farther away. Volatile	To be told from the lead oxide coating by iodide test
	Bismuth iodide BiI_3	Bright red with yellow ring near assay	This reaction when bismuth minerals heated with iodide flux

One of the important uses of the charcoal block is to obtain characteristic oxide coatings upon its surface. The preceding table gives a list of the elements which yield coatings when their minerals are heated in the oxidizing flame on charcoal. In some cases more characteristic coatings are obtained when the assay has had some chemical reagent added to it. The most important reagent is the so-called *iodide* or *bismuth flux*, which consists of a mixture of potassium iodide and sulfur (see page 110). When this reagent is used colored iodide coatings may result.

SUBLIMATES ON PLASTER

Element	Composition of Coating	Color and Character of Coating on Plaster Tablet	Remarks
Se	Selenium oxide SeO_2	Red to crimson. Volatile	Volatilizes giving reddish fumes and characteristic odor
Te	Tellurium oxide TeO_2	Dark brown. Volatile	In reducing flame coating gives bluish green flame color
Cd	Cadmium oxide CdO	Greenish yellow with brown both near assay and at a distance	Nonvolatile
Pb	Lead iodide PbI_2	Chrome yellow with iodide flux	
Bi	Bismuth iodide BiI_3	Chocolate-brown with underlying red with iodide flux	Subjected to ammonia fumes coating becomes first orange-yellow then red
Mo	Molybdenum oxide MoO_3	White in oxidizing flame. Red MoO_2 under assay	Coating turns deep ultramarine blue if touched with reducing flame
	Molybdenum iodide, MoI_4	Ultramarine blue with iodide flux	
Sb	Antimony iodide SbI_3	Orange to red with iodide flux	Disappears when subjected to ammonia fumes

Use of Plaster of Paris Tablets. In some cases it is preferable to collect sublimates on the surface of a plaster of Paris tablet rather than on charcoal. Such tablets can be easily made by spreading a thin layer of the wet plaster upon a glass plate, the surface of which has been oiled. While the plaster is still moist it should be cut into rectangular strips measuring about 1½ by 4 inches. After the plaster has hardened these can be broken out into the desired tablets. The material to be tested is placed in a small depression made near one end of the tablet and then heated before the blowpipe exactly as on charcoal. The plaster tablet is used to bring out the color of sublimates poorly displayed on the black background of charcoal. The iodide coatings are especially marked on the plaster tablet. The important tests are summarized in the table, page 102.

Open-Tube Test. Tubing of hard glass is used in making what are known as open-tube tests. The tubing, with an internal diameter of ¼ inch, should be cut into approximately 6-inch lengths. An open tube is used ordinarily for making oxidation tests. A small amount of

SUBLIMATES IN THE OPEN TUBE

Element	Products of Oxidation		Remarks
	Composition	Color and Character	
S	Sulfur dioxide SO_2	SO_2, a colorless gas, issues from the upper end of the tube	The gas has a pungent and irritating odor. If a moistened strip of blue litmus paper is placed at the upper end of the tube, it becomes red, owing to the acid reaction of sulfurous acid
As	Arsenious oxide As_2O_3	White, highly volatile, and crystalline	The sublimate condenses at a considerable distance above the heated portion in small octahedral crystals
Sb	Antimonious oxide Sb_2O_3	White, volatile, and crystalline	The sublimate forms a white ring closer to the heated portion of the tube than the arsenious oxide. Is obtained from antimony compounds which do not contain sulfur
	Antimony tetraoxide Sb_2O_4	Pale yellow when hot, white when cold. Dense, non-volatile, amorphous	Sb_2O_4 obtained from antimony sulfide and sulfantimonites. Settles mostly on the bottom of the tube and usually is accompanied by Sb_2O_3
Mo	Molybdenum trioxide MoO_3	Pale yellow to white crystals form a network near heated portion	If crystals are touched with reducing flame they turn blue
Hg	Mercury Hg	Gray, metallic globules	The globules may be made to unite by rubbing them together with a piece of paper. Heat must be applied slowly to insure complete oxidation

NOTE. Other reactions may be obtained from some of the above elements if the mineral is heated too rapidly or without the establishment of a strong current of air through the tube.

the mineral to be tested is powdered and placed in the tube at a point about one-third of its length from one end. A narrow strip of paper folded into a shallow trough will serve as a boat to introduce the powder into the tube. The tube is then inclined at as sharp an angle as possible, with the mineral lying nearer the lower end. The tube is held over a Bunsen burner flame in such a way that the flame plays on the upper part of the tube. This serves to convert the inclined tube into a chimney, up which a current of air flows. After a moment the tube is shifted so that the flame heats it at a point just above the mineral, or in some cases the flame may be directly beneath the mineral. The mineral is being heated under these conditions in a steady current of air, and it will be oxidized if such a reaction is possible. Various oxides may come off as gases and either escape at the end of the tube or be condensed as sublimates upon its walls. The table, page 103, gives a list of those elements which yield characteristic reactions in open tubes.

Closed-Tube Test. Frequently a small glass tube which has been closed at one end is useful in testing minerals. The tube is made out of soft glass and should have a length of about 3½ inches and an internal diameter from ⅛ to $\frac{3}{16}$ inch. Two closed tubes can easily be made by fusing the center of a piece of tubing 7 inches in length and pulling it apart. The closed-tube test is used to determine what takes place when a mineral is heated in the absence of oxygen. Ordinarily no chemical reaction is involved. In general, in the closed tube the mineral will break down into simpler parts if that is possible, but otherwise nothing will take place except possibly a fusion of the mineral. In performing the test the mineral is broken into small fragments or powdered, placed in the closed end of the tube, and heated in the Bunsen burner flame. The table, page 105, gives a list and brief descriptions of the important closed-tube tests.

Flame Test. Certain elements may be volatilized when minerals containing them are heated intensely and so impart characteristic colors to the flame. The flame color to be obtained from a mineral will often serve as an important means of its identification. A flame test may be made by heating a small fragment of the mineral held in the forceps, but a more decisive test is usually obtained when the fine powder of the mineral is introduced into the Bunsen burner flame on a piece of platinum wire. Some minerals contain elements which normally impart a color to the flame, but because of the nonvolatile nature of the chemical combination fail to give the characteristic flame until broken down by an acid or a flux.

Frequently a flame color is masked by the presence of a sodium flame. Although a mineral may contain no sodium, it may be coated with dust of a sodium compound ever present in the laboratory and a yellow flame may result. A filter of blue glass held in front of the flame will completely absorb the yellow sodium flame and allow the characteristic flame colors of some other elements to be observed. H. E. Merwin has

CLOSED-TUBE TESTS

Element	Substance	Color and Character	Remarks
	Water H_2O	Colorless liquid, easily volatile	All minerals containing water of crystallization or the hydroxyl radical give on moderate heating a deposit of drops of water on the cold upper walls of the tube. If pure, the water is neutral but may be acid from hydrochloric, hydrofluoric, sulfuric, or other volatile acid
S	Sulfur S	Red when hot, yellow when cold. Volatile	Given only by native sulfur and those sulfides which contain a high percentage of sulfur
As	Arsenic As	Two rings around tube: one composed of black amorphous material; the other coats the tube near the bottom with a silver gray crystalline material, the "arsenic mirror"	Given by native arsenic and some arsenides
	Arsenic sulfides AsS As_2S_3	Deep red liquid when hot, reddish yellow solid when cold	Given by realgar, AsS, and orpiment, As_2S_3, and some sulfarsenites
Sb	Antimony oxysulfide Sb_2S_2O	Slight reddish brown coating near the bottom of the tube	Given by antimony sulfide and some sulfantimonites
Hg	Mercury sulfide HgS	Black amorphous sublimate	This test given when cinnabar, HgS, is heated alone
	Mercury Hg	Gray, metallic globules	Metallic mercury is obtained when native mercury or amalgams are heated or when cinnabar is mixed with sodium carbonate and heated

devised a flame-color screen that can be conveniently used in the laboratory. It is made of two overlapping pieces of celluloid, one blue-green and the other deep blue-violet. The characteristic flame color of the various elements may be seen through one or the other, or both, of these celluloid screens without the interference of the sodium flame.

The table, page 106, lists the important elements which yield flame colors.

FLAME COLORATIONS

Element	Color of Flame	Remarks
Strontium Sr	Crimson	Strontium minerals which give the flame color also give alkaline residues after being heated. (See page 125)
Lithium Li	Crimson	Lithium minerals which give the flame color do not give alkaline residues after being heated. (Difference from strontium)
Calcium Ca	Orange	In the majority of cases a distinct calcium flame will be obtained only after the assay has been moistened with HCl
Sodium Na	Intense yellow	A very delicate reaction. The flame should be very strong and persistent to indicate the presence of sodium in the mineral as an essential constituent
Barium Ba	Yellow-green	Minerals which give the barium flame also give alkaline residues after ignition
Molybdenum Mo	Yellow-green	Obtained from the oxide or sulfide of molybdenum
Boron B	Yellow-green	Minerals giving a boron flame rarely give alkaline residues after ignition. Many boron minerals will give a green flame only after they have been broken down by sulfuric acid or the "boron flux." (See page 115)
Copper Cu	Emerald-green	Obtained from copper oxide
	Azure-blue	Obtained from copper chloride. Any copper mineral will give the copper chloride flame after being moistened with hydrochloric acid
Chlorine Cl	Azure-blue (copper chloride flame)	If a mineral containing chlorine is mixed with copper oxide and introduced into the flame, the copper chloride flame results
Phosphorus P	Pale bluish green	A phosphorus mineral may not give the flame color until moistened with sulfuric acid. Not a decisive test
Zinc Zn	Bluish green	Appears usually as bright streaks in the flame
Antimony Sb	Pale green	Flame best observed when mineral is fused on charcoal. Color plays about assay
Lead Pb	Pale azure-blue	Flame may be observed to play about assay when a lead mineral is fused on charcoal
Potassium K	Violet	It may be necessary to decompose mineral with a flux of gypsum, $CaSO_4 \cdot 2H_2O$, to obtain flame color

In order to remove any doubt as to the element yielding a given flame, a small spectroscope as shown in Fig. 254 may be used. Such an instrument can be made easily and inexpensively. It consists of a wooden box with a slit *a*, which can be made by using two razor blades. A small hole at *b* is covered with a ruled grating. A replica grating in collodion is quite satisfactory. An opening at *c* is covered with an exposed film on which the emulsion has been removed along lines corresponding to the spectral lines given by the different elements. The position of these lines must be determined by observing the position of lines of known elements.

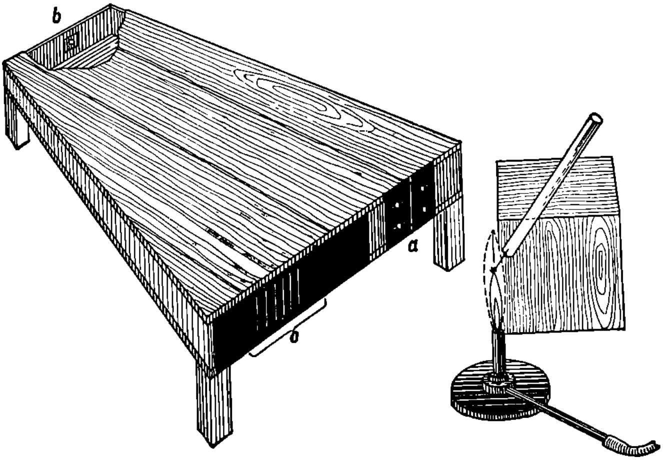

FIG. 254. Spectroscope for Analyzing Flame.

In using the spectroscope, the flame is placed close to the slit (Fig. 254) and viewed through the opening at *b*. If the sodium flame is present, the double sodium line will be seen at its appropriate place along the opening at *c*. Any other colors will be observed as lines. Thus, if lithium is present, a red line will be seen at a position quite different from that of strontium. If the positions of the lines have been previously determined and marked on the film, the element yielding the flame can be determined directly.

Color Reactions with the Fluxes. Some elements, when dissolved in certain fluxes, give a characteristic color to the fused mass. The fluxes that are most commonly used are borax, $Na_2B_4O_7 \cdot 10H_2O$; sodium carbonate, Na_2CO_3; and salt of phosphorus, $HNaNH_4PO_4 \cdot 4H_2O$. The operation is most satisfactorily performed by first fusing the flux on a small loop of platinum wire into the form of a lens-shaped bead. For best results the loop on the wire should have the shape and size shown in Fig. 255. After the flux has been fused into a bead on the wire, a small amount of the powdered mineral is introduced into it and is dissolved by further heating.* The color of the resulting bead may depend upon whether it was heated in the oxidizing or reducing flame and whether the bead is hot or cold. The table on the following page gives a list of the important bead tests.

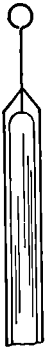

FIG. 255. Loop in Platinum Wire.

In addition, **sodium carbonate** with oxide of manganese, when heated with a grain of niter in the oxidizing flame, gives a nontransparent bead, green when hot, bluish green when cold. When heated in the reducing flame, it gives a colorless bead.

Etch Tests. During the past twenty years a method for the determination of metallic minerals known as *etch tests* has been developed. The specimen must first be polished and set in an appropriate mount so that the polished surface can be examined microscopically. When thus examined many minerals have a characteristic appearance and may be recognized by inspection. However, minerals which resemble one another on the polished surface can be differentiated by etching their surfaces with appropriate reagents. This method is used particularly by the economic geologist in the study of ore minerals. The technique has become so highly developed and specialized that one must refer to specific books on the subject for an adequate treatment.

Microchemical Reactions. Another method for the determination of the elements in minerals uses the microscope to observe chemical reactions and the products of such reactions. This microchemical method is particularly applicable to small quantities, and thus has a definite advantage over other methods if a limited amount of material is available. Its use, however, requires a petrographic microscope and a knowledge of the optical properties of crystalline substances. Consequently, a discussion of this method, also, is beyond the scope of the present book, and the reader is referred to specialized books on the subject.

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* All metallic minerals should be roasted before being introduced into the bead, for it is the oxide of the metal that is desired. It is especially desirable to rid the mineral of arsenic, for even small amounts of this element make the platinum brittle and cause the end of the wire to break off.

COLOR REACTIONS WITH THE FLUXES
(BEAD TESTS)

Oxides of		Borax Bead		Phosphorus Salt Bead	
		Oxidizing Flame	Reducing Flame	Oxidizing Flame	Reducing Flame
Titanium Ti	Hot	Pale yellow	Grayish	Pale yellow	Yellow
	Cold	Colorless to white	Brownish violet	Colorless	Violet
Tungsten W	Hot	Pale yellow	Yellow	Pale yellow	Dirty blue
	Cold	Colorless or white	Yellow to yellowish brown	Colorless	Fine blue
Molybdenum Mo	Hot	Pale yellow	Brown	Yellowish green	Dirty green
	Cold	Colorless or white	Brown	Colorless	Fine green
Chromium Cr	Hot	Yellow	Green	Dirty green	Dirty green
	Cold	Yellowish green	Fine green	Fine green	Fine green
Vanadium Va	Hot	Yellow	Dirty green	Yellow	Dirty green
	Cold	Yellowish green almost colorless	Fine green	Yellow	Fine green
Uranium U	Hot	Deep yellow to orange-red	Pale green	Yellow	Pale dirty green
	Cold	Yellow	Pale green to nearly colorless	Pale greenish yellow	Fine green
Iron Fe	Hot	Deep yellow to orange-red	Bottle-green	Deep yellow to brownish red	Red-yellow to yellow-green
	Cold	Yellow	Pale bottle-green	Yellow to almost colorless	Almost colorless
Copper Cu	Hot	Pale green	Colorless to green	Green	Brownish green
	Cold	Blue-green	Opaque red with much oxide	Blue	Opaque red

COLOR REACTIONS WITH THE FLUXES (*Continued*)

Oxides of		Borax Bead		Phosphorus Salt Bead	
		Oxidizing Flame	Reducing Flame	Oxidizing Flame	Reducing Flame
Cobalt Co	Hot	Blue	Blue	Blue	Blue
	Cold	Blue	Blue	Blue	Blue
Nickel Ni	Hot	Violet	Opaque gray	Reddish to brownish red	Reddish to brownish red
	Cold	Reddish brown	Opaque gray	Yellow to reddish yellow	Yellow to reddish yellow
Manganese Mn	Hot	Violet	Colorless	Grayish violet	Colorless
	Cold	Reddish violet	Colorless	Violet	Colorless

DRY REAGENTS

The following paragraphs give a description of the more important dry reagents used in testing minerals:

Sodium carbonate, Na_2CO_3, is a white salt used chiefly as a flux to decompose minerals by fusion on charcoal and more rarely as a flux in a bead test.

Borax, $Na_2B_4O_7 \cdot 10H_2O$, is a white salt used chiefly in making bead tests and more rarely as a flux on charcoal.

Microcosmic salt or salt of phosphorus, $HNaNH_4PO_4 \cdot 4H_2O$, is a white salt used in making bead tests.

Sodium metaphosphate, $NaPO_3$, is a white salt used in making the test for fluorine (see page 117).

Cupric oxide, CuO, is a black substance which in the powdered form is used in making the flame test for chlorine.

Potassium hydroxide, KOH, is used in making the test for aluminum if iron is present (see pages 112 and 130).

Potassium bisulfate and fluorite mixture, known as the boron flux, is a mixture of three parts of the former and one part of the latter. It is used in making a test for boron (see page 115).

Potassium iodide and sulfur mixture (bismuth flux), a mixture of equal parts of these two materials, is used in making a test for bismuth (see page 114).

Tin and zinc are used in granulated form to make certain reduction tests in hydrochloric acid solutions.

Test Papers. Blue litmus paper is a test paper which changes in color from blue to red when exposed to the action of an acid. It is most commonly used in the open-tube test for sulfur (see page 125). Yellow turmeric paper is a test paper that turns brown when exposed to the action of an alkali. It is most commonly used in making a test for the presence of an alkali or alkaline earth in a mineral (see under sodium, page 124; calcium, page 115; etc.). Red litmus paper can be substituted for the yellow turmeric; it turns blue when exposed to the action of an alkali.

WET REAGENTS

The following paragraphs give brief descriptions of the more important wet reagents used in testing minerals:

Hydrochloric acid (muriatic acid), HCl, is commonly used for the solution of minerals. It is a nonoxidizing acid. The concentrated acid is diluted with three parts of water for ordinary use.

Nitric acid, HNO_3, is a strong solvent and oxidizing agent. It is commonly used in its concentrated form.

Sulfuric acid, H_2SO_4, is less commonly used than the others as a solvent. It may be used in the concentrated form, but usually is diluted with four parts of water. In diluting it, the acid should be added to the water rather than the water to the acid.

Ammonium hydroxide, NH_4OH, is a strong alkali used chiefly to neutralize acid solutions and as a precipitant for aluminum and ferric hydroxides (see pages 112 and 119). For laboratory use it is commonly diluted with three parts of water.

Ammonium oxalate, $(NH_4)_2C_2O_4$, and ammonium carbonate, $(NH_4)_2CO_3$, are chiefly used in the form of aqueous solutions to precipitate the alkaline earths, calcium, strontium, and barium, from their solutions (see page 115).

Diabasic sodium phosphate, $Na_2HPO_4 \cdot 12H_2O$, is used in the form of an aqueous solution to test for the presence of magnesium (see page 120).

Barium hydroxide, $Ba(OH)_2$, is used in testing for carbon dioxide (see page 116).

Barium chloride, $BaCl_2$, is used in the test for sulfuric acid (see page 126).

Sodium sulfide, $Na_2S + 9H_2O$, is used in the form of an aqueous solution in testing for zinc (see page 128).

Ammonium molybdate, $(NH_4)_2MoO_4$, is used in the test for phosphoric acid (see page 123).

Silver nitrate, $AgNO_3$, is used in the test for chlorine (see page 116).

Potassium ferrocyanide, $K_4Fe(CN)_6 \cdot 3H_2O$, and potassium ferricyanide, $K_6Fe_2(CN)_{12}$, are used in dilute solutions to test for ferric and ferrous iron, respectively (see page 119). Ammonium sulfocyanate, NH_4CNS, is also used to test for ferric iron.

Cobalt nitrate, $Co(NO_3)_2$, is used in the form of a dilute solution in blowpipe tests for aluminum (see below) and zinc (see page 128).

Dimethylglyoxime, known as the nickel reagent, is a complex organic compound used in the test for nickel (see page 122).

Hydrogen peroxide, H_2O_2, is used in the test for titanium (see page 126).

E. TESTS FOR THE ELEMENTS

On the following pages are given brief descriptions of the important blowpipe and chemical tests for the elements that can be used by the student of elementary mineralogy. All the tests for a given element are grouped together, and thus there is a repetition of many of the tests. In order to facilitate reference to this section, the different elements are treated in alphabetical order. Under each element the tests are presented in the approximate order of importance. For a fuller discussion of this part of the subject reference must necessarily be made to textbooks that treat of it alone.

Aluminum

1. **Precipitation by Ammonium Hydroxide.** Aluminum is precipitated in the form of aluminum hydroxide, $Al(OH)_3$, when an excess of ammonium hydroxide is added to an acid solution. The precipitate is flocculent and colorless or white. It is precipitated under the same conditions as ferric hydroxide (see page 119), and since the latter has a dark color a small amount of aluminum hydroxide might be overlooked in a mixture of the two. To make a further test under these conditions, filter off the precipitate and treat it with a hot solution of sodium hydroxide, which will dissolve any aluminum hydroxide present but will not affect the ferric hydroxide. Filter, to the filtrate add hydrochloric acid in slight excess, and then make alkaline with ammonium hydroxide again. This will precipitate as pure aluminum hydroxide any aluminum that may be present.

2. **Blowpipe Test with Cobalt Nitrate.** Light-colored infusible aluminum minerals when moistened with a drop of cobalt nitrate and heated intensely before the blowpipe assume a dark blue color. Zinc silicates will also yield a blue color under similar conditions.

Antimony

1. **Oxide Coating on Charcoal.** When an antimony mineral is heated in the oxidizing flame on charcoal, a heavy white coating of

antimony oxide settles on the charcoal at a short distance from the mineral. The coating is readily volatile when heated.

2. **Open-Tube Test.** When metallic antimony or a compound of antimony is heated in the open tube, a white powdery sublimate of antimony oxide, Sb_2O_3, forms a ring on the inner wall of the tube, a short distance above the mineral. It is a volatile coating. If the mineral contains sulfur, as it usually does, a second coating will form as a pale yellow to white powder along the bottom of the tube. It is another oxide of antimony, Sb_2O_4. It is nonvolatile and is usually more conspicuous than the first.

3. **Sublimate on Plaster Tablet.** When an antimony mineral is powdered and mixed with a mixture of potassium iodide and sulfur, it yields in the oxidizing flame an orange to red sublimate of SbI_3 on a plaster tablet.

Arsenic

The test to be used for arsenic depends upon whether the mineral is oxidized. The majority of arsenic compounds are unoxidized, and then tests 1, 2, 3, and 4 will serve. If, on the other hand, the mineral is an oxygen compound, test 5 must be used.

1. **Oxide Coating on Charcoal.** When an arsenic mineral is heated in the oxidizing flame on charcoal, a white coating of arsenious oxide, As_2O_3, is deposited on the charcoal at some distance from the mineral. The coating is very volatile. Its formation is usually accompanied by a characteristic garlic odor.

2. **Sublimate on Plaster Tablet.** When mixed with a mixture of potassium iodide and sulfur, arsenic minerals yield in the oxidizing flame an orange-yellow coating of AsI_3.

3. **Open-Tube Test.** When an arsenic mineral is carefully heated in the open tube a colorless or white crystalline sublimate of arsenious oxide, As_2O_3, forms a ring on the inner wall of the tube at a considerable distance above the assay. It is very volatile. When examined with a lens the coating will usually show well-defined octahedral crystals. If the mineral is heated too rapidly, the oxide may not form but metallic arsenic may sublime as in the closed-tube test.

4. **Closed-Tube Test.** Many arsenic minerals when heated in a closed tube yield a sublimate of metallic arsenic, known as the arsenic mirror. This sublimate shows an amorphous black band above and a silver-gray crystalline band below. If the bottom of the tube is broken off and the metallic arsenic volatilized by heat, the characteristic garlic odor will be obtained.

5. **Closed-Tube Test for an Arsenate.** When arsenic occurs in a mineral in the form of an arsenate, i.e., an oxidized compound, none of the above tests will serve. In this case place the mineral in a closed tube with a splinter of charcoal and then heat. The charcoal will act as a reducing agent and set metallic arsenic free, which will condense on the wall of the tube as an arsenical mirror similar to that described under test 4.

Barium

1. **Flame Test.** Barium minerals, with the exception of barium silicates, when heated intensely give a yellowish green flame color.

2. **Precipitation as Barium Sulfate.** Barium is precipitated as barium sulfate, $BaSO_4$, from an acid solution by the addition of dilute sulfuric acid. The precipitate is white and finely divided and being very insoluble will form in a dilute solution (distinction from calcium and strontium).

3. **Alkaline Reaction.** Barium is an alkali-earth metal. When a mineral contains barium in combination with a volatile acid, it will give, after ignition, a residue which will react alkaline on a piece of moistened turmeric paper.

Beryllium

Beryllium is a rare element which has no simple diagnostic chemical test. Its reactions are very similar to those of aluminum, and therefore it is difficult to tell the two elements apart.

Bismuth

1. **Charcoal Tests.** When heated with sodium carbonate on charcoal in the reducing flame, a bismuth mineral will yield a metallic globule and an oxide coating. The metal is easily fusible; it is lead-gray when hot but becomes covered with an oxide coating on cooling. It is only imperfectly malleable, for when hammered out it flattens at first but later breaks into small grains. The oxide coating, Bi_2O_3, is white with a yellow ring next to the mineral. These bismuth reactions are similar to those for lead (see page 120); consequently the following modification is useful. If the bismuth mineral is fused on charcoal with a mixture of potassium iodide and sulfur (see page 102), a characteristic and distinctive coating is obtained. This sublimate is yellow next to the mineral and brilliant red farther away. Under similar conditions with lead a solid yellow coating is obtained.

2. **Sublimate on Plaster Tablet.** When mixed with a mixture of potassium iodide and sulfur and heated, a bismuth mineral will give a sublimate that is chocolate-brown with underlying red. If subjected to ammonia fumes, the coating becomes first orange-yellow, then red.

Boron

1. **Flame Test.** Some boron minerals give a yellow-green flame when heated alone. Most boron minerals, however, will yield the flame color only after they have been moistened with sulfuric acid or when their powders are mixed with acid potassium sulfate and fluorite mixture (see page 110) and then introduced on a platinum wire into a Bunsen burner flame. As the mixture fuses, a momentary but distinct green flame is obtained.

Calcium

1. **Precipitation as Calcium Oxalate or Carbonate.** Calcium is readily and completely precipitated from alkaline solutions as calcium oxalate, CaC_2O_4, or calcium carbonate, $CaCO_3$, by the addition of ammonium oxalate, $(NH_4)_2C_2O_4$, or ammonium carbonate, $(NH_4)_2CO_3$. Both precipitates are white and finely divided.

2. **Flame Test.** When calcium occurs in a mineral in such a state that it can be volatilized by heat, it will yield a characteristic orange flame color. Frequently the mineral has to be moistened with hydrochloric acid before heating. The flame should not be confused with the crimson and more persistent flame of strontium or lithium.

3. **Alkaline Reaction.** Calcium is an alkali-earth metal; consequently, if a mineral contains calcium in a combination with a volatile acid, it will give, after ignition, a residue which will react alkaline on a piece of moistened turmeric paper.

4. **Precipitation as Calcium Sulfate.** Calcium is precipitated from a concentrated hydrochloric acid solution as calcium sulfate on the addition of a little dilute sulfuric acid. The precipitate is readily soluble in water and therefore will not form in a dilute solution (distinction from barium and strontium).

Carbon

Carbon exists in minerals chiefly in the CO_3 radical in the carbonates.

1. **Test for Carbon Dioxide with an Acid.** All carbonates when treated with a strong acid (best hydrochloric) dissolve with a vigorous effervescence of carbon dioxide gas. With some carbonates (for example, dolomite, $CaMg(CO_3)_2$) the acid must be heated to start the

reaction, and with others (for example, cerussite, $PbCO_3$) the formation of an insoluble chloride quickly brings the reaction to an end. Effervescence will continue with nitric acid. Carbon dioxide gas is colorless and odorless. It will not support combustion, as is shown when a lighted match is placed in a test tube that contains it. The gas is heavier than air and can be poured from the test tube in which it has been generated into another in which some barium hydroxide solution has been placed. When the contents of the latter tube are shaken together, the carbon dioxide reacts with the barium hydroxide to form a white precipitate of barium carbonate, $BaCO_3$. This is a very sensitive test, and care should be taken to avoid taking carbon dioxide from the air.

Chlorine

1. **Precipitation as Silver Chloride.** Chlorine is precipitated from a dilute nitric acid solution as silver chloride, $AgCl$, by the addition of a small amount of silver nitrate, $AgNO_3$. The test is very delicate, traces of chlorine being shown by a milky appearance of the solution. When chlorine is present in large amount the precipitate is curdy and white but darkens on exposure to light. It is soluble in ammonium hydroxide. The rare elements, bromine and iodine, give similar reactions with the precipitation of silver bromide, $AgBr$, and silver iodide, AgI.

2. **Flame Test.** The presence of chlorine can be detected in a mineral by obtaining the blue flame of copper chloride. A small amount of copper oxide, CuO, should be dissolved in a bead of sodium metaphosphate. The mineral containing chlorine is then introduced into the bead, and the blue flame of copper chloride is obtained.

Chromium

1. **Bead Tests.** Chromium is usually detected by the color it gives to the fluxes as shown in the bead tests (see page 109). The salt of phosphorus bead when fused in the oxidizing flame yields a fine green color. This is the most characteristic chromium bead.

Cobalt

1. **Bead Tests.** A cobalt mineral when fused in either a borax or salt of phosphorus bead yields a distinctive dark blue color. The test is very delicate.

Columbium

Columbium is a rare element usually associated with tantalum in certain oxides.

1. **Reduction Test with Tin.** The best test for columbium is to fuse some of the powdered mineral with several parts of sodium carbonate. The resulting mass is dissolved in a few cubic centimeters of dilute hydrochloric acid, and then a few grains of metallic tin are added. The solution is boiled, and the hydrogen set free by the action of the acid on the tin serves as a reducing agent. The result is to form a compound of columbium which is dark blue in color. This color does not readily change to brown on continued boiling, and it disappears on addition of water. This distinguishes the columbium test from a similar one for tungsten (see page 127).

Copper

1. **Flame Tests.** An oxidized compound of copper when introduced into the flame gives it a vivid green color due to the copper oxide volatilized. When the mineral is moistened with hydrochloric acid and then heated, the flame is an intense blue tinged with green. If the mineral is a sulfide, it must be roasted in the oxidizing flame before moistening with hydrochloric acid.

2. **Blue Solution with Ammonium Hydroxide.** If an acid solution containing copper is made alkaline with ammonium hydroxide, it will assume a deep blue color.

3. **Reduction to Metal on Charcoal.** When a small amount of a copper mineral is mixed with the reducing mixture (equal parts of sodium carbonate and charcoal), placed on charcoal, and heated intensely in the reducing flame, metallic globules of copper will be formed. They are difficultly fusible and are bright when hot but become coated with an oxide on cooling. They are malleable and show the characteristic copper color. Sulfides of copper must first be roasted in the oxidizing flame in order to remove the sulfur before mixing with the flux.

Fluorine

1. **Etching Tests.** The ordinary test for fluorine consists in converting it into hydrofluoric acid and observing its etching effect upon glass. A watch glass or other piece of glass may be covered with paraffin and then the coating removed in spots. Upon this is placed the powdered mineral with a few drops of concentrated sulfuric acid. If it is a soluble fluoride the action of the acid will liberate hydrofluoric acid, which will in turn etch the glass where it has been exposed. The action should be allowed to continue for several minutes. On cleaning the glass the etched spots will be visible.

A modification of the above test can be made in a type of closed tube known as the bulb tube. Such a tube can be made by heating the end of an ordinary closed tube in a very hot flame until the glass becomes soft enough to be blown into the bulb. It is preferable to use hard glass, but with the Bunsen burner sufficient heat cannot be obtained to blow it and one may thus be required to use soft glass. A powdered mixture of mineral, potassium bisulfate, and glass is introduced into the bulb tube and heated in the Bunsen burner flame. The potassium bisulfate decomposes the mineral, liberating hydrofluoric acid, HF, which attacks the glass, forming a gas, silicon tetrafluoride, SiF_4. As this gas moves up the tube it combines with moisture in the tube and with water liberated by the reaction to form hydrofluosilicic acid, $2H_2SiF_6$, and silicon dioxide, SiO_2. The separated silica forms a white ring in the tube which is volatile in the presence of the hydrofluosilicic acid. If the bottom of the tube is broken and the acid dissolved by gently dipping in water, it will be found on drying the tube that the silica is no longer volatile. This silicon dioxide coating is a proof of the action of hydrofluoric acid in the bottom of the tube and therefore of the presence of fluorine in the mineral.

Gold

1. **Reduction to the Metal on Charcoal.** If gold occurs in the form of a telluride, it can be easily reduced to a metallic globule by heating on charcoal without the aid of a flux. The resulting globule is soft and yellow and remains bright. It is very malleable and can be hammered into a thin sheet. The telluride coating on the charcoal would accompany such a reduction.

Once the globule has been obtained, or if one is dealing with native gold, there is no simple blowpipe or chemical test to prove the presence of gold. Ordinarily its physical characteristics are sufficient to identify it. For a discussion of the occurrence and tests for gold see page 134.

Hydrogen

1. **Closed-Tube Test for Water.** Hydrogen exists in minerals either as water of crystallization (for example, gypsum, $CaSO_4 \cdot 2H_2O$) or as the hydroxyl radical (for example, alunite, $KAl_3(OH)_6(SO_4)_2$). In either form its presence may be detected by heating a fragment of the mineral in a closed tube and observing the water which condenses upon the upper cold wall of the tube. Water of crystallization is driven off more readily than water of hydroxyl, but the test is easily obtained for

either. Some minerals are broken down when heated in the closed tube so that a free acid may be given off with the water. The water then gives an acid reaction with litmus paper as it does with alunite. Gypsum, on the other hand, gives off a neutral water.

Iron

1. **Magnetic Test.** Any mineral that contains a sufficient amount of iron to permit it to be classified as an iron mineral will readily become magnetic when heated in the reducing part of the blowpipe flame. A comparatively small fragment should be used and, after it has cooled, the test made with a magnet.

2. **Precipitation with Ammonium Hydroxide.** Ferric iron is readily and completely precipitated as ferric hydroxide, $Fe(OH)_3$, from an acid solution by adding an excess of ammonium hydroxide. It is a flocculent precipitate with a reddish brown color. If there is any doubt as to the state of oxidation of the iron in the original solution, a few drops of nitric acid should be added and the solution heated in order to make certain that the iron is ferric.

3. **Cyanide Tests for Ferrous and Ferric Iron.** Occasionally it may be important to determine whether the iron in a mineral is ferrous or ferric. This can be done only when the mineral is soluble in a non-oxidizing acid like hydrochloric and when it is not a sulfide. If these conditions can be fulfilled, then divide the solution into two parts. To one add a few drops of a dilute solution of potassium ferricyanide, and if the solution contains any *ferrous* iron a heavy dark blue precipitate will form. If, on the other hand, it contained only ferric iron, there would be no precipitate but only a darkening of the color of the solution. To the second portion of the solution add a few drops of a dilute solution of potassium ferrocyanide, and if any *ferric* iron is present a heavy dark blue precipitate similar to the one in the previous test will form. But if the solution contained only ferrous iron, a light blue precipitate would be formed. The characteristic dark blue precipitate must contain both valences of iron and will form only when a cyanide is added containing iron whose valence differs from that already in the solution.

Ammonium or potassium sulfocyanate is also used in making the ferric test. A few drops of one of these reagents added to a ferric iron solution will give it a deep red color. All these tests are extremely delicate and will give good results if only a trace of iron is present. They should never be used to determine the presence of iron in a mineral but only to differentiate ferrous from ferric iron.

Lead

1. **Charcoal Test.** Any lead mineral when powdered and mixed with sodium carbonate will yield a metallic globule when the mixture is heated on charcoal in the reducing flame. The globule is bright lead color when hot but becomes covered with a dull oxide coating on cooling. It is very malleable and can be hammered out into a thin sheet. A coating on the charcoal of lead oxide, PbO, will also form, which varies in color from yellow next to the fused mass to white at a distance. It will be best obtained by removing the lead globule to a fresh piece of charcoal and heating it in the oxidizing flame.

2. **Iodide Tests.** When lead minerals are mixed with a mixture of potassium iodide and sulfur and heated on either charcoal or plaster they yield a chrome-yellow coating.

3. **Acid Tests.** Lead minerals as a rule are only slowly attacked by acids. Dilute nitric acid is the best solvent to use. If to a nitric acid solution a few drops of hydrochloric or sulfuric acid are added, white precipitates will form, which are respectively lead chloride, $PbCl_2$, and lead sulfate, $PbSO_4$. The sulfate is quite insoluble.

Lithium

1. **Flame Test.** Lithium is a rare element which is to be distinguished by the persistent and strong crimson color which it gives to the flame. In silicates it is best to mix the powdered mineral with powdered gypsum before testing for the flame color. The flame is very similar to that obtained from strontium, but the assay will not give an alkaline reaction after ignition.

Magnesium

1. **Precipitation as Ammonium Magnesium Phosphate.** The only common test for magnesium is to precipitate it in the form of ammonium magnesium phosphate, NH_4MgPO_4, by the addition of diabasic sodium phosphate, $Na_2HPO_4 \cdot 12H_2O$ to a strongly ammoniacal solution. The precipitate usually forms somewhat slowly, is white in color, and frequently is granular in texture. In order to make a decisive test, certain precautions are necessary. As the precipitation is made in an ammoniacal solution, any precipitates formed by an excess of ammonium hydroxide must first be filtered off. It may be necessary before adding the ammonium hydroxide to add a few drops of nitric acid so as to make certain that any iron in the solution is in the ferric state. Also, before making the final test, any elements, such as calcium, strontium, and

barium, that are precipitated in ammoniacal solution by means of ammonium oxalate, must be removed. In any event their presence must be tested for before adding the diabasic sodium phosphate, because, if present, they would be precipitated by that reagent along with the magnesium.

Manganese

1. **Bead Tests.** (*a*) Manganese gives to the sodium carbonate bead when heated in the oxidizing flame a characteristic bluish green color. To insure oxidation add a grain of potassium nitrate, KNO_3. The bead is nontransparent when cold.

(*b*) With the borax bead, when heated in the oxidizing flame manganese gives a purple or amethystine color but becomes colorless on heating in the reducing flame. The bead is transparent when cold.

Both tests are very delicate.

Mercury

1. **Closed-Tube Test.** The powdered mineral is thoroughly mixed with dry sodium carbonate and placed in a closed tube and then heated. The sodium carbonate will decompose the mineral and liberate metallic mercury, which will volatilize and condense in the upper part of the tube.

2. **Open-Tube Test.** When a mercury mineral is heated very slowly in the open tube so that complete oxidization can take place, globules of metallic mercury will condense on the cool upper part of the tube.

3. **Precipitation on Copper.** Boil the powdered mineral with hydrochloric acid in which some powdered pyrolusite, MnO_2, has been placed. The chlorine evolved by the action of the acid on the manganese dioxide will serve to dissolve the mercury mineral. If a clean strip of copper (a cent which has been cleaned with a little nitric acid will serve) is placed in this solution, it will become covered by a thin coating of metallic mercury.

The chief and only common mineral of mercury is cinnabar, HgS; for its distinctive physical and chemical tests see page 163.

Molybdenum

The tests for the element molybdenum depend upon whether it is in an oxidized or an unoxidized compound. In testing for molybdenum in unoxidized minerals, chiefly in molybdenite, MoS_2, tests 1, 2, and 3 should be used; for molybdenum in oxidized minerals, test 4 should be used.

1. **Test on Plaster.** If a molybdenum mineral is heated on a plaster block, a white sublimate of MoO_3 is formed. If this coating is touched with the reducing flame, it turns a deep ultramarine blue. A red stain of another oxide, MoO_2, forms under the assay.

2. **Iodide Test.** When a molybdenum mineral is heated on a plaster block with a mixture of potassium iodide and sulfur, a deep blue sublimate forms.

3. **Open-Tube Test.** In the open tube a network of crystals of MoO_3 forms near the assay when a molybdenum mineral is heated. If the tube is broken near the assay and the crystals touched with the reducing flame, they will turn blue.

4. **Bead Test.** An oxidized molybdenum compound with the salt of phosphorus gives in the reducing flame a green bead; in the oxidizing flame it gives a bead yellowish green when hot and almost colorless when cold.

Nickel

1. **Precipitation of Nickel by Dimethylglyoxime.** Dissolve the mineral in nitric acid and neutralize with ammonium hydroxide. Filter if necessary. Add a little of a solution of dimethylglyoxime (nickel reagent), and a scarlet crystalline precipitate forms. This is a very sensitive test.

2. **Borax Bead Test.** A nickel compound will give a brownish bead when dissolved in borax in the oxidizing flame. If the bead is heated in the reducing flame for some time, it will become an opaque gray because of the separation in it of metallic nickel. The nickel color is often masked by a deep blue owing to the presence of cobalt, which in minerals is frequently associated with nickel. In this case test number 1 should be used.

3. **In Ammoniacal Solution.** A comparatively strong acid solution of nickel, on the addition of an excess of ammonium hydroxide, will become light blue in color. The test should not be confused with the similar but stronger test for copper.

Oxygen

Though oxygen is one of the most common elements in minerals, its presence is ordinarily determined indirectly by testing for the different oxygen-containing radicals. For a few oxides in which there is an excess of oxygen, the following tests may be made.

1. **Closed-Tube Test.** The powdered oxide is placed in a closed tube with a small splinter of charcoal resting just above it. The tube is

heated, and if free oxygen is evolved the charcoal will first glow and then burn with a bright light. It is to be noted that only a few oxides which contain an excess of oxygen will give this test.

2. **Evolution of Chlorine.** Oxides that contain an excess of oxygen when dissolved in hydrochloric acid will produce chlorine gas.

Phosphorus

1. **Precipitation with Ammonium Molybdate.** Phosphorus exists in minerals in the PO_4 radical in the phosphates. It is best tested for by forming a dilute nitric acid solution of the mineral and adding a few cubic centimeters of this to an excess of ammonium molybdate solution. A canary-yellow precipitate of ammonium phosphomolybdate will be formed. The precipitate forms slowly at first and comes down best in a warm solution.

2. **Flame Test.** Many phosphates give a pale bluish green flame color. This may frequently be obtained better when the mineral has previously been moistened with a drop of concentrated sulfuric acid.

Silicon

Silicon exists as the acid element in the large group of minerals known as the silicates. Some of these are readily soluble in acids, but the greater part are quite insoluble. The tests employed differ somewhat in the two cases.

1. **Test for a Soluble Silicate.** If the silicate is soluble, it should be powdered and dissolved in boiling hydrochloric acid. When this solution is evaporated a jellylike material will separate out just before dryness is reached. This silica jelly, as it is called, is a form of silicic acid. On continued evaporation it will be dehydrated and converted into a sandy and insoluble substance having the composition of silicon dioxide, SiO_2. A small amount of concentrated hydrochloric and nitric acids is then added. The bases will go into solution but will leave the silica as a residue, thus proving the presence of silicon in the mineral.

2. **Test for an Insoluble Silicate.** An insoluble silicate must be decomposed by fusion with sodium carbonate before being treated with an acid. Make a mixture of one part of the powdered mineral to three parts of sodium carbonate and fuse thoroughly before the blowpipe on a loop of platinum wire. It is best to make two or three such beads. The fusion serves to decompose the silicate and to render the resulting mass wholly soluble in acids. The beads are powdered and dissolved in boiling dilute nitric acid. The evaporation is conducted as explained in test 1, and a similar silica jelly is obtained.

3. **Test with the Salt of Phosphorus Bead.** When the powder of a silicate is heated in a salt of phosphorus bead, the bases are dissolved, leaving the silica present as an insoluble translucent skeleton.

Silver

1. **Precipitation as Silver Chloride.** When a silver mineral is dissolved in nitric acid and to the solution a few drops of hydrochloric acid are added, a white curdy precipitate of silver chloride, $AgCl$, is formed. The test is very delicate, and if there is only a trace of silver in the solution its presence will be indicated by a milky-blue coloration. The precipitate is white at first but darkens on exposure to light. It is soluble in ammonium hydroxide. Frequently when a silver mineral is treated with nitric acid a precipitate will result at once. This may be metantimonic acid, lead sulfate, etc., and should be filtered off before making the silver test.

2. **Reduction to the Metal on Charcoal.** Silver can frequently be reduced to a metallic globule from its compounds by heating the powdered mineral on charcoal with sodium carbonate. The resulting globule is bright both when hot and cold. It is malleable. No accompanying coating is formed on the charcoal. This test for silver is frequently complicated by the presence of lead, arsenic, or antimony in the mineral. Usually the mineral should be carefully roasted on charcoal in the oxidizing flame before attempting the reduction in order to remove the arsenic and antimony; otherwise a brittle globule will result.

Sodium

1. **Flame Test.** Sodium compounds when heated give a strong and persistent yellow flame. The test is very delicate and must be used with care, for only a trace of sodium may yield a distinct flame. If the mineral contains sodium in any notable amount, it should give an intense and continuous flame color.

2. **Alkaline Reaction.** A compound of sodium with a volatile acid yields after ignition a residue that reacts alkaline on a moistened test paper.

Strontium

1. **Flame Test.** Strontium compounds give a very strong and persistent crimson flame. The only other flame which is similar is that obtained from lithium. Strontium can be positively determined from lithium by the following tests.

2. **Alkaline Reaction.** When a mineral contains strontium in combination with a volatile acid, it will give, after ignition, a residue which will react alkaline on a piece of moistened turmeric paper.

3. **Precipitation as Strontium Sulfate.** Strontium is precipitated from a mediumly dilute solution as strontium sulfate, $SrSO_4$, on the addition of a little dilute sulfuric acid. The precipitate is somewhat soluble and will not form in very dilute solutions (distinction from calcium and barium).

Sulfur

Sulfur exists in minerals either in unoxidized compounds, as in the sulfides, or in oxidized compounds, as in the sulfates. These two types of sulfur compounds in general require different tests, but the *hepar reaction* given below will serve for either.

GENERAL TEST FOR SULFUR

Hepar Reaction. When a mineral containing sulfur in either the oxidized or unoxidized state is fused on charcoal with the reducing mixture (sodium carbonate and charcoal), what is known as the *hepar reaction* takes place, producing a brown mass. The sodium carbonate reacts with either a sulfide or sulfate to produce soluble sodium sulfide. When, therefore, the fused mass is placed with a drop of water on a clean silver surface (a coin will serve), a dark brown stain of silver sulfide will form. This test is very sensitive, and one must perform the fusion on a charcoal block where no sulfide has previously been roasted.

TESTS FOR SULFUR IN SULFIDES

1. **Open-Tube Test.** Sulfides when heated in the open tube give off sulfur dioxide gas, which escapes with the current of air from the upper end of the tube. Its presence may be detected by the pungent and irritating odor. A piece of moistened blue litmus paper inserted into the upper end of the tube will turn red because of the formation of sulfurous acid.

2. **Closed-Tube Test.** Sulfides that contain a large percentage of sulfur (example, pyrite, FeS_2) when heated in the closed tube will give off sulfur that is red when hot and yellow when cold.

3. **Charcoal Test.** The odor of sulfur dioxide may be obtained when a sulfide is roasted on charcoal.

TESTS FOR SULFUR IN SULFATES

The test for sulfur in the SO_4 radical depends on whether the sulfate is soluble or insoluble in acids.

1. **Test for a Soluble Sulfate.** If the sulfate is soluble, dissolve it in hydrochloric acid, and to the resulting solution add a little barium chloride. A heavy white precipitate of barium sulfate will result.
2. **Test for an Insoluble Sulfate.** See general test for sulfur above.

Tantalum

There is no simple test for tantalum. It is usually associated, however, with columbium (see page 117).

Tellurium

1. **Charcoal Test.** When a mineral containing tellurium is heated on charcoal a white sublimate of TeO_2 is formed which somewhat resembles antimony oxide. It is volatile and when touched with the reducing flame gives a pale greenish flame color.
2. **Plaster Tablet Test.** On a plaster tablet tellurium minerals when heated give a purplish brown sublimate.
3. **Test with Sulfuric Acid.** When a telluride is heated in concentrated sulfuric acid, it gives a deep crimson color to the solution. The color will disappear if the acid is heated too hot, or if after cooling it is diluted with water.

Tin

1. **Reduction Test in Hydrochloric Acid.** Place fragments of a tin mineral and metallic zinc in dilute hydrochloric acid, and warm. The hydrogen set free by the action of the acid on the zinc reduces the surface of the tin mineral so that the fragments become coated with metallic tin.
2. **Reduction to Metallic Globule.** Mix a small amount of the finely powdered mineral with five or six volumes of reducing mixture (sodium carbonate and charcoal), and fuse intensely on charcoal. Small bright globules of metallic tin will result. They become covered with an oxide coating on cooling. A white and difficultly volatile tin oxide coating will form on the charcoal. If the tin globule is treated with a little concentrated nitric acid, it will be converted into a white powder, which is metastannic acid.

Titanium

1. **Test with Hydrogen Peroxide.** Fuse the mineral with sodium carbonate; dissolve in equal amounts of concentrated sulfuric acid and water. When the solution is cold, dilute it and add a few drops of hydrogen peroxide. The solution will become yellow to amber in color.

2. **Reduction Test in Hydrochloric Acid.** A comparatively concentrated hydrochloric acid solution containing titanium will become pale violet in color when it is boiled with a few grains of metallic tin. The hydrogen liberated by the action of the acid on the tin is a reducing agent and forms $TiCl_3$ in the solution which gives this color. The color is not a strong one, and the solution may have to be evaporated nearly to dryness in order to show it distinctly. Most titanium minerals are insoluble in hydrochloric acid and must first be thoroughly fused with sodium carbonate in order to bring the titanium into soluble form.

Tungsten

1. **Reduction Test in Hydrochloric Acid.** Tungsten minerals are insoluble and should be powdered and fused with sodium carbonate. When they are thus rendered in a soluble form and dissolved in hydrochloric acid a yellow precipitate of tungstic oxide, WO_3, separates. Add a few grains of metallic tin or zinc and boil. The hydrogen set free by the action of the acid on the metal serves as a reducing agent and converts the yellow WO_3 to a blue precipitate which is a mixture of the two oxides WO_3 and WO_2. On continued reduction the oxide becomes all WO_2 and is brown in color. The test is similar to the one for columbium but is to be distinguished from that, since the blue color in the tungsten test does not disappear on dilution of the solution; and further, it turns to brown on continued reduction.

Uranium

1. **Bead Tests.** The tests for uranium consist in the colors it imparts to the fluxes (see page 109). The yellowish green color given to the salt of phosphorus bead when heated in the oxidizing flame is the most characteristic.

Vanadium

1. **Bead Tests.** The best tests for vanadium are the bead tests (see page 109). The amber color given to the salt of phosphorus bead when heated in the oxidizing flame is the most characteristic.

2. **Test with Hydrogen Peroxide.** To an acid solution of a vanadate add a little hydrogen peroxide and the solution will assume a reddish brown color due to the presence of pervanadic acid.

Zinc

1. **Oxide Coating on Charcoal.** Metallic zinc is easily obtained from the zinc minerals by fusing them with reducing mixture on charcoal. But, since the metal is volatilized at a temperature considerably below

that of the blowpipe flame, no metallic globule can be formed. All the metallic zinc, therefore, is volatilized and, meeting the oxygen of the surrounding air, is converted into the oxide, ZnO, which drops upon the charcoal as a nonvolatile coating, which is yellow when hot but white when cold. The coating deposits very close to the assay. It may frequently be obtained in more distinct form by making the fusion on a loop of platinum wire, which is held about ¼ inch from the surface of a charcoal block, the blowpipe flame being so directed that the oxide coating is deposited upon the charcoal behind the bead. If the coating is moistened with a drop of cobalt nitrate and then heated intensely by the blowpipe flame, it will become dark green in color.

2. **Flame Color.** Some zinc minerals, when a fragment is held in the forceps and heated in the reducing flame, will show a characteristic flame color. This is due to the burning in the flame of the metallic zinc which has been volatilized. It takes the form of momentary streaks or threads in the flame and has a pale greenish blue color.

3. **Precipitation as Zinc Sulfide.** The zinc mineral is dissolved in hydrochloric acid, and a few drops of nitric acid are added to oxidize any iron present. The solution is made ammoniacal, and iron and aluminum, if present, are thus precipitated and filtered off. Sodium sulfide, $Na_2S + 9H_2O$, is added to the filtrate, and a white precipitate, ZnS, indicates the presence of zinc. For best results the solution to which sodium sulfide is added should not have a large excess of ammonium hydroxide.

Zirconium

1. **Test with Turmeric Paper.** A zirconium mineral should be fused with sodium carbonate and then dissolved in hydrochloric acid. A piece of turmeric paper placed in this hydrochloric acid solution containing zirconium assumes an orange color. The change in the color of the paper is not striking, and it is usually well to compare the test color with the color of tumeric paper wet with acid alone.

ORDER OF TESTS IN BLOWPIPE ANALYSIS

After one has become somewhat familiar with minerals, it is usually not difficult to select the one or two tests which will give the desired information about a certain specimen. Frequently, however, the beginner is at a loss as to what tests he should make, and the following scheme is presented to aid him.

- I. Metallic minerals.
  - A. Heat a fragment of the mineral on charcoal. Note the sublimate, if any, and see if the mineral is wholly volatile or if there is a residue.
    - 1. If there is a sublimate on the charcoal, use closed and open tubes for further information.
    - 2. If a residue, test with:
      - *a.* HCl for copper.
      - *b.* Magnet for iron.
      - *c.* Beads for color with fluxes.
      - *d.* Reducing mixture for a metal.
  - B. If nothing definite is obtained under A, use special tests for the rare elements tungsten, titanium, tin, etc.
- II. Nonmetallic minerals.
  - A. Heat a fragment of the mineral in the forceps and note fusion and flame color. See whether the residue will give an alkaline reaction.
    - 1. If infusible, make cobalt nitrate test for aluminum.
    - 2. If very fusible, heat on charcoal to test for a metal.
  - B. Test in a closed tube for water.
  - C. Test the solubility of a fine powder of the mineral in hydrochloric acid.
    - 1. If soluble, boil to dryness and take up again with hydrochloric and nitric acid, and thus test for silica.
      - *a.* If the mineral is a silicate, make analysis of the solution for bases as described below under III.
      - *b.* If no silicate, test the solution for acid and bases.
    - 2. If insoluble, decompose the mineral with sodium carbonate and proceed as before.
  - D. Make special tests for rare elements if no results are obtained by above.
- III. Analysis of silicates.

  The presence of silicon, manganese, aluminum, iron, calcium, magnesium, potassium, and sodium may be determined by using the following scheme of analysis.
  - A. Using gypsum as a flux, determine the presence of *potassium* and *sodium* by the flame test.
  - B. Decompose the mineral by fusing with sodium carbonate using a grain of niter, KNO_3, to show the presence of *manganese.*
  - C. Dissolve the fused mass (B) (or mineral itself, if soluble) in hydrochloric acid and boil to dryness. A gelatinous or powdery silica may separate.
    - 1. Moisten the dry mass after cooling with a few drops of concentrated hydrochloric and nitric acids, and boil with a little water. A white residue in the test tube proves the presence of *silicon.*
    - 2. Filter the solution, and add ammonium hydroxide to the filtrate. A precipitate indicates *aluminum* if white, *iron* if red. In the latter case aluminum may also be present (see under *c*, next page).

a. Remove the precipitate by filtering, and to the filtrate add ammonium oxalate; a white precipitate indicates *calcium.* Strontium and barium will also be precipitated.

b. If a calcium precipitate, filter; if no calcium, add directly sodium phosphate. A precipitate indicates *magnesium.*

c. If the precipitate with ammonium hydroxide is red, remove it from the filter to a test tube with a little water. Add a small piece of potassium hydroxide, boil, and filter. If aluminum is present, it will be dissolved and will be in the filtrate. Make filtrate acid by addition of hydrochloric acid, then add ammonium hydroxide to obtain a precipitate of *aluminum.*

IV. DESCRIPTIVE MINERALOGY

INTRODUCTION

A description of about 200 minerals will be found on the following pages. This is a relatively small number, since considerably over 1,000 minerals have been described and recognized by mineralogists as bona fide species. This list of 200 includes all the common minerals and those that are of most importance economically. The names of some other minerals and their chemical compositions are given.

In the individual descriptions the crystallographic, chemical, and general physical properties are first considered, and then those features and tests which aid one in recognizing the mineral and distinguishing it from others are discussed. In addition a brief account of its mode of occurrence and characteristic associations is given. The localities at which a mineral occurs in notable amount or quality are also mentioned. For those minerals that are found abundantly the world over emphasis is placed on American localities. For minerals possessing economic value there are brief statements of their uses. When possible, the derivation of the mineral name is given. At the end of some of the individual descriptions is a heading "Similar Species"; the similarity of the species listed to the mineral whose description precedes may be either on the basis of chemical composition or crystal structure. Consequently the names of these minerals are not necessarily in those places where they would appear if this book were extended to include their descriptions.

The headings under which the various data are arranged for each mineral are:

Crystallography	Alteration
Physical Properties	Occurrence
Composition	Use
Tests	Name
Diagnostic Features	Similar Species

The mineral classification used in this book* is based on chemical composition, the broadest divisions of which are the following *classes:*

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* The classification presented in this book follows that used in the new edition of *Dana's System of Mineralogy* now in the process of preparation.

1. Native elements.
2. Sulfides.
3. Sulfo salts
4. Oxides and hydroxides.
5. Halides.
6. Carbonates.
7. Borates, nitrates.
8. Phosphates, vanadates, arsenates.
9. Sulfates, chromates.
10. Tungstates, molybdates, uranates.
11. Silicates.

The above classes are subdivided into *families* on the basis of chemical types, and the family in turn may be further divided into *groups* which show a close crystallographic and structural similarity. A group is made up of *species*, which may form *series* with each other, and finally a species may have several *varieties*. In each of the classes the minerals with the highest ratio of metal to nonmetal are given first, followed by those containing progressively less metal. Such a relatively small number of minerals are described in this book that often only one member of a group or family is represented, and thus a rigorous adherence to division and subdivision is impractical.

NATIVE ELEMENTS

With the exception of the free gases of the atmosphere, only about twenty elements are found in the native state. These elements can be divided into: (1) metals; (2) semi-metals; (3) nonmetals. The native metals are gold, silver, copper, platinum, iron, mercury, lead, palladium, iridium, osmium, tantalum, and tin. Solid solutions of the elements as electrum (Au,Ag) and amalgam (Ag,Hg) are considered as native metals. The native semi-metals, arsenic, antimony, and bismuth, form a group by themselves since they all crystallize in rhombohedrons with closely agreeing angles. The important nonmetals are carbon, in the form of diamond and graphite, sulfur, selenium, and tellurium.

Native Metals

	Gold	Au
GOLD GROUP	Silver	Ag
	Copper	Cu
	Platinum	Pt
	Iron	Fe

Native Semi-Metals

ARSENIC GROUP	Arsenic	As
	Bismuth	Bi

Native Nonmetals

Sulfur	S
Diamond	C
Graphite	C

GOLD — Au

Crystallography. Isometric; hexoctahedral. Crystals are commonly octahedral, rarely showing the faces of the dodecahedron, cube, and trapezohedron {311} (Figs. 256–259). Often in arborescent crystal groups with crystals elongated in the direction of a 3-fold symmetry axis, or flattened parallel to an octahedron face. Crystals irregularly distorted, passing into filiform, reticulated, and dendritic shapes (Fig. 260). Seldom shows crystal forms, usually in irregular plates, scales, or masses.

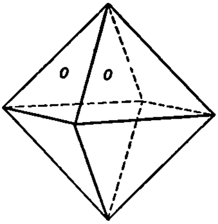


FIG. 256.

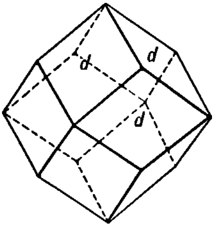


FIG. 257.

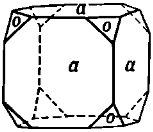


FIG. 258.

Crystal Forms of Gold.

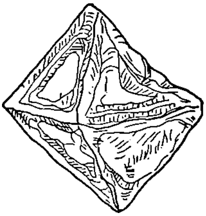


FIG. 259. Distorted Gold Octahedron.

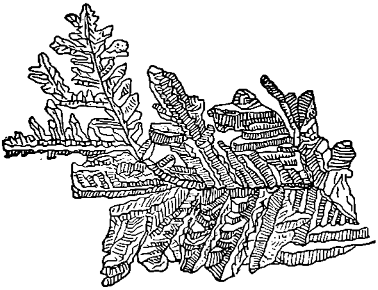


FIG. 260. Dendritic Gold.

Physical Properties. H. = $2\frac{1}{2}$–3. G. = 19.3 when pure. The presence of other metals decreases the specific gravity, which may be as low as 15. Very malleable and ductile. Opaque. Color various shades of yellow depending on the purity, becoming paler with the increase in the percentage of silver present.

Composition. Gold. Commonly alloyed with small amounts of silver, and may contain traces of copper and iron. Ordinarily native gold contains varying amounts of alloyed silver up to 16 per cent. California gold contains between 10 and 15 per cent of silver. The greater part of native gold is about 90 per cent " fine " or contains 10 per cent of other metals. Gold containing unusually high percentages of silver (20 to 40 per cent) is known as *electrum.*

Tests. Fuses easily at 3 (1,063° C.). Insoluble in ordinary acids but soluble in *aqua regia* (a mixture of hydrochloric and nitric acids).

Diagnostic Features. Gold is to be distinguished from certain yellow sulfides (particularly pyrite and chalcopyrite) and from yellow flakes of altered micas by its malleability, its insolubility in nitric acid, and its high specific gravity.

Occurrence. Although gold is a rare element, it occurs in nature widely distributed in small amounts. It is found most commonly in veins which bear a genetic relation to silicic types of igneous rocks. In places it has been found intimately associated with igneous rocks as in The Bushveld Igneous Complex in the Transvaal, South Africa. Most gold occurs as the native metal; tellurium and possibly selenium is the only element that is combined with it in nature.

The chief source of gold is the so-called hypothermal gold-quartz veins where, together with pyrite and other sulfides, gold was deposited from ascending mineral-bearing solutions. The gold is merely mechanically mixed with the sulfides and is not in any chemical combination. At and near the surface of the earth the gold-bearing sulfides are usually oxidized, thus setting free the gold and making its extraction easy. Such ores are called " free-milling " because their gold content can be recovered by amalgamation with mercury. Finely crushed ore is washed over copper plates coated with mercury. When sulfides are present in any quantity, not all the gold can be recovered by amalgamation, and either the cyanide or chlorination process must be used. In the cyanide process finely crushed ore is treated with a solution of potassium or sodium cyanide, forming a soluble cyanide. The gold is then recovered by precipitation with zinc or by electrolysis. The chlorination process renders the gold in a soluble form by treating the crushed and roasted ore with chlorine. In the majority of veins the gold is so finely divided and uniformly distributed that its presence in the ore cannot be detected with the eye. With the chemical processes of gold extraction ores carrying values as low as $1.00 per ton can be worked at a profit. It is interesting to note that, with the value of gold at $35 per troy ounce, such ore would contain about 0.0001 per cent gold by weight.

When gold-bearing veins are weathered, the gold liberated either remains behind in the soil mantle or is washed into the neighboring streams. In the former case, a residual concentration takes place, and in the latter, placer deposits form. Because of its high specific gravity, gold is mechanically separated from the lighter material of the sands and gravels of the stream bed. In this way a concentration takes place behind projecting irregularities and in cavities on the stream floor, and a gold placer is formed. The gold is found in round or flattened grains and nuggets. Very fine flakes of gold may be carried long distances by the streams. Placer gold can be recovered by panning the sands by hand and washing away all but the heavy concentrate from which the gold can be easily separated. Sluices are used to operate on a larger scale. The gold-bearing sand is washed through sluices where the gold collects behind cross-bars or riffles, and amalgamates with mercury placed behind the riffles for that purpose. Hydraulic mining is sometimes used to move great quantities of gravels through sluices. Most placer mining is today carried on with dredges, some of which are gigantic and can extract the gold from thousands of cubic yards of gravel a day. Some dredges can operate at a profit handling gravels which average no more than 10 cents in gold per cubic yard. Some alluvial gold deposits have been covered by lava flows and thus preserved as buried placers. Much of the placer gold of California has come from such deposits that now stand high on ridges between valleys owing to changes in elevation and rearrangement of the drainage.

The most important gold-producing states and territories of the United States, in the order of the amount of gold produced at present, are: California, Philippine Islands, South Dakota, Alaska, Colorado, Arizona, Nevada, Utah, and Montana. California has been the leading state in gold production since gold was discovered there in 1848. The most important gold-producing districts of California are those of the Mother Lode, a series of gold-quartz veins which lie along the western slope of the Sierra Nevada Mountains in Amador, Calaveras, Eldorado, Tuolumne, and Mariposa counties. Nearly one-half of California's gold comes from placer deposits worked mostly by dredging operations. Most of the gold mined in the Philippine Islands and in Alaska has come from placers. The largest single gold mine in the United States today is the Homestake Mine at Lead, South Dakota.

Nearly 40 per cent of the world's gold production comes from the Witwatersrand, " the Rand," near Johannesburg in the Transvaal, South Africa. The gold is scattered through a steeply dipping quartz conglomerate which extends for sixty miles in an east-west direction.

The gold production of the U.S.S.R. is great although no accurate figures are available. Most of it comes from placers in Siberia and from mines on the eastern slopes of the Ural Mountains. Other productive countries are: Australia, especially Kalgoorlie (largely tellurides), Bendigo, and Ballarat; Canada, notably the Porcupine District in eastern Ontario and the Klondike in Yukon Territory; Mexico; Japan; and India.

Use. The principal uses of gold are in coinage and jewelry. Only a small amount is used for dental purposes, gold leaf, and minor industrial uses.

SILVER — Ag

Crystallography. Isometric; hexoctahedral. Crystals commonly distorted and in branching, arborescent, or reticulated groups. Found usually in irregular masses, plates, and scales; in places as coarse or fine wire.

Physical Properties. **H.** = 2½–3. **G.** = 10.5 when pure, 10–12 when impure. Fracture hackly. Malleable and ductile. Luster metallic. Color and streak silver-white, often tarnished to brown or gray-black.

Composition. Silver, frequently containing alloyed mercury, copper, and gold, more rarely traces of platinum, antimony, bismuth. *Amalgam* is a solid solution of silver and mercury.

Tests. Fusible at 2 (960.5° C.) to bright globule. No oxide coating on charcoal. Soluble in nitric acid, giving on addition of hydrochloric acid a curdy white precipitate of silver chloride, which turns dark on exposure to light. Deposited from solution on a clean copper plate.

Diagnostic Features. *Silver can be told from similar appearing* minerals by its malleable nature, its color on a fresh surface, and its high specific gravity.

Occurrence. Native silver is widely distributed in small amounts, principally in the oxidized zone of ore deposits. The large deposits of native silver are probably the result of primary deposition of silver from hydrothermal solutions. There are three such types: native silver with sulfides and other silver minerals, with cobalt and nickel minerals, and with uraninite.

The mines at Kongsberg, Norway, worked for several hundred years, have produced magnificent specimens of crystallized wire silver. Other old and famous silver mines are at Freiberg and Schneeberg in Saxony. Native silver is also found in Bohemia, Alsace, Siberia, New South Wales at Broken Hill, and in Mexico.

In the United States native silver has been found with the native copper in the Lake Superior copper mines; in Montana at Butte and at the Elkhorn mine, Jefferson County; in Idaho at the Poorman mine, Silver City district; in Colorado at Aspen; and in Arizona at the Silver King mine. In Canada native silver has been found abundantly at Cobalt, Ontario; one slab weighing 1,640 pounds was taken from there; in the Thunder Bay District on the north shore of Lake Superior, at Silver Islet; associated with uraninite at Great Bear Lake, Northwest Territories.

Use. An ore of silver, although most of the world's supply comes from other minerals. Silver is used for ornamental purposes, for coinage, and plating. It is usually alloyed with copper. The standard silver coin in the United States contains one part of copper to nine parts of silver.

COPPER — Cu

Crystallography. Isometric; hexoctahedral. Tetrahexahedron faces common (Fig. 261), also the cube, dodecahedron, and octahedron. Crystals usually distorted and in branching and arborescent groups (Fig. 262 and Plate VI, Fig. 1). Usually in irregular masses, plates, and scales. In twisted and wirelike forms.

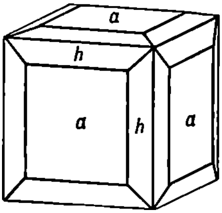


FIG. 261. Copper Crystal.

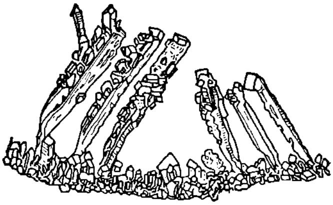


FIG. 262. Dendritic Copper.

Physical Properties. **H.** = $2\frac{1}{2}$–3. **G.** = 8.9. Highly ductile and malleable. Fracture hackly. Color copper-red on fresh surface, usually dark with dull luster because of tarnish.

Composition. Copper, often containing small amounts of silver, bismuth, mercury, arsenic, antimony.

Tests. Fuses at 3 (1,083° C.) to a globule, which becomes covered with an oxide coating on cooling. Dissolves readily in nitric acid, and the solution is colored a deep blue on addition of an excess of ammonium hydroxide.

Diagnostic Features. Native copper can be recognized by its red color on fresh surfaces, its hackly fracture, high specific gravity, and malleability.

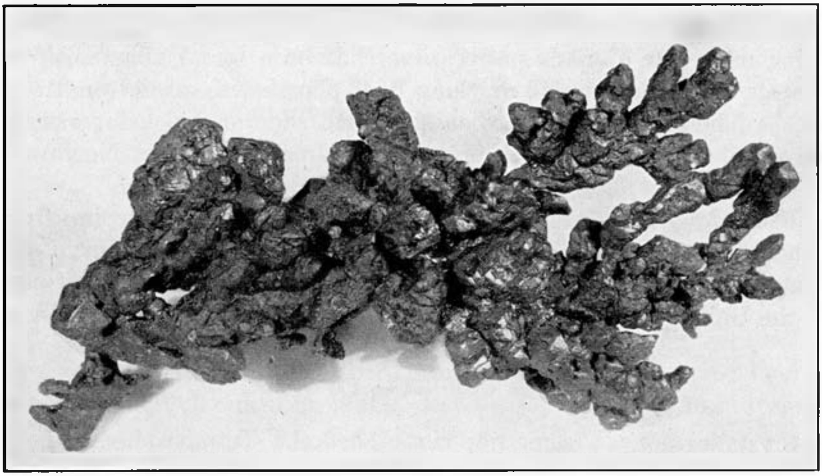


FIG. 1. Native Copper, Keweenaw Peninsula, Michigan.

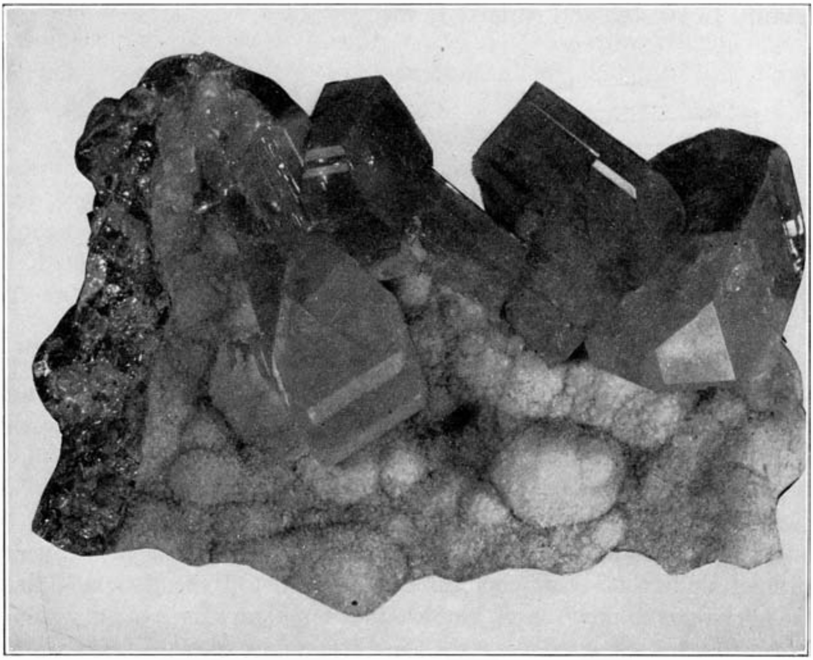


FIG. 2. Sulfur Crystals, Cianciana, Sicily.

PLATE VI

Occurrence. Native copper is widely distributed in copper veins, but usually in small amounts. It is commonly found in the oxidized zones of copper deposits associated with cuprite, malachite, and azurite.

The most notable deposit of native copper known in the world is on Keweenaw Peninsula in northern Michigan, on the southern shore of Lake Superior. The region is occupied by a series of igneous flows of trap rock interbedded with conglomerates. The whole series dips toward the north. The copper is found in veins intersecting this rock series, in the amygdaloidal belts at the top of the various trap flows, and as a cementing material in the conglomerate. This last type has furnished the most important ore deposits, some of which have been worked for considerably over a mile in vertical depth. Not only does the copper act as a cement to bind the conglomerate together, but it has often penetrated the boulders of the rock to a depth of a foot or more. It is associated with such minerals as epidote, datolite, calcite, and various zeolites. The mines were worked superficially by the Indians and have been actively developed since the middle of the nineteenth century. Most of the copper of the district occurs in very small irregular specks, but notable large masses have been found; one weighing 420 tons was discovered in 1857.

Sporadic occurrences of copper similar to that of the Lake Superior District have been found in the sandstone areas of the eastern United States, notably in New Jersey, and in the glacial drift overlying a similar area in Connecticut. In Bolivia at Corocoro, southwest of La Paz, there is a noted occurrence in sandstone. Native copper occurs in small amounts associated with the oxidized copper ores of Arizona, New Mexico, and northern Mexico.

Use. A minor ore of copper. Copper sulfides are today the principal ores of the metal. The greatest use of copper is for electrical purposes, mostly as wire. It is also extensively used in alloys, such as brass (copper and zinc), bronze (copper and tin with some zinc), and German silver (copper, zinc, and nickel). These and many other minor uses make copper second only to iron as a metal essential to modern civilization.

PLATINUM — Pt

Crystallography. Isometric; hexoctahedral. Cubic crystals are rare and commonly distorted. Usually found in small grains and scales. In places in irregular masses and nuggets of larger size.

Physical Properties. **H.** = 4–4½. (Unusually high for a metal). **G.** = 21.45 when pure; 14–19 when native. Opaque. Malleable and ductile. Color steel-gray, with bright luster. Magnetic when rich in iron.

Composition. Platinum, usually alloyed with several per cent of iron and with smaller amounts of iridium, osmium, rhodium, palladium; also copper, gold, nickel.

Tests. Infusible. Unattacked by ordinary reagents; soluble only in hot aqua regia, a mixture of hydrochloric and nitric acids.

Diagnostic Features. Determined by its high specific gravity, malleability, infusibility, and insolubility.

Occurrence. Platinum is a rare metal which occurs almost exclusively in the native state; only one rare natural compound, *sperrylite*, $PtAs_2$, is known. Most platinum can be traced to ultrabasic rocks, especially dunites, as its source. When *in situ*, it is usually associated with olivine, chromite, pyroxene, and magnetite. The most productive deposits are placers which are usually close to the platinum-bearing igneous rock.

Platinum was first discovered in the United States of Colombia, South America. It was taken to Europe in 1735 where it received the name *platina* from the word *plata* (Spanish for silver) because of its resemblance to silver. A small amount of platinum is still produced in Colombia from placers in two districts near the Pacific Coast. In 1822 platinum was discovered in placers on the Upper Tura River on the eastern slope of the Ural Mountains, U.S.S.R. Since that time most of the world's supply of platinum has come from placers of that district which centers around the town of Nizhne Tagil. The placers are now becoming exhausted, and an effort is at present being made to mine the platinum in place. Platinum in smaller amounts has come from Borneo, New South Wales, New Zealand, Brazil, Peru, Madagascar, and South Africa.

In the United States small amounts of platinum have been recovered from the gold-bearing sands of North Carolina and from black sand placers in California and Oregon. Alaska also produces some platinum. In Canada platinum is found in gold placers in several localities, but in amounts that are insignificant compared with the relatively large quantity recovered from the nickel-copper ores of Sudbury, Ontario. Until 1934 the Soviet Union led the world in platinum production; since then Canada has been the principal producer because of the output of the Sudbury district.

Use. The uses of platinum depend chiefly upon its refractory nature and superior hardness. (See page 400.) It is used for chemical apparatus, electrical equipment, and jewelry, and as a catalytic agent in the manufacture of sulfuric acid; it is also used in dentistry, surgical instruments, and pyrometry.

Similar Species. *Iridium; iridosmine,* an alloy of iridium and osmium; and *palladium* are rare minerals of the platinum group associated with platinum.

Iron — Fe

Crystallography. Isometric; hexoctahedral. Crystals rare. Terrestrial: in blebs and large masses; meteoric: in plates and lamellar masses, frequently shows an octahedral pattern on etching polished surface; artificial: in octahedral, rarely cubic crystals and dendritic growths.

Physical Properties. Cleavage cubic {001} poor. **H.** = 4½. **G.** = 7.3–7.9. Fracture hackly. Malleable. Opaque. Luster metallic. Color steel-gray to black. Strongly magnetic.

Composition. Iron, always with some nickel and frequently small amounts of cobalt, copper, manganese, sulfur, carbon. The mineral *nickel-iron* contains about 76 per cent nickel.

Tests. Infusible. Soluble in hydrochloric acid. Red flocculent ferric hydroxide precipitated from acid solution by ammonium hydroxide.

Diagnostic Features. Iron can be recognized by its strong magnetism, its malleability, and the oxide coating usually on its surface.

Occurrence. Occurs sparingly as terrestrial iron and in meteorites. Terrestrial iron is regarded as a primary magmatic constituent or a secondary product formed by the reduction of iron compounds by assimilated carbonaceous material. The most important locality is on the west coast of Greenland where fragments ranging from small grains to masses of many tons are included in basalts. It was known in 1819 that the natives used it, but it was not until 1870 that the source became known. Terrestrial iron has been noted in a few other localities with a similar association.

Meteoric iron with a nickel content varying from 5 to 15 per cent makes up nearly the whole mass of iron meteorites and shows a hexagonal structure on a polished and etched surface. Iron is found disseminated through stony meteorites in small grains. Meteorites are usually recognized by their fused and pitted surface and by a coating of ferric oxide.

Arsenic — As

Crystallography. Rhombohedral; scalenohedral. Crystals rare. Usually granular massive, reniform, and stalactitic.

Physical Properties. Perfect basal {0001} cleavage. **H.** = 3½. **G.** = 5.7. Luster nearly metallic on fresh surface. Color tin-white on fresh fracture, tarnishes on exposure to dark gray. Gray streak.

Composition. Arsenic, often with antimony and traces of iron, silver, gold, bismuth.

Tests. Volatile without fusion. Before blowpipe on charcoal gives white volatile coating of arsenious oxide and odor of garlic. In the open tube gives volatile crystalline deposit of arsenious oxide. In the closed tube gives arsenic mirror.

Occurrence. Arsenic is a comparatively rare species found in veins in crystalline rocks associated with silver, cobalt, or nickel ores. Found in the silver mines of Freiberg, in Saxony; at Andreasberg in the Harz Mountains; in Bohemia; Rumania; Alsace. Found sparingly in the United States.

Name. The name arsenic is derived from a Greek word meaning *masculine*, a term first applied to the sulfide of arsenic on account of its potent properties.

Use. Very minor ore of arsenic. (See under arsenopyrite, page 173.)

Bismuth — Bi

Crystallography. Rhombohedral; scalenohedral. Distinct crystals are rare. Usually laminated and granular; may be reticulated or arborescent. Artificial crystals pseudocubic $\{10\bar{1}1\}$.

Physical Properties. Perfect basal {0001} cleavage. **H.** = 2–2½. **G.** = 9.8. Sectile. Brittle. Luster metallic. Color silver-white with a decided reddish tone. Streak silver-white, shining.

Composition. Bismuth. Small amounts of arsenic, sulfur, tellurium, antimony may be present.

Tests. Fusible at 1 (271° C.). Before blowpipe on charcoal gives metallic globule and yellow to white coating of bismuth oxide. The globule is somewhat malleable but cannot be hammered into as thin a sheet as lead. Mixed with potassium iodide and sulfur and heated on charcoal gives a brilliant yellow to red coating and under same conditions on a plaster tablet gives a chocolate-brown sublimate with underlying red.

Diagnostic Features. Bismuth is recognized chiefly by its laminated nature, its reddish silver color, its perfect cleavage, and its sectility.

Occurrence. Bismuth is a comparatively rare mineral, occurring usually in connection with ores of silver, cobalt, nickel, lead, and tin. Found in the silver veins of Saxony; in Norway and Sweden; Cornwall, England. Important deposits are found in Australia, but the most productive deposits are in Bolivia. It is found in small veins associated with silver and cobalt minerals at Cobalt, Ontario, Canada. Found only sparingly in the United States.

Use. An ore of bismuth. (See page 391.)

Name. Etymology in dispute; possibly from the Greek meaning *lead white.*

SULFUR — S

Crystallography. Orthorhombic; dipyramidal. Pyramidal in habit (Fig. 263), often with two dipyramids, brachydome and base in combination (Fig. 264). A group of sulfur crystals is shown in Plate VI, Fig. 2. Commonly in irregular masses imperfectly crystallized. Also massive reniform, stalactitic, as incrustations, earthy.

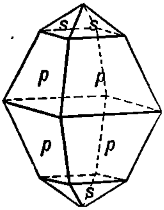


FIG. 263.

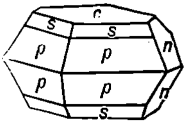


FIG. 264.

Sulfur Crystals.

There are three polymorphic forms of sulfur. The ordinary natural sulfur is orthorhombic; the other two are monoclinic and very rare as minerals.

Physical Properties. Fracture conchoidal to uneven. Brittle. **H.** = $1\frac{1}{2}$–$2\frac{1}{2}$. **G.** = 2.05–2.09. Luster resinous. Color sulfur-yellow, varying with impurities to yellow shades of green, gray, and red. Transparent to translucent. Poor conductor of heat. When a crystal is held in the hand close to the ear it will be heard to crack. This is due to the expansion of the surface layers because of the heat from the hand, while the interior, on account of the slow heat conductivity, is unaffected. Crystals of sulfur should, therefore, be handled with care.

Composition. Sulfur; often impure with clay or asphalt.

Tests. Fusible at 1 (112.8° C.) and burns with a blue flame to sulfur dioxide. Sublimates in closed tube, giving a red to dark yellow liquid when hot, yellow solid when cold.

Diagnostic Features. Sulfur can be told by its yellow color and the ease with which it burns. The absence of a good cleavage distinguishes it from orpiment.

Occurrence. Sulfur often occurs at or near the crater rims of active or extinct volcanoes where it has been derived from the gases given off in fumaroles. These may furnish sulfur as a direct sublimation product or by the incomplete oxidation of hydrogen sulfide gas. It is also formed by the reduction of sulfates, especially gypsum. It may be deposited from sulfur-bearing waters by the action of the so-called sulfur bacteria. Sulfur may be found in veins associated with metallic sulfides and formed by the oxidation of the sulfides. It is most commonly found in the Tertiary sedimentary rocks and most frequently associated with gypsum and limestone; often in clay rocks; frequently with bituminous deposits. The large deposits near Girgenti, Sicily, are noteworthy for the fine crystals associated with celestite, gypsum, calcite, aragonite. Sulfur is also found associated with the volcanoes of Mexico, Hawaii, Chile, and Japan.

In the United States the most productive deposits are in Texas and Louisiana. Here the sulfur is associated with anhydrite, gypsum, and calcite in the cap rock of salt domes. At present over 80 per cent of the sulfur production of the United States is from Texas. There are several producing localities, but the largest output is from the Boling Dome. In Louisiana the chief production is at Grand Ecaille, Plaquemines Parish. There are many other workable deposits of sulfur associated with salt domes. Sulfur is obtained from these deposits by what is known as the Frasch method. Superheated water is pumped down to the sulfur horizon, where it melts the sulfur; compressed air then forces it to the surface. Sulfur also occurs in Wyoming, Utah, and California.

Use. Used in the manufacture of sulfuric acid, matches, gunpowder, fireworks, insecticides, rubber, in medicine, and in the preparation of wood pulp for paper manufacture.

DIAMOND — C

Crystallography. Isometric; hextetrahedral. Crystals are usually octahedral in appearance with $\{111\}$ and $\{1\bar{1}1\}$ equally well developed. Flattened and elongated crystals are common. Curved faces, especially of the positive and negative hextetrahedron (Fig. 266), and pitted faces (Fig. 265) are frequently observed. Cube and dodecahedron faces are rare. Rarely massive. Spinel twins, usually flattened parallel to the twin plane, are common. *Bort*, a variety of diamond, has rounded forms and rough exterior resulting from a radial or cryptocrystalline aggregate. The term is also applied to badly colored or flawed diamonds without gem value.

Physical Properties. Perfect $\{111\}$ and $\{1\bar{1}1\}$ cleavage. **H.** = 10 (hardest known substance). **G.** = 3.5. Luster adamantine; uncut crystals have a characteristic greasy appearance. The very high refractive index, 2.42, and the strong dispersion of light account for the brilliancy and " fire " of the cut diamond. Usually pale yellow or colorless; also pale shades of red, orange, green, blue, and brown. Deeper shades are rare. *Carbonado* or *carbon* is black or grayish black bort. It is noncleavable, opaque, and less brittle than crystals.

Composition. Pure carbon.

Tests. Insoluble in acids and alkalis. At a high temperature in oxygen will burn to CO_2 gas, leaving no ash.

Diagnostic Features. Diamond is distinguished from similar appearing minerals by its great hardness, adamantine luster, and cleavage.

Occurrence. Diamonds have been discovered in many different localities but in only a few in notable amount. Most commonly the diamond is found in the sands and gravels of stream beds, where it has been preserved because of its inert chemical nature, its great hardness, and its fairly high specific gravity. In South Africa and more recently in Arkansas, diamonds have been found in a certain kind of peridotite known as *kimberlite*. The three countries which up to the present have furnished practically the entire world's output of diamonds are India, Brazil, and South Africa. The important diamond fields of India were located in the eastern and southern portions of the peninsula, but most of the famous mines are now abandoned. Only about 100 carats a year are now produced from the gravels which during a period of 2,000 years produced over 20,000,000 carats. Until the eighteenth century India remained the only source of diamonds, and many of the famous stones were found there.

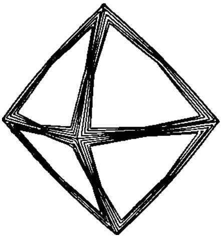


Fig. 265.

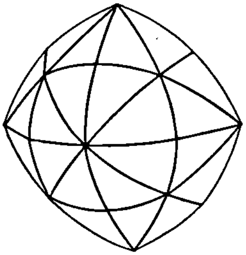


Fig. 266.

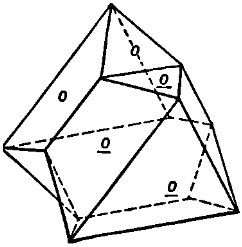


Fig. 267.

Diamond Crystals.

Diamonds were discovered in Brazil in the first half of the eighteenth century, and have since been mined there. At present, however, the production is comparatively small. Diamonds are found in the stream gravels in several different districts, the two most important being located in the provinces of Minas Geraes and Bahia. The city of Diamantina, Minas Geraes, is situated in the center of the most productive field, the diamonds being found chiefly in the gravels of the Rio Jequitinhonha and Rio Doce. Extensive upland deposits of diamond-bearing gravels and clays are also worked. The black carbonado comes only from Bahia.

About 95 per cent of the world's output of diamonds comes at present from South Africa. The first African diamonds were discovered in 1867 in the gravels of the Vaal River. In 1871 diamonds were discovered imbedded in the rock of several volcanic necks or pipes located near the present town of Kimberley in Griqualand-West, south of the Vaal River, near the boundary of the Orange Free State. The diamonds in this district were first found in the soil resulting from the disintegration of the underlying altered peridotite. This soil was colored yellow by iron oxides and was known as "yellow ground." The principal mines near the town of Kimberley are the Kimberley, Du Toitspan, De Beers, and Bultfontein. The Kimberley mine was developed to a depth of 3,500 feet before it was abandoned. The mines were originally worked as open pits, but as they increased in depth, underground methods were adopted. The early method of treatment was to crush the blue ground into coarse fragments and spread it out on platforms to disintegrate gradually under atmospheric influences. The present method is to crush the rock fine enough to permit immediate concentration. The diamonds are finally separated on shaking tables that have been coated with grease, to which the diamonds adhere, while the rest of the material is washed away.

Diamonds have also been discovered in beach sands near Lüderitz Bay, Southwest Africa. To the south in Little Namaqualand on the desert coast of the northwest part of Cape province, terrace deposits containing high-quality stones were discovered in 1927 but as yet are undeveloped. Alluvial diamonds have also been found in the Belgian Congo abundantly, French Angola, the Gold Coast, Tanganyika, and French Equatorial Africa.

Diamonds have been found sparingly in various parts of the United States. Small stones have occasionally been discovered in the stream sands along the eastern slope of the Appalachian Mountains from Virginia south to Georgia. Diamonds have also been reported from the gold sands of northern California and southern Oregon. Sporadic occurrences of diamonds have been noted in the glacial drift in Wisconsin, Michigan, and Ohio. In 1906 the first diamond was found at a new locality situated near Murfreesboro, Pike County, Arkansas. The stones are found here not only in the detrital soil but also imbedded in the underlying peridotite rock in a manner quite similar to that of the

South African occurrence. The Arkansas locality has yielded about 40,000 stones but is at present unproductive.

Use. *In industry.* Fragments of diamond crystals are used to cut glass. The fine powder is employed in grinding and polishing diamonds and other gem stones. Wheels are impregnated with diamond powder for cutting rocks and other hard materials. Steel bits are set with diamonds, especially the cryptocrystalline variety, carbonado, to make diamond drills used in exploratory mining work. The diamond is also used in wire drawing and in tools for the truing of grinding wheels.

In gems. The diamond is the most important of the gem stones, and only in modern times has it been put to other uses. Its value depends upon its hardness, its brilliancy, which is due to its high index of refraction, and to its " fire," which is due to its strong dispersion of light into the prismatic colors. In general the most valuable are those flawless stones which are colorless or possess a " blue-white " color. A faint straw-yellow color, which diamond often shows, detracts much from its value. Deep shades of yellow, red, green, or blue are greatly prized, and fine stones of these colors bring very high prices.

The value of a cut diamond depends upon its color and purity, upon the skill with which it has been cut, and upon its size. A 1-carat stone weighs 200 milligrams, and if cut in the form of a brilliant would be 6.25 millimeters in diameter and 4 millimeters in depth. A 2-carat stone of the same quality would have a value three or four times as great.

Famous Stones. The older famous diamonds include the following: the *Kohinoor,* weighing 106 carats, one of the crown jewels of Great Britain; the *Regent* or *Pitt,* weighing 137 carats, belonging to France; the *Orloff,* which is mounted in the Russian imperial scepter, weighing 199 carats; the *Florentine* yellow diamond, which weighs 137 carats; the *Star of the South,* weighing 129 carats.

Large stones found more recently in South Africa include the following: the *Victoria* or *Imperial,* which weighed 468 carats when found, and 236 when cut. It was later recut, however, its present weight being 190 carats. The *Stewart* weighed before and after cutting 296 and 123 carats, respectively. The *Tiffany* diamond, which is of a brilliant yellow color, weighed 287 carats before and 125 carats after cutting. The *Green Dresden* diamond weighs 50 carats, and the blue *Hope* diamond 45. The *Colenso* diamond, presented to the British Museum in 1887 by John Ruskin, weighs 133 carats. The Excelsior diamond, found at Jagersfontein in 1903, weighed 650 carats, is now known as the *Jubilee,* and weighs 245 carats. The *Cullinan* or *Star of Africa* diamond found at the Premier Mine, Transvaal, was the largest stone ever found, weighing 3,106 carats or about 22 ounces, and measured 4 by 2½ by 2 inches. This stone was presented to King Edward VII by the Transvaal Government and has been cut into nine large stones, and into ninety-six smaller brilliants, the largest two weighing 530 and 317 carats, respectively. The largest stone found in recent years, known as the Jonker diamond, was discovered by Jacobus Jonker in 1934 in stream gravels near the Premier Mine. It weighed 726.25 carats when found and has since been cut. The most recent find of a large stone was the discovery of the *Vargas* diamond in Brazil. It weighed about ½ carat more than the Jonker diamond.

Name. The name diamond is a corruption of the Greek word *adamas*, meaning *invincible.*

GRAPHITE — C

Plumbago. Black Lead

Crystallography. Hexagonal; dipyramidal. In tabular crystals of hexagonal outline with prominent basal plane. Distinct faces of other forms very rare. Triangular markings on the base are the result of gliding along an undetermined second-order pyramid. Usually in foliated or scaly masses, but may be radiated or granular.

Physical Properties. Perfect basal {0001} cleavage. **H.** = 1–2 (readily marks paper and soils the fingers). **G.** = 2.3. Luster metallic, sometimes dull earthy. Color black to steel-gray. Black streak. Greasy feel. Folia flexible but not elastic.

Composition. Carbon. Some graphite impure with iron oxide, clay, or other minerals.

Tests. Infusible, but may burn to CO_2 at a high temperature. Unattacked by acids.

Diagnostic Features. Graphite is recognized by its color, foliated nature, and softness. Distinguished from molybdenite by its black color (molybdenite has a blue tone), and the lack of chemical tests. On glazed porcelain graphite gives a black streak, molybdenite a greenish streak.

Occurrence. Graphite most commonly occurs in metamorphic rocks such as crystalline limestones, schists, and gneisses. It may be found as large crystalline plates inclosed in the rock or disseminated in small flakes in sufficient amount to form a considerable proportion of the rock. In these cases, it has probably been derived from carbon material of organic origin which has been converted into graphite during the metamorphism of the rock. Instances are known in which coal beds, under the influence of strong metamorphic action, such as the intrusion into them of an igneous rock, have in a greater or less degree been converted into graphite. Examples of such an occurrence are to be found in the graphite coals of Rhode Island, and in the coal fields of Sonora, Mexico. Graphite also occurs in fissure veins associated with other minerals in the deposits at Ticonderoga, New York. Here the veins traverse a gneiss and, in addition to graphite, contain quartz, biotite, orthoclase, tourmaline, apatite, pyrite, and sphene. The graphite may have been formed in these veins from hydrocarbons introduced into them during the metamorphism of the region and derived from the surrounding carbon-bearing rocks. Graphite occurs occasionally as an original constituent of igneous rocks as in the basalts of Ovifak, Greenland, in a nepheline syenite in India, in a granite pegmatite in Maine. It is also found in some meteorites.

The most productive deposits of graphite at present are on the island of Ceylon, where coarsely foliated masses are found in veins in gneisses interbedded with limestones. It occurs in large amounts in various localities in Austria, Italy, India, Mexico, etc. Graphite is found in quantity with schistose rocks in Madagascar. The chief deposits in the United States are in the Adirondack region of New York, in Essex, Warren, and Washington Counties, particularly at Ticonderoga.

Artificial graphite is manufactured on a large scale in the electrical furnaces at Niagara Falls. Anthracite coal or petroleum coke with a small amount of evenly distributed ash is subjected to the intense heat of the electrical furnace and converted into graphite. The output of artificial graphite is considerably in excess of that of the natural mineral.

Use. Used in the manufacture of refractory crucibles for the steel, brass, and bronze industries. Most of the graphite used in this way is imported from Ceylon. Used widely, when mixed with oil, as a lubricant. Mixed with fine clay, it forms the " lead " of pencils. Much of the graphite used in the United States for this purpose comes from Sonora, Mexico. Used in the manufacture of a protective paint for structural iron and steel works. Used in the coating of foundry facings, for electrodes, stove polishes, in electrotyping, etc.

Name. Derived from the Greek word meaning *to write,* in allusion to its use in pencils.

SULFIDES

The sulfides form an important class of minerals which includes the majority of the ore minerals. With them are classed the similar but rarer selenides, tellurides, arsenides, and antimonides.

Sulfides

Argentite	Ag_2S	Cinnabar	HgS
Chalcocite	Cu_2S	Realgar	AsS
Bornite	Cu_5FeS_4	Orpiment	As_2S_3
Galena	PbS	Stibnite	Sb_2S_3
Sphalerite	ZnS	Bismuthinite	Bi_2S_3
Chalcopyrite	$CuFeS_2$	Pyrite	FeS_2
Stannite	Cu_2FeSnS_4	Cobaltite	$CoAsS$
Greenockite	CdS	Marcasite	FeS_2
Pyrrhotite	$Fe_{1-x}S$	Arsenopyrite	$FeAsS$
Niccolite	$NiAs$	Molybdenite	MoS_2
Millerite	NiS	Calaverite	$AuTe_2$
Pentlandite	$(Fe,Ni)S$	Sylvanite	$(Au,Ag)Te_2$
Covellite	CuS	Smaltite	$(Co,Ni)As_2$

Argentite — Ag_2S

Silver Glance

Crystallography. Isometric; hexoctahedral. Crystals most commonly show the cube, octahedron, and dodecahedron, but are frequently distorted and arranged in branching or reticulated groups. Most commonly massive, or as a coating.

Physical Properties. **H.** = 2–2½. **G.** = 7.3. Very sectile; can be cut with a knife like lead. Luster metallic. Color and streak blackish lead-gray. Streak shining. Opaque. Bright on fresh surface but on exposure becomes dull black, owing to the formation of an earthy sulfide.

Composition. Silver sulfide, Ag_2S. Ag = 87.1 per cent, S = 12.9 per cent.

Tests. Fusible at 1½ with intumescence. When fused on charcoal in the oxidizing flame gives off odor of sulfur dioxide and yields a globule of metallic silver.

Diagnostic Features. Argentite can be distinguished by its color, sectility, and high specific gravity.

Occurrence. Argentite is an important primary silver mineral found in veins associated with native silver, the ruby silvers, polybasite, stephanite, galena, and sphalerite. It may also be of secondary origin.

It is found in microscopic inclusions in so-called argentiferous galena. Argentite is an important ore in the silver mines of Guanajuato and elsewhere in Mexico; in Peru, Chile, and Bolivia. Important European localities for its occurrence are Freiberg in Saxony, Joachimsthal in Bohemia, Schemnitz and Kremnitz in Czechoslovakia, Kongsberg in Norway. In the United States it has been an important ore mineral in Nevada, notably at the Comstock Lode and at Tonopah. It is also found in the silver districts of Colorado, and in Montana at Butte associated with copper ores.

Use. An important ore of silver.

Name. The name argentite comes from the Latin *argentum*, meaning silver.

CHALCOCITE — Cu_2S

Copper Glance

Crystallography. Orthorhombic; dipyramidal (below 91° C. orthorhombic; above 91° C. isometric). Crystals very rare, usually small and tabular with hexagonal outline; striated parallel to the brachy-axis. (Figs. 268 and 269.) Commonly fine grained and massive.

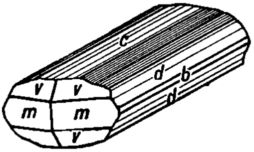


FIG. 268.

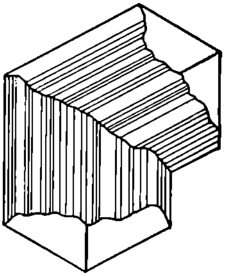


FIG. 269.

Chalcocite.

Physical Properties. Fracture conchoidal. **H.** = $2\frac{1}{2}$–3. **G.** = 5.5–5.8. Luster metallic. Imperfectly sectile. Color shining lead-gray, tarnishing on exposure to dull black. Streak grayish black.

Composition. Cuprous sulfide, Cu_2S. Cu = 79.8 per cent, S = 20.2 per cent.

Tests. Fusible at 2–$2\frac{1}{2}$. Heated in the open tube on charcoal gives odor of sulfur dioxide. Roasted mineral, moistened with hydrochloric acid, gives azure-blue flame. Easily reduced to metallic copper on charcoal.

Diagnostic Features. Chalcocite is distinguished by its lead-gray color and sectility.

Occurrence. Chalcocite is one of the most important copper-ore minerals. It occurs principally as a supergene mineral in enriched zones of sulfide deposits. The greatest copper mines in the United States today work what is called " porphyry copper " ore. In these deposits primary copper minerals disseminated through the rock, usually a porphyry, have been altered to chalcocite and thus enriched to form a workable ore body. The amount of copper in such deposits is small, rarely greater than 2 or 3 per cent. Chalcocite also occurs with bornite and other hypogene minerals in sulfide veins.

Fine crystals have been found at Cornwall, England, and at Bristol, Connecticut. Found as an ore at Monte Catini, Tuscany; Tsumeb, Southwest Africa; French Congo; Mexico; Peru; Chile. Found in large amounts in many mining districts in western United States such as Butte, Montana; Miami, Morenci, and Clifton, Arizona; Bingham, Utah; Ely, Nevada. At Kennecott in the Copper River District, Alaska.

Use. An important copper ore.

Similar Species. *Stromeyerite,* $(Ag,Cu)_2S$, is a steel-gray mineral found in copper-silver veins.

BORNITE — Cu_5FeS_4

Purple Copper Ore. Peacock Ore

Crystallography. Isometric; hexoctahedral. Rarely in rough cubic and less commonly in dodecahedral and octahedral crystals. Usually massive.

Physical Properties. **H.** = 3. **G.** = 5.06–5.08. Luster metallic. Color brownish bronze on fresh fracture but quickly tarnishing on exposure to variegated purple and blue and finally to almost black. Streak grayish black.

Composition. Copper iron sulfide, Cu_5FeS_4. Cu = 63.3 per cent, Fe = 11.2 per cent, S = 25.5 per cent. Microscopic admixed blebs of other minerals cause the composition of what appears to be bornite to vary considerably, but analyses of pure material agree with the above formula.

Tests. Fusible at $2\frac{1}{2}$. Gives odor of sulfur dioxide on charcoal. Yields only a very little sulfur in the closed tube. Becomes magnetic in the reducing flame. If, after roasting, it is moistened with hydrochloric acid and heated, it gives an azure-blue flame (copper). Easily soluble in nitric acid with separation of sulfur; solution neutralized with ammonia gives red-brown precipitate of ferric hydroxide and blue color (copper) to filtrate.

Diagnostic Features. Bornite is distinguished by its characteristic bronze color on the fresh fracture and the purple tarnish.

Alteration. Bornite alters readily to chalcocite and covellite.

Occurrence. Bornite is an important and widely occurring copper ore usually found associated with other copper minerals in hypogene deposits. It is much less frequently found as a secondary mineral, formed in the upper, enriched zone of copper veins through the action of descending copper-bearing solutions upon chalcopyrite. It is found disseminated in basic rocks, in contact metamorphic deposits, and in pegmatites. Bornite frequently occurs in intimate mixtures with chalcopyrite and chalcocite.

Good crystals of bornite are found associated with crystals of chalcocite at Bristol, Connecticut, and at Cornwall, England. Found in large masses in Chile, Peru, Bolivia, and Mexico. In the United States it is found at Magma Mine, Pioneer, Arizona; Butte, Montana; Engels Mine, Plumas County, California; Halifax County, Virginia; Superior, Arizona.

Use. An important ore of copper.

Name. Bornite was named after the German mineralogist, von Born (1742–1791).

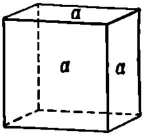


Fig. 270.

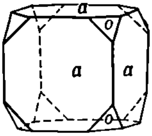


Fig. 271.

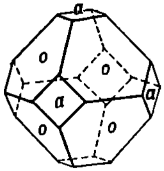


Fig. 272.

Galena.

GALENA — PbS

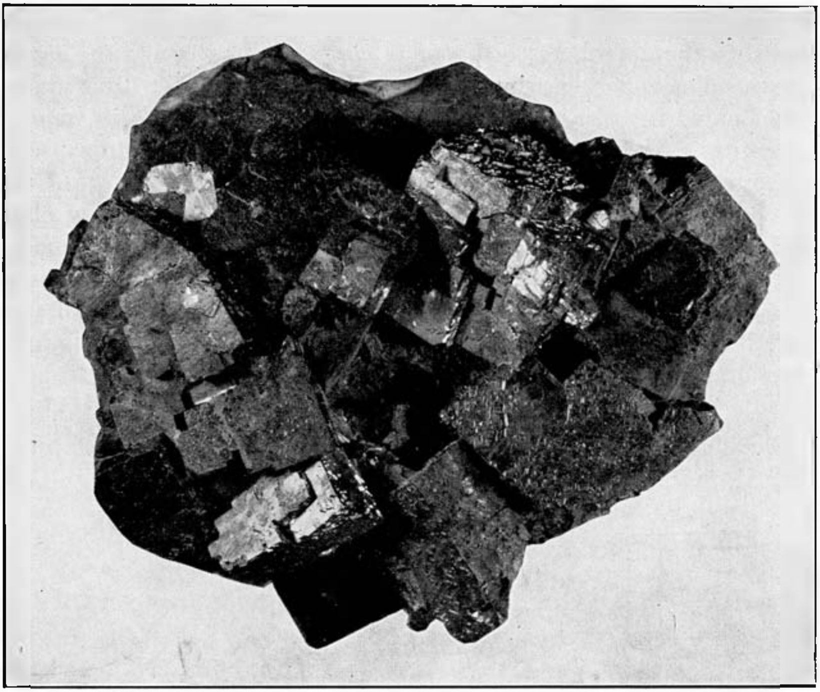
Galenite

Crystallography. Isometric; hexoctahedral. The most common form is the cube, Fig. 270. The octahedron sometimes is present as truncations to the cube (Figs. 271, 272). Dodecahedron and trisoctahedron rare. A group of galena crystals is shown in Plate VII.

Physical Properties. Perfect cubic {100} cleavage. **H.** = $2\frac{1}{2}$. **G.** = 7.4–7.6. Luster bright metallic. Color and streak lead-gray.

Composition. Lead sulfide, PbS. Pb = 86.6 per cent, S = 13.4 per cent. Analyses almost always show the presence of silver. Galena may also contain small amounts of selenium, zinc, cadmium, antimony, bismuth, and copper.

Tests. Fusible at 2. Reduced on charcoal to lead globule with formation of yellow to white coating of lead oxide. When heated rapidly in the oxidizing flame the coating is heavier and consists chiefly of a white volatile combination of oxides of lead and sulfur, which resembles the antimony oxide coating. Odor of sulfur dioxide when roasted on charcoal. When treated with strong nitric acid is oxidized to white lead sulfate.



Galena Crystals, Joplin, Missouri.

PLATE VII

Diagnostic Features. Galena can be easily recognized by its good cleavage, high specific gravity, softness, and black streak.

Alteration. By oxidation galena is converted into the sulfate anglesite, and the carbonate cerussite.

Occurrence. Galena is a very common metallic sulfide, found in veins associated with sphalerite, pyrite, marcasite, chalcopyrite, cerussite, anglesite, dolomite, calcite, quartz, barite, and fluorite. The veins are commonly in igneous rocks or show a close connection with such rocks. In such deposits galena is frequently found with silver minerals and often contains that metal itself and so becomes an important silver ore. A large part of the supply of lead comes as a secondary product from ores mined chiefly for their silver. A second type of galena deposit is associated with limestones, either as veins, open space fillings, or replacement deposits. The replacement deposits in limestone are commonly accompanied by a dolomitization of the rock and may have no apparent association with igneous rocks. Galena is also found in contact metamorphic deposits.

The most famous foreign localities are, Freiberg, Saxony; the Harz Mountains; Westphalia and Nassau; Přibram, Bohemia; Cornwall, Derbyshire, and Cumberland, England; Broken Hill, Australia.

In the United States there are many lead-producing districts; only the most important are mentioned here. In southeastern Missouri the ore occurs in the form of beds with galena disseminated through the limestone. In the Tri-State district of Missouri, Kansas, and Oklahoma centering around Joplin, Missouri, the galena is associated with zinc ores, and is found in irregular veins and pockets in limestone and chert. It is found in a similar manner but in smaller amount in Illinois, Iowa, and Wisconsin. In Idaho, an important producing state, the lead is derived chiefly from lead-silver vein deposits located near Wallace in Shoshone County. Lead is produced in Utah from the silver deposits of the Tintic and Park City Districts; and in Colorado, chiefly from the lead-silver ores of the Leadville District.

Use. Practically the only source of lead and an important ore of silver. Metallic lead is used chiefly as follows: for conversion into white lead (a basic lead carbonate), which is the principal ingredient of the best white paints, or into the oxides used in making glass and in giving a glaze to earthenware; as pipe and sheets; for shot; it is one of the ingredients of solder (an alloy of lead and tin), of type metal (an alloy of lead and antimony), and of low-fusion alloys consisting of lead, bismuth, and tin.

Name. The name galena is derived from the Latin *galena,* a name originally given to lead ore.

SPHALERITE — ZnS

Zinc Blende. Black Jack

Crystallography. Isometric; hextetrahedral. Tetrahedron, dodecahedron, and cube common forms (Figs. 273 and 274), but the crystals, frequently highly complex and usually distorted or in rounded aggregates, often show polysynthetic twinning. Usually found in cleavable masses, coarse to fine granular. Compact, botryoidal, cryptocrystalline.

The dimorphic form of ZnS, *wurtzite,* is hexagonal.

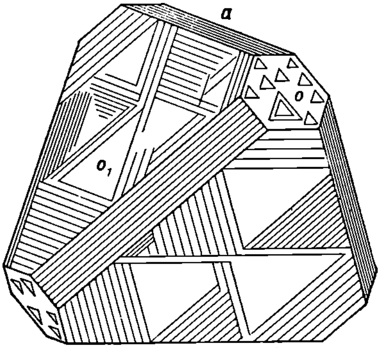


FIG. 273.

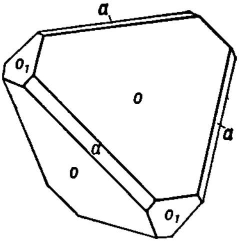


FIG. 274.

Sphalerite.

Physical Properties. Perfect dodecahedral {110} cleavage. **H.** = $3\frac{1}{2}$–4. **G.** = 3.9–4.1. Nonmetallic and resinous to submetallic luster; also adamantine. Color white when pure, and green when nearly so. Commonly yellow, brown to black, darkening with increase in the amount of iron present. Also red (ruby zinc). Transparent to translucent. Streak white to yellow and brown.

Composition. Zinc sulfide, ZnS. Zn = 67 per cent, S = 33 per cent when pure. Nearly always contains iron (Zn,Fe)S, the maximum iron content being about 18 per cent. Manganese and cadmium are usually present in small amounts.

Tests. Pure zinc sulfide infusible; becomes fusible, but difficultly so, with increase in amount of iron. Gives odor of sulfur dioxide when heated on charcoal or in the open tube. Decomposed in powder by warm hydrochloric acid with evolution of hydrogen sulfide gas, which may be detected by its disagreeable odor. When heated on charcoal with reducing mixture gives a coating of zinc oxide (yellow when hot, white when cold) which is nonvolatile in oxidizing flame.

Diagnostic Features. Sphalerite can be recognized by its striking resinous luster and perfect cleavage. The dark varieties (black jack) can be told by the reddish brown streak.

Occurrence. Sphalerite, the most important ore of zinc, is an extremely common mineral, and is associated with galena, pyrite, marcasite, chalcopyrite, smithsonite, calcite, and dolomite. In its occurrence and mode of origin it is closely allied with galena, with which it is most commonly found. It is widely distributed, but is chiefly in veins and irregular replacement deposits in limestone. Sphalerite is also found in veins in igneous rocks and in contact metamorphic deposits.

The most noteworthy European occurrences are at Schemnitz and other localities in the gold- and silver-mining districts of Czechoslovakia and Rumania; at Alston Moor and other places in the lead-mining districts of northern England; at Binnenthal, Switzerland, in fine crystals. Large zinc deposits are found in the United States in Missouri, Colorado, Montana, Wisconsin, Idaho, and Kansas. The chief locality for its production is the Joplin District in southwestern Missouri and in adjacent districts in Kansas and Oklahoma.

Use. The most important ore of zinc. The chief uses for metallic zinc, or *spelter*, are in galvanizing iron; making brass, an alloy of copper and zinc; in electric batteries; and as sheet zinc. Zinc oxide, or zinc white, is used extensively for making paint. Zinc chloride is used as a preservative for wood. Zinc sulfate is used in dyeing and in medicine. Sphalerite also serves as the most important source of cadmium.

Name. Sphalerite from the Greek meaning *treacherous.* Blende because, while often resembling galena, it yielded no lead; from the German word meaning *blind* or *deceiving.*

CHALCOPYRITE — $CuFeS_2$

Copper Pyrites. Yellow Copper Ore

Crystallography. Tetragonal; scalenohedral. Commonly pseudotetrahedral in aspect with the sphenoidal faces {112} present (Fig. 275). Other forms shown in Figs. 276 and 277 rare. Usually massive.

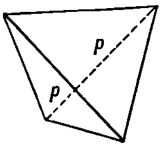


Fig. 275.

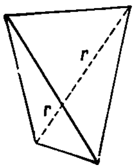


Fig. 276.

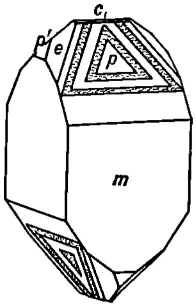


Fig. 277.

Chalcopyrite.

Physical Properties. **H.** = $3\frac{1}{2}$–4. **G.** = 4.1–4.3. Luster metallic. Brittle. Color brass-yellow; often tarnished to bronze or iridescent. Streak greenish black.

Composition. A sulfide of copper and iron, $CuFeS_2$. Cu = 34.5 per cent, Fe = 30.5 per cent, S = 35.0 per cent. Anaylses often show variations from the percentages given because of mechanical admixtures of other sulfides, chiefly pyrite.

Tests. Fusible at 2 to a magnetic globule. Gives odor of sulfur dioxide when heated on charcoal or in the open tube. Decrepitates and gives sulfur in the closed tube. After roasting, and moistening with hydrochloric acid, gives the azure-blue copper chloride flame. Readily decomposed by nitric acid, giving separated sulfur; solution made ammoniacal gives red-brown precipitate of ferric hydroxide and, if filtered, a blue filtrate (copper).

Diagnostic Features. Recognized by its brass-yellow color, greenish black streak, and its softness. Distinguished from pyrite by being softer than steel and from gold by being brittle. Known as "fool's gold," a term which is also applied to pyrite.

Occurrence. Chalcopyrite is the most widely occurring copper mineral and one of the most important sources of that metal. Occurs widely distributed in metallic veins, especially of the high-temperature type. It is associated with pyrite, pyrrhotite, sphalerite, galena, quartz, calcite, dolomite, siderite, and various copper minerals. It is commonly of primary origin, and from it, by various alteration processes, many secondary copper minerals are derived. Also occurs as an original constituent of igneous rocks; in pegmatite veins; in contact metamorphic deposits; and disseminated in schistose rocks. May carry gold or silver and become an ore of those metals. Often in subordinate amount with large bodies of pyrite, making them serve as low-grade copper ores.

A few of the localities at which chalcopyrite is the chief ore of copper are: Cornwall, England; Falun, Sweden; Schemnitz, Czechoslovakia; Schlaggenwald, Bohemia; Freiberg, Saxony; Rio Tinto, Spain; South Africa; Chile. Found widely in the United States but usually in connection with other copper minerals in equal or greater amount; found at Butte, Montana; Bingham, Utah; Jerome, Arizona; Ducktown, Tennessee; various districts in California, Colorado, New Mexico. In Canada the most important occurrences of chalcopyrite are at Sudbury, Ontario; at Rouyn District, Quebec.

Alteration. Chalcopyrite alters often to malachite, covellite, chalcocite, and iron oxides. Concentrations of copper in the zone of secondary enrichment are often the result of such alteration and removal of copper in solution with its subsequent deposition.

Use. Important ore of copper.

Name. Derived from Greek word meaning *brass* and from *pyrites.*

Stannite — Cu_2FeSnS_4

Crystallography. Tetragonal; scalenohedral. Appears pseudoisometric through twinning. Practically always massive.

Physical Properties. **H.** = 4. **G.** = 4.4. Luster metallic. Color steel-gray to iron black. Streak black. Opaque.

Composition. A sulfide of copper, tin, and iron. S = 29.9 per cent, Cu = 29.5 per cent, Sn = 27.5 per cent, Fe = 13.1 per cent.

Tests. Fusible at 1½. Slightly magnetic after heating in the reducing flame. After roasting, and moistening with hydrochloric acid, gives when ignited the blue copper chloride flame. Fused alone on charcoal gives a nonvolatile white coating of tin oxide.

Diagnostic Features. Characterized by its low fusibility and tests for copper, tin, and iron.

Occurrence. Stannite occurs in tin-bearing veins associated with cassiterite, chalcopyrite, wolframite, pyrite, and quartz.

It is a rare mineral found in Bohemia, in various places in Cornwall, and in the tin ores of Bolivia.

Use. A minor ore of tin.

Name. From the Latin name for tin.

Greenockite — CdS

Crystallography. Hexagonal; dihexagonal-pyramidal. Rare and small; crystals hemimorphic, showing prism faces and terminated usually below with base and above with pyramids. Usually pulverulent, and as powdery incrustations.

Physical Properties. **H.** = 3–3½. **G.** = 4.9. Luster adamantine to resinous, earthy. Color various shades of yellow and orange. Streak between orange-yellow and brick-red.

Composition. Cadmium sulfide, CdS. Cd = 77.8 per cent, S = 22.2 per cent.

Tests. Infusible. Yields odor of sulfur dioxide when heated on charcoal or in the open tube. Decomposed by hydrochloric acid with the evolution of hydrogen sulfide gas. Gives a reddish brown coating of cadmium oxide when heated with sodium carbonate on charcoal.

Diagnostic Features. Characterized by its yellow color and pulverulent form and association with zinc ores.

Occurrence. Greenockite is the most common mineral containing cadmium but is found only in a few localities and in small amount. Occurs usually as an earthy coating on zinc ores, especially sphalerite.

Found in crystals at Bishopton, Renfrew, Scotland; also in Bohemia and Carinthia. In the United States is found with the zinc ores of southwestern Missouri, in Arkansas, and in small amounts at Franklin, New Jersey.

Use. A source of cadmium. (See page 391.) Cadmium-bearing zinc ores furnish the greater part of the metal produced. Cadmium is used in alloys for dental and other purposes. The sulfide serves as a yellow pigment.

Name. Named after Lord Greenock (later Earl Cathcart). The first crystal was found about 1810. It was over half an inch across and was mistaken for sphalerite.

PYRRHOTITE — $Fe_{1-x}S$

Magnetic Pyrites

Crystallography. Hexagonal; dihexagonal-dipyramidal. Crystals usually tabular, in some cases pyramidal (Fig. 278). Practically always massive with granular or lamellar habit.

Physical Properties. H. = 4. G. = 4.58–4.65. Luster metallic. Color brownish bronze. Streak black. Magnetic, but varying much in intensity, the less magnetic kinds having more iron. Opaque.

Composition. Sulfide of iron, $Fe_{1-x}S$ with x between 0 and 0.2. The mineral *troilite* is close to FeS; most other pyrrhotites vary in composition but with a deficiency in iron.

Tests. Fusible at 3. Heated on charcoal or in the open tube gives odor of sulfur dioxide and becomes strongly magnetic. Little or no sulfur in the closed tube. Decomposed by hydrochloric acid, giving off hydrogen sulfide gas.

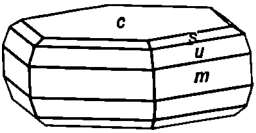


FIG. 278 Pyrrhotite.

Diagnostic Features. Recognized usually by its massive nature, bronze color, and magnetic properties.

Occurrence. Pyrrhotite is a common minor constituent of igneous rocks. It occurs in large masses associated with pentlandite, chalcopyrite, and other sulfides in basic igneous rocks from which it may have been segregated by some form of magmatic differentiation. It is also found in contact metamorphic deposits, in vein deposits, and in pegmatites.

Found in large quantities in Finland, Norway, and Sweden; and at Sudbury, Ontario, Canada. Nickel minerals are associated with it, and thus pyrrhotite is the world's greatest nickel ore. In Germany from Andreasberg in the Harz Mountains; at Schneeberg, Saxony; Bodenmais, Bavaria. In the United States in crystals from Standish, Maine; was found at the Gap Mine, Lancaster County, Pennsylvania; in considerable amount at Ducktown, Tennessee.

Use. Serves as an important ore of nickel, particularly at Sudbury, Ontario.

Name. The name pyrrhotite comes from the Greek meaning *reddish.*

NICCOLITE — NiAs

Copper Nickel

Crystallography. Hexagonal; dihexagonal-dipyramidal, rarely in crystals. Usually massive, reniform with columnar structure.

Physical Properties. **H.** = $5-5\frac{1}{2}$. **G.** = 7.78. Luster metallic. Color pale copper-red (hence called *copper nickel*), with gray to blackish tarnish. Streak brownish black. Opaque.

Composition. Nickel arsenide, NiAs. Ni = 43.9 per cent, As = 56.1 per cent. Usually with a little iron, cobalt, and sulfur. Arsenic frequently replaced in part by antimony.

Tests. Fusible at 2. When it is heated on charcoal a white volatile deposit of arsenious oxide forms and a garliclike odor is given off. Gives to borax bead a reddish brown color (nickel). Gives the nickel test with dimethylglyoxime.

Diagnostic Features. Characterized by its copper-red color.

Alteration. Quickly alters to annabergite (nickel bloom) in moist atmosphere.

Occurrence. Niccolite, with other nickel arsenides and sulfides, pyrrhotite, and chalcopyrite, frequently occurs in, or associated with, norites. Also found in vein deposits with cobalt and silver minerals.

Found in Germany in the silver mines of Saxony, the Harz Mountains, in Hessen-Nassau; and at Cobalt, Ontario.

Use. A minor ore of nickel.

Name. The first name of this mineral, *kupfernickel,* gave the name *nickel* to the metal. Niccolite is from the Latin for nickel.

Millerite —NiS

Capillary Pyrites

Crystallography. Rhombohedral; scalenohedral. Usually in hairlike tufts and radiating groups of slender to capillary crystals. In velvety incrustations.

Physical Properties. Cleavage rhombohedral $\{10\bar{1}1\}$. **H.** = $3-3\frac{1}{2}$. **G.** = 5.5 ± 0.2. Luster metallic. Color pale brass-yellow; with a greenish tinge when in fine hairlike masses. Streak black, somewhat greenish.

Composition. Nickel sulfide, NiS. Ni = 64.7 per cent, S = 35.3 per cent.

Tests. Fusible at 1½–2 to magnetic globules. Gives odor of sulfur dioxide when heated on charcoal or in the open tube. The roasted mineral colors the borax bead reddish brown in the oxidizing flame. Gives nickel test with dimethylglyoxime.

Diagnostic Features. Characterized by its capillary crystals and distinguished from minerals of similar color by nickel tests.

Occurrence. Millerite forms as a low-temperature mineral often in cavities and as an alteration of other nickel minerals, or as crystal inclusions in other minerals.

Occurs in various localities in Saxony, Westphalia, and Hessen-Nassau and in Bohemia. In the United States is found with hematite and ankerite at Antwerp, New York; with pyrrhotite at the Gap Mine, Lancaster County, Pennsylvania; in geodes in limestone at St. Louis, Missouri; Keokuk, Iowa; and Milwaukee, Wisconsin.

Use. A subordinate ore of nickel.

Name. In honor of the mineralogist, W. H. Miller (1801–1880), who first studied the crystals.

Pentlandite — (Fe,Ni)S

Crystallography. Isometric; hexoctahedral. Massive, usually in granular aggregates.

Physical Properties. Octahedral {111} parting. **H.** = 3½–4. **G.** = 4.6–5.0. Brittle. Luster metallic. Color yellowish bronze. Streak light bronze-brown. Opaque. Nonmagnetic.

Composition. A sulfide of iron and nickel, (Fe,Ni)S. Usually with Fe : Ni close to 1 : 1. Usually contains small amounts of cobalt.

Tests. Fusible at 1½–2. Gives odor of sulfur dioxide in the open tube, becomes magnetic on heating. Roasted mineral in the oxidizing flame colors borax bead reddish brown (nickel). Gives nickel test with dimethylglyoxime.

Diagnostic Features. Pentlandite closely resembles pyrrhotite in appearance but can be distinguished from it by the octahedral parting and its lack of magnetism.

Occurrence. Pentlandite is almost always associated with pyrrhotite and usually occurs in basic rocks such as norites, and is perhaps derived from them by magmatic segregation. Also found with chalcopyrite and other iron and nickel minerals.

Found at widely separated localities in small amounts, but its chief occurrence is with pyrrhotite at Sudbury, Ontario, where it is the principal source of nickel in the ore.

Use. The principal ore mineral of nickel. Nickel is used largely in making alloys. Is used in greatest amount in nickel steel for armor plate. Alloys with copper are used in coinage, monel metal, etc.

Name. After J. B. Pentland, who first noted the mineral.

Covellite — CuS

Crystallography. Hexagonal; dipyramidal. Rarely in tabular hexagonal crystals. Usually massive as coatings or disseminations through other copper minerals.

Physical Properties. Perfect basal {0001} cleavage giving flexible plates. **H.** = 1½–2. **G.** = 4.6–4.76. Luster metallic. Color indigo-blue or darker. Streak lead-gray to black. Often iridescent. Opaque.

Composition. Cupric sulfide, CuS. Cu = 66.4 per cent, S = 33.6 per cent. A small amount of iron may be present.

Tests. Fusible at 2½. Gives odor of sulfur dioxide on charcoal and in the open tube, and much sulfur in the closed tube. The roasted mineral, moistened with hydrochloric acid and ignited, gives the blue copper chloride flame. When moistened with water shows a strong purple color.

Diagnostic Features. Characterized by the indigo-blue color, micaceous cleavage yielding flexible plates, and association with other copper sulfides.

Occurrence. Covellite is not an abundant mineral, but is found in most copper deposits as a secondary mineral, usually as a coating, in the zone of sulfide enrichment. It is associated with other copper minerals, principally chalcocite, chalcopyrite, bornite, and enargite, and derived from them by alteration. Primary covellite is known but uncommon.

Found at Bor, Serbia; Yugoslavia; Leogang, Austria. In large iridescent crystals from the Calabona Mine, Alghero, Sardinia.

In the United States covellite is found in appreciable amounts at Butte, Montana; Summitville, Colorado; La Sal District, Utah. Also at Kennecott, Alaska.

Use. A minor ore of copper.

Name. In honor of N. Covelli (1790–1829), the discoverer of the Vesuvian covellite.

CINNABAR — HgS

Crystallography. Rhombohedral; trigonal-trapezohedral. Crystals usually rhombohedral, often in penetration twins. Trapezohedral faces rare. Usually fine granular massive; also earthy, as incrustations and disseminations through the rock.

Physical Properties. Perfect prismatic {10$\bar{1}$0} cleavage. **H.** = 2½. **G.** = 8.10. Luster adamantine when pure, to dull earthy when impure. Color vermilion-red when pure, to brownish red when impure. Streak scarlet. Transparent to translucent. *Hepatic cinnabar* is an inflammable variety with liver-brown color and in some cases a brownish streak, usually granular or compact.

Composition. Mercuric sulfide, HgS. Hg = 86.2 per cent, S = 13.8 per cent. Frequently impure from admixture of clay, iron oxide, bitumen.

Tests. Wholly volatile when free from impurities. Gives black sublimate of mercuric sulfide when heated alone in the closed tube. When heated in the closed tube with dry sodium carbonate gives globules of metallic mercury. Carefully roasted in the open tube gives odor of sulfur dioxide and sublimate of metallic mercury.

Diagnostic Features. Recognized by its red color and scarlet streak, high specific gravity, and cleavage.

Occurrence. Cinnabar is the most important ore of mercury, but found in quantity at comparatively few localities. Occurs as impregnations and as vein fillings, usually in sedimentary rocks, but near recent volcanic rocks and hot springs and evidently deposited near the surface from solutions which were probably alkaline. Associated with pyrite, marcasite, stibnite, and sulfides of copper in a gangue of opal, chalcedony, quartz, barite, calcite, fluorite.

The important localities for the occurrence of cinnabar are at Almaden, Spain; Idria in Gorizia, Italy; Huancavelica in southern Peru; Provinces of Kweichow and Hunan, China. In the United States the important deposits are in California at New Idria in San Benito County, Napa County, and New Almaden in Santa Clara County. Also occurs in Nevada, Utah, Oregon, Arkansas, Idaho.

Use. The only important source of mercury.

Name. The name cinnabar is supposed to have come from India, where it is applied to a red resin.

REALGAR — AsS

Crystallography. Monoclinic; prismatic. Found in short, vertically striated, prismatic crystals (Fig. 279). Frequently coarse to fine granular and often earthy and as an incrustation.

Physical Properties. Cleavage parallel to clinopinacoid {010}. **H.** = 1½–2. **G.** = 3.48. Sectile. Luster resinous. Color and streak red to orange. Translucent to transparent.

Composition. Arsenic monosulfide, AsS. As = 70.1 per cent, S = 29.9 per cent.

Tests. Fusible at 1. Easily volatile. Heated on charcoal yields a volatile white sublimate of arsenious oxide with characteristic garlic odor. Roasted in the open tube gives volatile crystalline sublimate of arsenious oxide and odor of sulfur dioxide. Heated in closed tube gives a red sublimate.

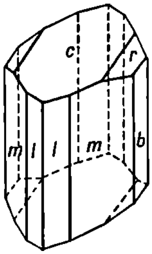


FIG. 279. Realgar.

Diagnostic Features. Realgar can be distinguished by its red color, resinous luster, and almost invariable association with orpiment. Its orange-red streak serves to distinguish it from other red minerals.

Occurrence. Realgar is found in veins of lead, silver, and gold ores associated with orpiment, other arsenic minerals, and stibnite. It also occurs as a volcanic sublimation product and as a deposit from hot springs.

Realgar is found associated with silver and lead ores in Hungary, Bohemia, Saxony. Found in good crystals at Nagyág, Transylvania; Binnenthal, Switzerland; Allchar, Macedonia. In the United States realgar is found at Mercur, Utah; at Manhattan, Nevada; and deposited from the geyser waters in the Norris Geyser Basin, Yellowstone National Park.

Use. Realgar was used in fireworks to give a brilliant white light when mixed with saltpeter and ignited. Artificial arsenic sulfide is at present used for this purpose. It was formerly used as a pigment.

Name. The name is derived from the Arabic, Rahj al ghar, *powder of the mine.*

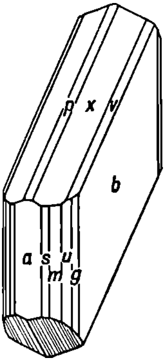


FIG. 280. Orpiment.

ORPIMENT — As_2S_3

Crystallography. Monoclinic; prismatic. Crystals small, tabular (Fig. 280) or short prismatic, and rarely distinct. Usually in foliated or columnar masses.

Physical Properties. Very perfect cleavage parallel to clinopinacoid {010}. Cleavage laminae flexible but not elastic. Sectile. **H.** = $1\frac{1}{2}$–2. **G.** = 3.49. Luster resinous, pearly on cleavage face. Color lemon-yellow. Translucent.

Composition. Arsenic trisulfide, As_2S_3. As = 61 per cent, S = 39 per cent.

Tests. Same as for realgar (see above).

Diagnostic Features. Characterized by its yellow color and foliated structure. Distinguished from sulfur by its perfect cleavage.

Occurrence. Orpiment is a rare mineral, associated usually with realgar and formed under similar conditions. Found in various places in Rumania; in Kurdistan; in Peru; Japan; etc. In the United States occurs at Mercur, Utah, and at Manhattan, Nevada. Deposited with realgar from geyser waters in the Norris Geyser Basin, Yellowstone National Park.

Use. Used in dyeing and in a preparation for the removal of hair from skins. Artificial arsenic sulfide is largely used in place of the mineral. Formerly both realgar and orpiment were used as pigments but are no longer because of their poisonous nature.

Name. Derived from the Latin, *auripigmentum*, "golden paint," in allusion to its color and because the substance was supposed to contain gold.

STIBNITE — Sb_2S_3

Crystallography. Orthorhombic; dipyramidal. Slender prismatic habit, prism zone vertically striated. Crystals often steeply terminated (Fig. 281). Crystals sometimes curved or bent (Plate VIII). Often in radiating crystal groups or in bladed forms with prominent cleavage. Massive, coarse to fine granular.

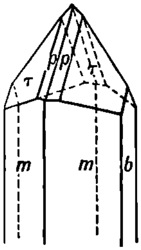


Fig. 281. Stibnite.

Physical Properties. Perfect cleavage parallel to brachypinacoid, {010}. **H.** = 2. **G.** = 4.52–4.62. Luster metallic, splendent on cleavage surfaces. Color and streak lead-gray to black. Opaque.

Composition. Antimony trisulfide, Sb_2S_3. Sb = 71.4 per cent, S = 28.6 per cent. May carry small amounts of gold, silver, iron, lead, copper.

Tests. Fusible at 1. Heated on charcoal gives dense white coating of antimony trioxide and odor of sulfur dioxide. When roasted in the open tube gives nonvolatile white sublimate near bottom of tube and a white volatile sublimate as ring around tube. Heated in the closed tube gives a faint ring of sulfur and below a red (when cold) deposit of oxysulfide of antimony.

Diagnostic Features. Characterized by its easy fusibility, bladed habit, perfect cleavage in one direction, lead-gray color, and soft black streak.

Occurrence. Stibnite is deposited by alkaline waters, usually in association with quartz. Found in quartz veins or beds in granite and gneiss with few other minerals present. May occur as a replacement in limestones and shales, probably owing its origin to hot-spring deposits. Often associated with intrusive rocks. Associated with other antimony

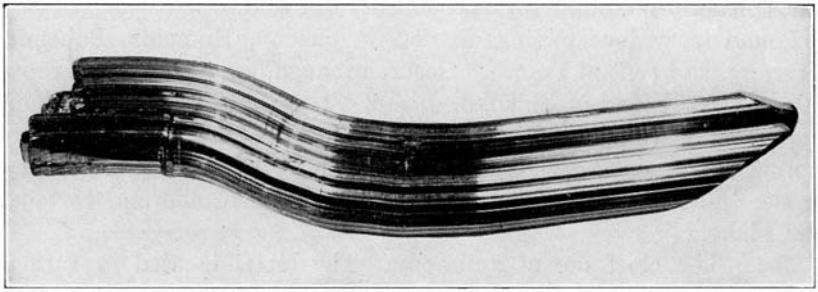


FIG. 1. Curved Stibnite Crystal, Ischinokowa, Japan.

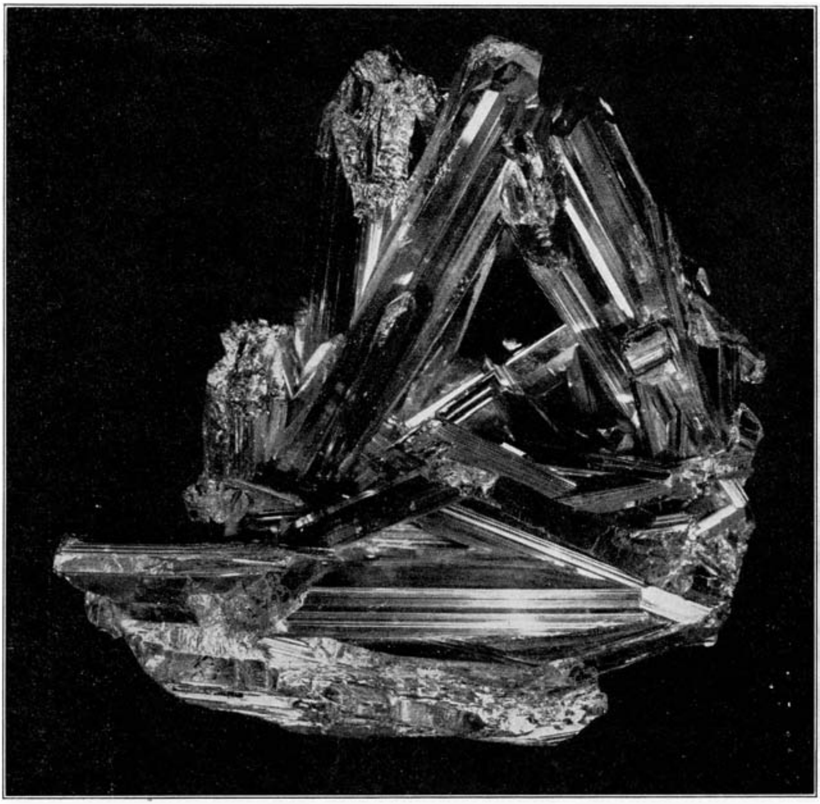


FIG. 2. Group of Stibnite Crystals, Japan.

PLATE VIII

minerals, as the products of its decomposition, and with galena, cinnabar, sphalerite, barite, realgar, orpiment, and gold.

Found in various mining districts in Saxony, Rumania, Bohemia, Tuscany, and central France. Occurs in magnificent crystals in Province of Iyo, Island of Shikoku, Japan. The world's most important producing district is in the Province of Hunan, China. Occurs also in Borneo, Peru, and Mexico. Found in quantity at only a few localities in the United States, the chief deposits being in California, Nevada, and Idaho.

Use. The chief ore of antimony. The metal is used in various alloys, as antimonial lead for storage batteries, type metal, pewter, babbit, britannia metals, and anti-friction metal. The sulfide is employed in the manufacture of fireworks, matches, and percussion caps. Used in vulcanizing rubber. Used in medicine as tartar emetic and other compounds. Antimony trioxide is used as a pigment and for making glass.

Name. The name stibnite comes from an old Greek word that was applied to the mineral.

Bismuthinite — Bi_2S_3

Crystallography. Orthorhombic; dipyramidal. In acicular, striated crystals. Usually massive with foliated or fibrous texture.

Physical Properties. Perfect cleavage parallel to brachypinacoid, {010}. **H.** = 2. **G.** = 6.78 ± 0.03. Luster metallic. Color and streak lead-gray. Opaque.

Composition. Bismuth trisulfide, Bi_2S_3. Bi = 81.2 per cent, S = 18.8 per cent. Often with antimony, lead, copper, iron.

Tests. Fusible at 1. Roasted in the open tube or on charcoal gives odor of sulfur dioxide. Mixed with iodide flux and heated on charcoal gives characteristic red coating, and treated similarly on a plaster tablet gives a chocolate-brown coating underlain by red.

Diagnostic Features. Resembles stibnite; recognized by the test for bismuth.

Occurrence. Bismuthinite is a rare mineral occurring commonly in veins that show definite relations to igneous rocks.

Found in Cornwall and Cumberland, England; Saxony; Sweden; Bohemia; Mexico. Important deposits associated with tin and tungsten ores occur in Bolivia. In the United States from Beaver County, Utah; Haddam, Connecticut; Delaware County, Pennsylvania; various localities in Colorado.

Use. An ore of bismuth. (See page 391.)

PYRITE — FeS_2

Iron Pyrites

Crystallography. Isometric; diploidal. Frequently in crystals. The most common forms are the cube, the faces of which are usually striated, the striae on adjacent faces being perpendicular to each other (Fig. 282); the pyritohedron (Fig. 283); and the octahedron. Figures 284 to 286 show characteristic combinations of these forms. Figure 287 shows a penetration twin, known as the *iron cross*, (with {011} the twin plane). Also massive, granular, reniform, globular, and stalactitic.

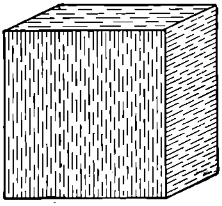


Fig. 282.

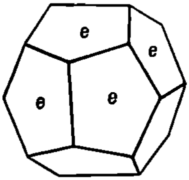


Fig. 283.

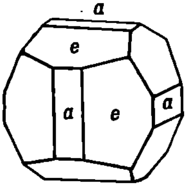


Fig. 284.

Pyrite.

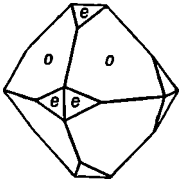


Fig. 285.

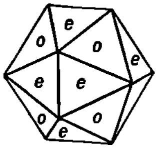


Fig. 286.

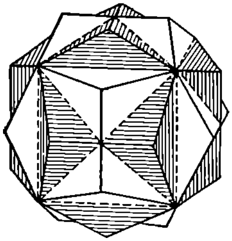


Fig. 287.

Pyrite.

Physical Properties. Brittle. **H.** = 6–6½ (unusually hard for a sulfide). **G.** = 5.02. Luster metallic, splendent. Color pale brass-yellow; may be darker because of tarnish. Streak greenish or brownish black. Opaque.

Composition. Sulfide of iron, FeS_2. Fe = 46.6 per cent, S = 53.4 per cent. May contain small amounts of nickel, cobalt, and arsenic. Frequently carries minute quantities of gold and copper but presumably as microscopic impurities.

Tests. Fusible at 2½–3 to a magnetic globule. Yields much sulfur in the closed tube. Gives off sulfur dioxide when heated in the open tube or on charcoal. Insoluble in hydrochloric acid. Fine powder completely soluble in nitric acid, but may yield separated sulfur when too rapidly decomposed.

Diagnostic Features. Distinguished from chalcopyrite by its paler color and the fact that it cannot be scratched by steel; from gold by its brittleness and hardness; and from marcasite by its deeper color and crystal form.

Alteration. Pyrite is easily altered to oxides of iron, usually limonite. In general, however, it is much more stable than marcasite. Pseudomorphic crystals of limonite after pyrite are common. Pyrite veins are usually capped by a cellular deposit of limonite, termed *gossan.* Rocks that contain pyrite are unsuitable for structural purposes because the ready oxidation of the pyrite in them would serve both to disintegrate the rock and to stain it with iron oxide.

Occurrence. Pyrite is the most common of the sulfides. It has formed at both high and low temperatures, but the largest masses probably at high temperature. It occurs as direct magmatic segregation and as an accessory mineral in igneous rock. Also in contact metamorphic and vein deposits. Pyrite is a common mineral in sedimentary rocks, being both primary and secondary in origin. It is associated with many minerals but found most frequently with chalcopyrite, sphalerite, galena.

Large and extensively developed deposits occur at Rio Tinto and elsewhere in Spain; also in Portugal. Important deposits of pyrite in the United States are in Prince William, Louisa, and Pulaski Counties, Virginia, where it occurs in large lenticular masses which conform in position to the foliation of the inclosing schists; in St. Lawrence County, New York; at the Davis Mine, near Charlemont, Massachusetts; in various places in California, Colorado, and Arizona.

Use. Pyrite is often mined for the gold or copper associated with it. Because of the large amount of sulfur present in the mineral it is used as an iron ore only in those countries where oxide ores are not available. It is chiefly used to furnish sulfur for sulfuric acid and *copperas* (ferrous sulfate). Sulfuric acid is perhaps the most important of all chemicals, being used for many different purposes, some of the more important being in the purification of kerosene and in the preparation of mineral fertilizers. The gas SO_2 derived either through burning sulfur or by roasting pyrite is used extensively in the preparation of wood pulp for manufacture into paper. Copperas is used in dyeing, in the manufacture of inks, as a preservative of wood, and for a disinfectant.

Name. The name *pyrite* is from a Greek word meaning *fire,* in allusion to the fact that when struck with steel it gives off brilliant sparks.

COBALTITE — CoAsS

Crystallography. Isometric; tetartoidal. Commonly in cubes o pyritohedrons with the faces striated as in pyrite. Also granular.

Physical Properties. Perfect cubic {100} cleavage. Brittle. **H.** = $5\frac{1}{2}$. **G.** = 6.33. Luster metallic. Color silver-white, inclined to red. Streak grayish black.

Composition. Sulfarsenide of cobalt with considerable amounts (maximum about 10 per cent) of iron, CoAsS. Cobaltite is completely isomorphous with the sulfarsenide of nickel, *gersdorffite,* NiAsS, but intermediate members of the series are rare.

Tests. Fusible at 2–3. On charcoal gives a volatile white sublimate of arsenious oxide with characteristic garlic odor. In the oxidizing flame in borax bead gives deep blue color (cobalt).

Diagnostic Features. Although in crystal form cobaltite resembles pyrite, it can be distinguished by its silver color and cleavage.

Occurrence. Cobaltite is usually found in high-temperature deposits, as disseminations in metamorphosed rocks, or in vein deposits with other cobalt and nickel minerals. Notable occurrences of cobaltite are at Tunaberg, Sweden, and Cobalt, Ontario.

Use. An ore of cobalt.

MARCASITE — FeS_2

White Iron Pyrites

Crystallography. Orthorhombic; dipyramidal. Crystals commonly tabular parallel to basal plane, showing also short prisms and low brachydomes (Fig. 288). The brachydomes usually striated parallel to the brachy-axis. Often twinned, giving cockscomb and spear-shaped groups (Figs. 289 and 290). Usually in radiating forms. Often stalactitic, having an inner core with radiating structure and covered on the outside with irregular crystal groups. Also globular and reniform.

Physical Properties. **H.** = $6–6\frac{1}{2}$. **G.** = 4.89. Luster metallic. Color pale bronze-yellow to almost white on fresh fracture, yellow to brown tarnish. Streak grayish black. Opaque.

Composition. Iron disulfide, like pyrite, FeS_2. Fe = 46.6 per cent, S = 53.4 per cent.

Tests. Fusible at $2\frac{1}{2}$–3 to a magnetic globule. Heated on charcoal or in the open tube gives odor of sulfur dioxide. Much sulfur in the closed tube. When fine powder is treated by cold nitric acid, and the solution allowed to stand until vigorous action ceases and then boiled, the mineral is decomposed with separation of sulfur. Pyrite treated in the same manner would have been completely dissolved.

Diagnostic Features. Usually recognized and distinguished from pyrite by its pale yellow color, its crystals or its fibrous habit, and the above chemical test.

Alteration. Marcasite usually disintegrates more easily than pyrite with the formation of ferrous sulfate and sulfuric acid.

Occurrence. Marcasite is found in metalliferous veins, frequently with lead and zinc ores. Also in sedimentary rocks. It is less stable than pyrite, being easily decomposed, and is much less common. It is deposited at low temperatures from acid solutions and commonly formed under surface conditions. Marcasite most frequently occurs as replacement deposits in limestone; and often in concretions imbedded in clays, marls, and shales.

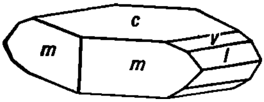


Fig. 288. Marcasite.

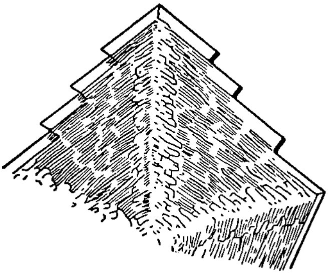


Fig. 289.

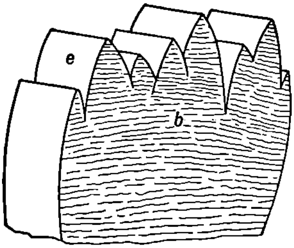


Fig. 290.

" Cockscomb " Marcasite.

Found abundantly in clay near Carlsbad and elsewhere in Bohemia; in various places in Saxony; in the chalk marl of Folkestone and Dover, England. In the United States marcasite is found with zinc and lead deposits of the Joplin, Missouri, District; at Mineral Point, Wisconsin; from Galena, Illinois.

Use. To a slight extent as a source of sulfur for sulfuric acid.

Name. Derived from an Arabic word, at one time applied generally to pyrite.

ARSENOPYRITE — FeAsS

Mispickel

Crystallography. Monoclinic; prismatic. Crystals are prismatic parallel to the *c* axis and less commonly parallel to the *b* axis (Fig. 291). The prism zone vertically striated, also *n*{101} striated as shown in Fig. 292. Twinning (1) on {100} and {001} produces pseudo-orthorhombic crystals; (2) on {101} as contact or penetration twins; may be repeated, as in marcasite; (3) on {012} to produce star-shaped trillings.

Physical Properties. H. = 5½–6. G. = 6.07 ± 0.15. Luster metallic. Color silver-white. Streak black. Opaque.

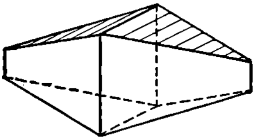


FIG. 291.

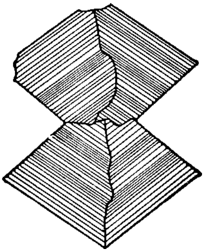


FIG. 292.

Arsenopyrite.

Composition. Essentially iron arsenide-sulfide, FeAsS. Fe = 34.3 per cent, As = 46 per cent, S = 19.7 per cent. Cobalt may replace a part of the iron (*danaite*).

Tests. Fusible at 2 to magnetic globule. Heated on charcoal gives a volatile coating of arsenious oxide and a characteristic garlic odor. In the open tube gives odor of sulfur dioxide and a volatile ring of arsenious oxide. In the closed tube gives arsenic mirror.

Diagnostic Features. Distinguished from marcasite by its silver-white color. Its crystal form and lack of cobalt test distinguish it from smaltite.

Occurrence. Arsenopyrite is the most common mineral containing arsenic. It occurs with tin and tungsten ores in high-temperature deposits, in veins formed by deposition from hot waters, associated with silver and copper ores, galena, sphalerite, pyrite, chalcopyrite. Frequently associated with gold. Often found sparingly in pegmatites, in contact metamorphic deposits, disseminated in crystalline limestones.

Arsenopyrite is a widespread mineral and is found in considerable abundance in many foreign localities, notably at Freiberg and Munzig, Saxony; with tin ores in Cornwall, England; from Tavistock, Devonshire; in various places in Bolivia. In the United States in fine crystals at Franconia, New Hampshire; from Roxbury, Connecticut; from Franklin, New Jersey. It is associated with gold at Lead, South Dakota. Large quantities occur at Deloro, Ontario.

Use. An ore of arsenic. (See page 390.) Arsenious oxide is used in the manufacture of glass, as a poison, and as a preservative. Lead arsenate is used as an insecticide. Paris green, an arsenate and acetate of copper, is a poison and a pigment. Sulfides of arsenic are used for paints and fireworks.

Name. Arsenopyrite is a contraction of the older term *arsenical pyrites.*

MOLYBDENITE — MoS_2

Crystallography. Hexagonal; dihexagonal-dipyramidal. Crystals in hexagonal-shaped plates or short, slightly tapering prisms. Commonly foliated, massive or in scales.

Physical Properties. Perfect basal {0001} cleavage. Laminae flexible but not elastic. Sectile. **H.** = 1–1½. **G.** = 4.62–4.73. Greasy feel. Luster metallic. Color lead-gray. Streak grayish black. Opaque.

Composition. Molybdenum sulfide, MoS_2. Mo = 59.9 per cent, S = 40.1 per cent.

Tests. Infusible. Heated before the blowpipe gives yellowish green flame. Roasted in the open tube gives odor of sulfur dioxide and deposit of thin plates of molybdic oxide, crossing the tube above the mineral. Heated on charcoal in the oxidizing flame gives a white coating of molybdic oxide; when this coating is touched with the reducing flame, it turns a deep blue color. When heated with potassium iodide and sulfur on a plaster tablet gives a deep blue sublimate.

Diagnostic Features. Resembles graphite but is distinguished from it by higher specific gravity; by a blue tone to its color, while graphite has a brown tinge; and by its reactions for sulfur and molybdenum. On glazed porcelain, molybdenite gives a greenish streak, graphite a black streak.

Occurrence. Molybdenite forms as an accessory mineral in certain granites; in pegmatites and aplites. Commonly in vein deposits associated with cassiterite, scheelite, wolframite, and fluorite. Also in contact metamorphic deposits with lime silicates, scheelite, and chalcopyrite.

Occurs with the tin ores of Bohemia; from various places in Norway and Sweden; from New South Wales; England; China; Mexico. In the United States molybdenite is found in many localities. Found at Blue Hill, Maine; Westmoreland, New Hampshire; in Okanogan County, Washington. From various places in Ontario, Canada. The bulk of the world's supply comes from Climax, Colorado, where molybdenite occurs in quartz veinlets in silicified granite with fluorite and topaz.

Use. An ore of molybdenum.

Name. The name molybdenite comes from the Greek word meaning *lead.*

Calaverite — $AuTe_2$

Crystallography. Monoclinic; prismatic. Rarely in distinct crystals which are developed parallel to the ortho-axis and the faces of the orthodome zone deeply striated. Terminated at the ends of the ortho-axis with a large number of faces. Twinning frequent. Usually granular.

Physical Properties. **H.** = $2\frac{1}{2}$. **G.** = 9.35. Luster metallic. Color brass-yellow to silver-white, in some cases with yellowish tarnish. Streak yellowish to greenish gray. Opaque.

Composition. Gold ditelluride, $AuTe_2$. Au = 44.03 per cent, Te = 55.97 per cent. Silver usually replaces the gold to a small extent.

Tests. Fusible at 1. On charcoal fuses with a bluish green flame yielding globules of metallic gold. When decomposed in hot concentrated sulfuric acid the solution assumes a deep red color (tellurium), and a spongy mass of gold separates.

Diagnostic Features. Distinguished from sylvanite by the presence of only a small amount of silver and by the lack of cleavage.

Occurrence. Calaverite is formed under conditions similar to those for sylvanite and is associated with it and other tellurides in the Cripple Creek District, Colorado, and at Kalgoorlie, West Australia.

Use. An ore of gold.

Name. Named from Calaveras County, California, where it was originally found in the Stanislaus Mine.

Similar Species. Other rare tellurides are *krennerite,* $AuTe_2$; *altaite,* PbTe; *hessite,* Ag_2Te; *petzite,* $(Ag,Au)_2Te$; and *nagyagite,* a sulfotelluride of lead and gold.

Sylvanite — $(Au,Ag)Te_2$

Crystallography. Monoclinic; prismatic. Distinct crystals rare. Usually bladed or granular. Often in skeleton forms deposited on rock surfaces and resembling writing in appearance.

Physical Properties. Perfect cleavage parallel to clinopinacoid, {010}. **H.** = $1\frac{1}{2}$–2. **G.** = 8–8.2. Luster brilliant metallic. Color silver-white. Streak gray. Opaque.

Composition. A ditelluride of gold and silver, (Au,Ag)Te_2. The ratio of the amounts of gold and silver varies somewhat; when Au : Ag = 1 : 1, Te = 62.1 per cent, Au = 24.5 per cent, Ag = 13.4 per cent.

Tests. Fusible at 1. If a little of the powdered mineral is heated in concentrated sulfuric acid the solution assumes a deep red color (tellurium). When decomposed in nitric acid leaves a rust-colored, spongy mass of gold, and the solution with hydrochloric acid gives white precipitate of silver chloride. Heated on charcoal gives a gold-silver globule.

Diagnostic Features. Determined by above tests and its silver color, and distinguished from calaverite by its good cleavage.

Occurrence. Sylvanite is a rare mineral associated with calaverite and other tellurides, pyrite and other sulfides in small amounts, gold, quartz, chalcedony, fluorite, and carbonates. Usually in veins formed at low temperatures but may be in higher-temperature veins.

It is found at Offenbánya and Nagyág in Transylvania; at Kalgoorlie and Mulgabbie, West Australia. In the United States it is found sparingly at several localities in California and Colorado, but the most notable occurrence is at Cripple Creek, Colorado.

Use. An ore of gold and silver.

Name. Derived from Transylvania, where it was first found, and in allusion to *sylvanium,* one of the names first proposed for the element tellurium.

SMALTITE — $CoAs_2$

Crystallography. Isometric; diploidal. Common crystal forms are cube and octahedron, more rarely dodecahedron and pyritohedron. Usually massive, dense to granular.

Physical Properties. **H.** = 5½–6. **G.** = 6.5 ± 0.4. Brittle. Luster metallic. Color tin-white to silver-gray. Streak black. Opaque.

Composition. Essentially cobalt diarsenide, $CoAs_2$. Smaltite is isomorphous with *chloanthite,* $NiAs_2$, and all gradations between the two species occur. Iron may take the place of nickel or cobalt, and sulfur the place of arsenic.

Tests. Fusible at 2–2½. Before blowpipe on charcoal gives a volatile coating of arsenious oxide with garlic odor. In borax bead in oxidizing flame gives blue color (cobalt).

Diagnostic Features. It is necessary to make the test for cobalt to distinguish it from massive arsenopyrite, for no physical properties distinguish the two.

Occurrence. Smaltite is usually associated with cobaltite and niccolite in veins formed at moderate temperature. Native silver, bismuth, arsenopyrite, and calcite are also commonly associated with it.

Notable localities are Annaberg, Schneeberg, and Freiberg in Saxony, and Cobalt, Ontario, where smaltite is associated with silver ores.

Use. An ore of cobalt and nickel. Cobalt is chiefly used in alloys for making high-speed tool steel. Cobalt oxide is used as a blue pigment in pottery and glassware.

Name. Smaltite from its use as a source of the blue pigment, *smalt,* made by fusing together cobalt oxide, silica, and potash.

SULFO SALTS

The term sulfo salt was originally proposed to indicate that a compound was a salt of one of a series of acids in which sulfur had replaced the oxygen of an ordinary acid. Since such acids may be purely hypothetical, it is perhaps misleading to endeavor to thus explain this class of minerals. Nevertheless, the term sulfo salt is serviceable and is retained for indicating a certain type of unoxidized sulfur mineral distinct from a sulfide.

The sulfides are those minerals in which a metal or a semi-metal is combined with sulfur. If both a semi-metal and a metal are present, the semi-metal takes the place of sulfur in the structure, as in arsenopyrite, FeAsS, and thus acts as an electronegative element. In the sulfo salts, the semi-metals play a role more or less like that of metals in the structure, and thus may, in a sense, be considered double sulfides. Enargite, Cu_3AsS_4, may be considered as $3Cu_2S \cdot As_2S_5$. There are nearly 100 sulfo salts, but those in the following list are the only ones considered important enough to warrant description here.

Sulfo Salts

Polybasite	$Ag_{16}Sb_2S_{11}$
Stephanite	Ag_5SbS_4
Pyrargyrite	Ag_3SbS_3
Proustite	Ag_3AsS_3
Tetrahedrite	$(Cu,Fe,Zn,Ag)_{12}Sb_4S_{13}$
Enargite	Cu_3AsS_4
Jamesonite	$Pb_4FeSb_6S_{14}$
Bournonite	$PbCuSbS_3$

Polybasite — $Ag_{16}Sb_2S_{11}$

Crystallography. Monoclinic; prismatic. Crystals are pseudorhombohedral in symmetry, occurring in short hexagonal prisms, often thin tabular. Basal planes show triangular markings. Also granular.

Physical Properties. **H.** = 2–3. **G.** = 6.0–6.2. Luster metallic. Color steel-gray to iron-black. Streak black. Opaque.

Composition. Essentially a sulfantimonide of silver, $Ag_{16}Sb_2S_{11}$. Ag = 74.3 per cent, Sb = 10.5 per cent, S = 15.2 per cent. Cu replaces Ag to about 30 atomic per cent, and As may replace Sb.

Tests. Fusible at 1. On charcoal fuses with spirting to a globule and gives dense white coating of antimony trioxide with odor of sulfur dioxide. After decomposition by nitric acid, the filtrate with hydrochloric acid gives white precipitate of silver chloride.

Diagnostic Features. To be distinguished from similar species chiefly by its crystals.

Occurrence. Polybasite is a comparatively rare silver mineral, associated with other silver sulfantimonides and with silver ores in general.

Found in the silver mines of Mexico, Chile, Saxony, and Bohemia. In the United States found at the Comstock Lode and Tonapah, Nevada; Ouray and Leadville, Colorado; Silver City and Delamar, Idaho.

Use. An ore of silver.

Name. Name is in allusion to the *many metallic bases* contained in the mineral.

Stephanite — Ag_5SbS_4

Crystallography. Orthorhombic; pyramidal. Crystals usually small and short prismatic and tabular parallel to the base. Edges of crystals truncated by various pyramids. Prism zone usually shows the four prism faces and the two of the brachypinacoid, all making nearly 60° angles with each other and so giving the crystals a hexagonal aspect. Also twinned in pseudohexagonal crystals. Massive, compact, or disseminated.

Physical Properties. **H.** = 2–2½. **G.** = 6.2–6.3. Luster metallic. Brittle. Color and streak iron-black. Opaque.

Composition. Silver sulfantimonide, Ag_5SbS_4. Ag = 68.5 per cent, Sb = 15.2 per cent, S = 16.3 per cent.

Tests. Fusible at 1. Before the blowpipe on charcoal gives dense white sublimate of antimony trioxide and odor of sulfur dioxide. Decomposed by nitric acid, and, if after filtering a little hydrochloric acid is added to filtrate, it gives a white precipitate of silver chloride.

Diagnostic Features. Recognized by its stout pseudohexagonal crystals and the above tests. Differs from argentite by being brittle and from tetrahedrite by being soft.

Occurrence. Stephanite is a rare silver mineral of primary origin and is usually one of the last minerals to form in silver veins. Associated with other silver sulfo salts, argentite, silver, tetrahedrite, and the commoner sulfides.

Notable localities for fine crystals are: Přibram, Czechoslovakia; Freiberg, Saxony; Mt. Narba, Sardinia; Zacatecas, Mexico. In the United States an important ore mineral at the Comstock Lode and other silver deposits in Nevada. Also at Leadville, Colorado.

Use. An ore of silver.

Name. After the Archduke Stephan, formerly Mining Director of Austria.

PYRARGYRITE — Ag_3SbS_3

Dark Ruby Silver

Crystallography. Rhombohedral; ditrigonal-pyramidal. Crystals prismatic with hemimorphic development, often with rhombohedral and scalenohedral terminations. Usually distorted and with complex development. Frequently twinned. Also massive, compact, in disseminated grains.

Physical Properties. Rhombohedral cleavage, $\{10\bar{1}1\}$. **H.** = $2\frac{1}{2}$. **G.** = 5.85. Luster adamantine. Translucent. Color deep red to black, in thin splinters deep ruby-red. Streak Indian-red.

Composition. Silver sulfantimonide, Ag_3SbS_3. Ag = 59.7 per cent, Sb = 22.5 per cent, S = 17.8 per cent. May contain a small amount of As. Compare proustite.

Tests. Fusible at 1. On charcoal gives dense white coating of antimony trioxide. After prolonged heating, coating becomes tinged with a reddish color near assay due to a small amount of volatilized silver. Gives the odor of sulfur dioxide and coatings of antimony oxides when heated in the open tube. Decomposed by nitric acid with separation of sulfur; the solution on addition of hydrochloric acid gives white precipitate of silver chloride.

Diagnostic Features. Similar to proustite but of a deeper red color and less translucent.

Occurrence. Pyrargyrite is found in places as an important silver ore. It forms in silver veins at low temperatures as one of the last minerals to crystallize in the sequence of primary deposition. Associated with proustite and other silver sulfo salts, argentite, tetrahedrite, silver.

Notable localities are: at Andreasberg, Harz Mountains; at Freiberg, Saxony; Přibram, Bohemia; Guanajuato, Mexico; at Chanarcillo, Chile; in Bolivia. In the United States is found in various silver veins in Colorado; Nevada; New Mexico; Idaho. In Canada is found in the silver veins at Cobalt, Ontario.

Use. An ore of silver.

Name. Derived from two Greek words meaning *fire* and *silver*, in allusion to its color and composition.

PROUSTITE — Ag_3AsS_3

Light Ruby Silver

Crystallography. Rhombohedral; ditrigonal-pyramidal. Crystals commonly prismatic with prominent steep rhombohedrons and scalenohedrons. Often distorted and frequently complex in development. Commonly massive, compact, in disseminated grains.

Physical Properties. Rhombohedral $\{10\bar{1}1\}$ cleavage. **H.** = 2–2½. **G.** = 5.55. Brittle. Luster adamantine. Color ruby-red. Streak vermilion. Translucent, transparent to red light.

Composition. Silver sulfarsenide, Ag_3AsS_3. Ag = 65.4 per cent, As = 15.2 per cent, S = 19.4 per cent. May contain a small amount of antimony. Compare pyrargyrite.

Tests. Fusible at 1. Heated on charcoal gives volatile sublimate of arsenious oxide with characteristic garlic odor. In the open tube gives odor of sulfur dioxide and volatile crystalline sublimate of arsenious oxide. In the closed tube gives abundant sublimate of arsenic sulfide, reddish black when hot, reddish yellow when cold. With sodium carbonate on charcoal gives a globule of silver. Decomposed by nitric acid with the separation of sulfur.

Diagnostic Features. Characterized chiefly by its ruby-red color and vermilion streak and its brilliant luster. Distinguished from pyrargyrite by being lighter in color and by giving the tests for arsenic.

Occurrence. Proustite is a rare mineral, found in the same localities as pyrargyrite and with similar mode of occurrence and associations.

Use. An ore of silver.

Name. In honor of the French chemist, J. L. Proust (1755–1826).

TETRAHEDRITE — $(Cu,Fe,Zn,Ag)_{12}Sb_4S_{13}$

Gray Copper. Fahlore

Crystallography. Isometric; hextetrahedral. Habit tetrahedral; may be in groups of parallel crystals. Tetrahedron (Fig. 293), tristetrahedron, dodecahedron, and cube the common forms. Frequently in crystals. Also massive, coarse or fine granular.

Physical Properties. **H.** = 3–4½ (with tennantite harder than tetrahedrite). **G.** = 4.6–5.1. Luster metallic, often splendent. Color grayish black to black. Streak black to brown. Opaque.

Composition. Essentially copper, iron, zinc, and silver sulfantimonide, $(Cu,Fe,Zn,Ag)_{12}Sb_4S_{13}$. Cu is always predominant, but considerable substitution takes place by Fe and Zn, less commonly by Ag, Pb, Hg. Arsenic may take the place of antimony in all proportions, and thus there exists a complete series from the pure antimony end member, *tetrahedrite,* to the pure arsenic end member, *tennantite.* The highly argentiferous variety is known as *freibergite.*

Tests. Fusible at 1½. On charcoal or in the open tube gives tests for antimony or arsenic, or both. After roasting, and moistening with hydrochloric acid, gives azure-blue copper chloride flame. Decomposed by nitric acid with separation of sulfur and antimony trioxide; solution made alkaline with ammonia turns blue. Tetrahedrite and tennantite can be told apart only by testing for the presence of antimony and arsenic, and as both are often present in the same specimen a quantitative analysis may be necessary in order to determine positively to which end of the series it belongs.

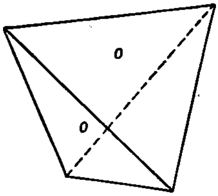


Fig. 293.

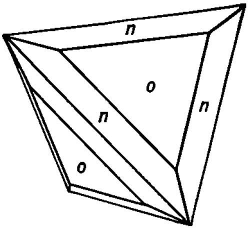


Fig. 294.

Tetrahedrite.

Diagnostic Features. Recognized by its tetrahedral crystals, or when massive by its brittleness and its gray color.

Occurrence. Tetrahedrite, the most common member of the sulfosalt group, is widespread in occurrence and varied in association. Tennantite is less widely distributed. Commonly found in hydrothermal veins of copper or silver minerals formed at low to moderate temperatures. Rarely in higher-temperature veins or in contact metamorphic deposits. Usually associated with chalcopyrite, pyrite, sphalerite, galena, and various other silver, lead, and copper minerals. May carry sufficient silver to become an important ore of that metal.

Notable localities: Cornwall, England; the Harz Mountains, Germany; Freiberg, Saxony; Přibram, Bohemia; various places in Rumania; the silver mines of Mexico, Peru, and Bolivia. Found in the United States in various silver and copper mines in Colorado, Montana, Nevada, Arizona, Utah.

Use. An ore of silver and copper.

Name. Tetrahedrite in allusion to the tetrahedral form of the crystals. Tennantite after the English chemist, Smithson Tennant (1761–1815).

ENARGITE — Cu_3AsS_4

Crystallography. Orthorhombic; pyramidal. Prismatic crystals with prism zone vertically striated, also tabular parallel to basal pinacoid. Columnar, bladed, massive.

Physical Properties. Cleavage perfect prismatic, {110}. **H.** = 3. **G.** = 4.43–4.45. Luster metallic. Color and streak grayish black to iron-black. Opaque.

Composition. Copper sulfarsenide, Cu_3AsS_4. Cu = 48.3 per cent, As = 19.1 per cent, S = 32.6 per cent. Sb substitutes for As up to 6 per cent by weight.

Tests. Fusible at 1. On charcoal gives volatile white sublimate of arsenious oxide and characteristic garlic odor. In the open tube gives white crystalline sublimate of arsenious oxide and odor of sulfur dioxide. Roasted on charcoal, then moistened with hydrochloric acid and again ignited, gives azure-blue copper chloride flame.

Diagnostic Features. Characterized by its color and its cleavage. Distinguished from stibnite by a test for copper.

Occurrence. Enargite is a comparatively rare mineral, found in vein and replacement deposits associated with pyrite, sphalerite, bornite, galena, tetrahedrite, covellite, chalcocite.

Notable localities: Bor, near Zajecar, Yugoslavia. Found abundantly at Morococha and Cerro de Pasco, Peru; also from Chile and Argentina; Island of Luzon, Philippines. In the United States is an important ore mineral at Butte, Montana, and to a lesser extent at Bingham Canyon, Utah. Occurs in the silver mines of the San Juan Mountains, Colorado.

Use. An ore of copper. Arsenic oxide also obtained from it at Butte, Montana.

Name. From the Greek meaning *distinct*, in allusion to the cleavage.

Similar Species. *Famatinite*, Cu_3SbS_4, is the antimony analogue of enargite, but the two minerals have different structures and are not isomorphous.

Jamesonite — $Pb_4FeSb_6S_{14}$

Brittle Feather Ore

Crystallography. Monoclinic; prismatic. Usually in acicular crystals or in capillary forms. Also fibrous to compact massive.

Physical Properties. Basal {001} cleavage. Brittle. **H.** = 2–3. **G.** = 5.5–6. Luster metallic. Color and streak steel-gray to grayish black. Opaque.

Composition. Sulfantimonide of lead, probably $Pb_4FeSb_6S_{14}$. Cu and Zn may be present in small amounts. Apparently several different compounds are often designated "feather ore."

Tests. Fusible at 1. On charcoal gives a combination coating of lead and antimony oxides. Roasted in the open tube gives sublimates of antimony oxides. Heated on charcoal with iodide flux gives a chrome-yellow coating of lead iodide.

Diagnostic Features. Recognized by its characteristic fibrous (feathery) appearance, and distinguished from stibnite by lack of good lengthwise cleavage. Difficult to distinguish from similar species (see below).

Occurrence. Jamesonite is found in ore veins formed at low to moderate temperatures. Associated with other lead sulfo salts, with galena, stibnite, tetrahedrite, sphalerite.

Found in Cornwall, England, and from various localities in Czechoslovakia, Rumania, Saxony; from Tasmania and Bolivia. In the United States from Sevier County, Arkansas, and at Silver City, South Dakota.

Use. A minor ore of lead.

Name. After the mineralogist, Robert Jameson (1774–1854) of Edinburgh.

Similar Species. A number of minerals similar to jamesonite in composition and general physical characteristics are included under the term *feather ore.* These include such minerals as *zinkenite,* $Pb_6Sb_{14}S_{27}$; *boulangerite,* $Pb_5Sb_4S_{11}$; *meneghinite,* $Pb_{13}Sb_7S_{23}$. Other minerals of similar composition but different habit are: *plagionite,* $Pb_5Sb_8S_{17}$; *semseyite,* $Pb_9Sb_8S_4$; *geocronite,* $Pb_5(Sb,As)_2S_8$.

Bournonite — $PbCuSbS_3$

Cogwheel Ore

Crystallography. Orthorhombic; dipyramidal. Crystals usually short prismatic to tabular. May be complex with many prism, pyramid, and dome faces. Frequently twinned, giving tabular crystals with recurring re-entrant angles in the prism zone (Fig. 295), whence the common name of *cogwheel ore.* Also massive; granular to compact.

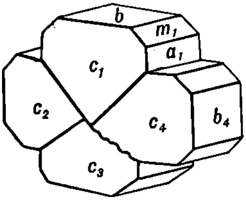


FIG. 295. Bournonite.

Physical Properties. H. = $2\frac{1}{2}$–3. G. = 5.8–5.9. Luster metallic. Color and streak steel-gray to black. Opaque.

Composition. A sulfantimonide of lead and copper, $PbCuSbS_3$. The percentages of the elements: Pb = 42.4, Cu = 13.0, Sb = 24.9, S = 19.7. Arsenic may substitute for antimony to about Sb : As = 4 : 1.

Tests. Fusible at 1. Before the blowpipe on charcoal gives a combination coating of antimony and lead oxides. Roasted in the open tube gives sublimates of antimony oxides. Heated on charcoal with a mixture of potassium iodide and sulfur gives a chrome-yellow coating of lead iodide. Decomposed with nitric acid, with separation of sulfur, solution turns blue with excess of ammonia (copper).

Diagnostic Features. Recognized by its characteristic crystals, high specific gravity, and above tests.

Occurrence. Bournonite, one of the commonest of the sulfo salts, occurs typically in hydrothermal veins formed at moderate temperature. It is associated with galena, tetrahedrite, chalcopyrite, sphalerite, pyrite. Frequently noted as microscopic inclusions in galena.

Notable localities are: the Harz Mountains; Kapnik and elsewhere in Rumania; Liskeard, Cornwall; also found in Australia, Mexico, and Bolivia. In the United States has been found in various places in Arizona, Utah, Nevada, Colorado, and California, but not in notable amount or quality.

Use. An ore of copper, lead, and antimony.

Name. After Count J. L. de Bournon (1751-1825), French crystallographer and mineralogist.

OXIDES

The oxide class contains several minerals of great economic importance, notably: hematite, magnetite, chromite, cassiterite, and bauxite.

Quartz and the other silica minerals are considered (page 273) under the silicates. The anhydrous oxides are given first, followed by the hydrous oxides.

Oxides

	Ice	H_2O
	Cuprite	Cu_2O
	Zincite	ZnO
	Corundum	Al_2O_3
	Hematite	Fe_2O_3
	Ilmenite	$FeTiO_3$
SPINEL GROUP	Spinel	$MgAl_2O_4$
	Gahnite	$ZnAl_2O_4$
	Magnetite	Fe_3O_4
	Franklinite	$(Fe,Zn,Mn)(Fe,Mn)_2O_4$
	Chromite	$FeCr_2O_4$
	Chrysoberyl	$BeAl_2O_4$
	Cassiterite	SnO_2
	Rutile	TiO_2
	Pyrolusite	MnO_2
	Columbite	$(Fe,Mn)(Cb,Ta)_2O_6$

Hydrous Oxides

Diaspore	$AlO(OH)$
Goethite	$FeO(OH)$
Manganite	$MnO(OH)$
Limonite	$FeO(OH)\cdot nH_2O$
Bauxite	Aluminum hydrates
Brucite	$Mg(OH)_2$
Psilomelane	$H_4R_2Mn_8O_{20}$

Ice — H_2O

Crystallography. Hexagonal; dihexagonal-pyramidal. Ice in the form of snow shows a great diversity of habit in the beautiful lacelike crystals. In countless crystals differing in detail, the hexagonal outline may be seen. Ice occurs most abundantly in massive and granular form.

Physical Properties. **H.** = 1½. **G.** = 0.917. Luster vitreous. Colorless to white.

Composition. H_2O. H = 11.19, O = 88.81. Frequently contains foreign material.

Occurrence. Ice forms on the surface of open water in cold regions, is precipitated in the form of snow and hail, and crystallizes in place as frost. In polar regions permanent ice exists; the largest masses today being in the icecaps of Greenland and Antarctica. Smaller amounts are to be found in mountain glaciers and, in the winter, on the surface of lakes and rivers and as snow on the land in more temperate zones.

CUPRITE — Cu_2O

Ruby Copper, Red Copper Ore

Crystallography. Isometric; gyroidal. Commonly in crystals showing the cube, octahedron, and dodecahedron, frequently in combination (Fig. 296). Sometimes in much elongated cubic crystals, capillary in size; known as "plush copper" or *chalcotrichite.* Frequently in fine-grained aggregate or massive.

Physical Properties. **H.** = $3\frac{1}{2}$-4. **G.** = 6. Luster metallic-adamantine in clear crystallized varieties. Color red of various shades; ruby-red in transparent crystals. Streak brownish red, Indian-red.

Composition. Cuprous oxide, Cu_2O. Cu = 88.8 per cent, O = 11.2 per cent. Usually pure, but iron oxide may be present as an impurity.

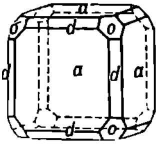


FIG. 296.

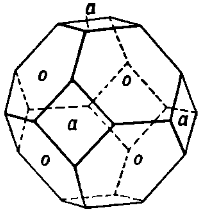


FIG. 297.

Cuprite.

Tests. Fusible at 3. Azure-blue copper chloride flame obtained if moistened with hydrochloric acid and then heated. Gives globule of copper on charcoal in the reducing flame. When dissolved in small amount of concentrated hydrochloric acid and solution diluted with cold water gives a white precipitate of cuprous chloride (test for cuprous copper).

Diagnostic Features. Usually distinguished from other red minerals by its crystal form, high luster, streak, and association.

Occurrence. Cuprite is an important ore of copper of secondary origin. It is found in the upper oxidized portions of copper veins, associated with limonite and the other secondary copper minerals as native copper, malachite, azurite, chrysocolla.

Noteworthy foreign countries where cuprite is an ore are Chile, Bolivia, Australia, French Congo. Fine crystals have been found at Cornwall, England; Chessy, France; and the Ural Mountains. Found in the United States in excellent crystals in connection with the copper deposits at Bisbee, Arizona. Also found at Clifton and Morenci, Arizona.

Use. An ore of copper.

Name. Derived from the Latin *cuprum*, copper.

Similar Species. *Tenorite* or *melaconite*, the cupric oxide, CuO, is a black mineral of secondary origin.

ZINCITE — ZnO

Crystallography. Hexagonal; dihexagonal-pyramidal. Crystals are rare, terminated at one end by faces of a steep pyramid and the other with a basal plane. Usually massive with platy or granular appearance.

Physical Properties. Perfect prismatic $\{10\bar{1}0\}$ cleavage; basal parting. **H.** = $4\text{–}4\frac{1}{2}$. **G.** = 5.5. Luster subadamantine. Color deep red to orange-yellow. Streak orange-yellow. Translucent.

Composition. Zinc oxide, ZnO. Zn = 80.3 per cent, O = 19.7 per cent. Manganese protoxide often present and probably colors the mineral; chemically pure ZnO is white.

Tests. Infusible. Soluble in hydrochloric acid. When the finely powdered mineral is mixed with reducing mixture and intensely heated on charcoal it gives a nonvolatile coating of zinc oxide, yellow when hot, white when cold. Usually with borax bead in the oxidizing flame gives a reddish violet color (manganese).

Diagnostic Features. Told chiefly by its red color, orange-yellow streak, and the association with franklinite and willemite.

Occurrence. Zincite is confined almost exclusively to the zinc deposits at Franklin, New Jersey, where it is associated with franklinite and willemite, often in an intimate mixture. (See frontispiece.) Also imbedded in pink calcite. Reported only in small amounts from other localities.

Use. An ore of zinc, particularly used for the production of zinc white (zinc oxide).

CORUNDUM — Al_2O_3

Crystallography. Rhombohedral; scalenohedral. Crystals usually prismatic in habit or tapering hexagonal pyramids (Figs. 298 and 299). Often rounded into barrel shapes. Frequently with deep horizontal striations. May show rhombohedral faces (Fig. 300). Usually rudely crystallized or massive with parting planes nearly cubic in angle; coarse or fine granular.

Physical Properties. Parting basal $\{0001\}$ and rhombohedral $\{10\bar{1}1\}$, the latter giving nearly cubic angles; more rarely prismatic parting. **H.** = 9 (next to the diamond in hardness). **G.** = 4.02 (unusually high for a nonmetallic mineral). Luster adamantine to vitreous. Transparent to translucent. Color various; usually some shade of brown, pink, or blue. May be white, gray, green, ruby-red, or sapphire-blue.

Color difference gives rise to several varieties of gem corundum. The *ruby* is the deep red and the *sapphire* is the blue. Varieties having a stellate opalescence when viewed in the direction of the *c* crystal axis are termed asteriated, or *star sapphire* or *star ruby*.

Emery is a black granular corundum intimately mixed with magnetite, hematite, or iron spinel.

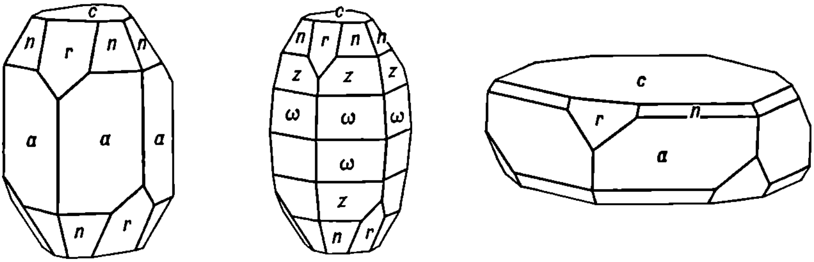


Fig. 298. Fig. 299. Fig. 300.

Corundum.

Composition. Aluminum oxide, Al_2O_3. Al = 52.9 per cent, O = 47.1 per cent.

Tests. Infusible. Insoluble. Finely pulverized material moistened with cobalt nitrate and intensely ignited assumes a blue color (aluminum).

Diagnostic Features. Characterized chiefly by its great hardness, high luster, specific gravity, and parting.

Occurrence. Corundum is common as an accessory mineral in the metamorphic rocks, such as crystalline limestone, mica-schist, gneiss. Found also as an original constituent of certain igneous rocks; usually those deficient in silica, as syenites and nepheline syenites. May be found in large masses in the zone separating peridotites from adjacent country rocks. It is disseminated in small crystals through certain lamprophyric dikes. Found frequently in crystals and rolled pebbles in detrital soil and stream sands, where it has been preserved through its hardness and chemical inertness. Associated minerals are commonly chlorite, micas, olivine, serpentine, magnetite, spinel, kyanite, diaspore.

Rubies are found chiefly in Burma, Siam, and Ceylon. The most important locality in Burma is near Mogok, 90 miles north of Mandalay. The stones are found here chiefly in the soil resulting from the solution of a metamorphosed limestone. They have also been found *in situ* in the limestone. The rubies of Siam are found near Bangkok, on the Gulf of Siam, where they occur in a clay, derived from the decomposition of a basalt. The rubies of Ceylon are found with other gem stones in the stream gravels. In the United States a few rubies have been found in the gravels and in connection with the larger corundum deposits of North Carolina.

Sapphires are found associated with the rubies of Siam and Ceylon. They occur in Kashmir, India, and are found over an extensive area in central Queensland, Australia. In the United States small sapphires of fine color are found in various localities in Montana. They were first discovered in the river sands east of Helena when washing them for gold, and have more recently been found imbedded in the rock of a lamprophyre dike at Yogo Gulch. The rock is mined and after exposure to the air for a time it gradually decomposes, setting the sapphires free.

Common corundum is found in the United States in various localities along the eastern edge of the Appalachian Mountains in North Carolina and Georgia. It has been extensively mined in southwestern North Carolina. It occurs here in large masses lying at the edges of intruded masses of an olivine rock (dunite) and is thought to have been a separation from the original magma. Found as an original constituent of a nepheline syenite in the Province of Ontario, Canada. At times the corundum is so abundant as to form more than 10 per cent of the rock mass.

Emery is found in large quantities on Cape Emeri on the island of Naxos and in various localities in Asia Minor. In the United States emery has been extensively mined at Chester, Massachusetts.

Artificial. Artificial corundum is now being made from bauxite on a large scale in the electrical furnaces at Niagara Falls. Synthetic rubies and sapphires, colored with minute amounts of chromium, are made in considerable amount in Switzerland and France. It is difficult to distinguish many of these from the naturally occurring stones. Also small grains of the natural stone have been fused together into larger masses, from which stones of two or three carats in size can be cut. These are known as reconstructed rubies and sapphires.

Use. As a gem stone. The deep red ruby is one of the most valuable of gems, second only to emerald. The blue sapphire is also valuable, and stones of other colors may command good prices. Stones of gem quality are used as watch jewels and as bearings in scientific instruments.

Used also as an abrasive, either ground from the pure massive material or in its impure form as emery. Artificial Al_2O_3 and other artificial products have largely replaced corundum as an abrasive.

HEMATITE — Fe_2O_3

Crystallography. Rhombohedral; scalenohedral. Crystals usually thick to thin tabular. Basal planes prominent, often showing triangular markings (Figs. 301 and 302). Edges of plates may be beveled with rhombohedral forms (Fig. 303). Thin plates may be grouped in rosette forms (iron roses) (Fig. 304). More rarely crystals are distinctly rhombohedral, often with nearly cubic angles. Usually earthy. Also in botryoidal to reniform shapes with radiating structure, *kidney ore.* (See Plate II, page 67.) May also be micaceous and foliated, *specular.* Called *martite* when in octahedrons pseudomorphous after magnetite.

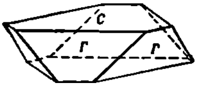


FIG. 301.

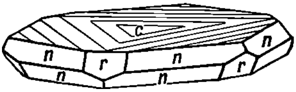


FIG. 302.

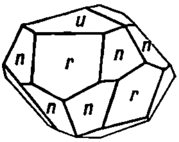


FIG. 303.

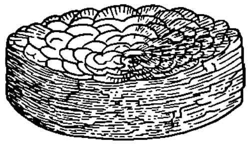


FIG. 304.

Hematite.

Physical Properties. Rhombohedral parting with nearly cubic angles. **H.** = $5\frac{1}{2}$–$6\frac{1}{2}$. **G.** = 5.26. Luster metallic. Color reddish brown to black. Red earthy variety is known as *red ocher.* Streak light to dark Indian-red which becomes black on heating. Translucent.

Composition. Ferric oxide, Fe_2O_3. Fe = 70 per cent, O = 30 per cent. May contain titanium and magnesium, passing into ilmenite.

Tests. Infusible. Becomes strongly magnetic on heating in the reducing flame. Slowly soluble in hydrochloric acid; solution with potassium ferrocyanide gives dark blue precipitate (test for ferric iron).

Diagnostic Features. Told chiefly by its characteristic Indian-red streak.

Occurrence. Hematite is a widely distributed mineral in rocks of all ages and forms the most abundant ore of iron. It may occur as a sublimation product in connection with volcanic activities. Occurs in contact metamorphic deposits, and as an accessory mineral in feldspathic igneous rocks such as granite. Also replaces siliceous rocks on a large scale. Found from microscopic scales to enormous masses in connection with regionally metamorphosed rocks where it may have originated by the alteration of limonite, siderite, or magnetite. Like limonite, it may be formed in irregular masses and beds as the result of the weathering of iron-bearing rocks. The oölitic ores are of sedimentary origin and may occur in beds of considerable size. It is found in red sandstones as the cementing material that binds the quartz grains together.

Noteworthy localities for hematite crystals are the island of Elba; St. Gothard, Switzerland, in " iron roses "; in the lavas of Vesuvius; at Cleator Moor, Cumberland, England.

In the United States the columnar and earthy varieties are found in enormous beds that furnish a large proportion of the iron ore of the world. The chief iron-ore districts of the United States are grouped around the southern and northwestern shores of Lake Superior in Michigan, Wisconsin, and Minnesota. The chief districts, which are spoken of as iron ranges, are, from east to west, the Marquette in northern Michigan; the Menominee in Michigan to the southwest of the Marquette; the Penokee-Gogebic in northern Wisconsin. In Minnesota the Mesabi, northwest of Duluth, and the Vermilion, near the Canadian boundary. The iron ore of these different ranges varies from the hard specular variety to the soft red earthy type. They are mined in part by underground methods, and in part, where the ore is soft and lies sufficiently near the surface, by means of large electric shovels.

Hematite is also found in the United States in the rocks of the Clinton formation which extends from central New York south along the line of the Appalachian Mountains to central Alabama. The most important deposits of the series lie in eastern Tennessee and northern Alabama, near Birmingham. Hematite has been found at Iron Mountain and Pilot Knob in southeastern Missouri. Deposits of considerable importance are located in Wyoming, in Laramie and Carbon Counties.

Use. Most important ore of iron. Also used in red pigments and as polishing powder.

Name. Derived from a Greek word meaning *blood*, in allusion to the color of the powdered mineral.

ILMENITE — $FeTiO_3$

Titanic Iron Ore, Menaccanite

Crystallography. Rhombohedral; trigonal-rhombohedral. Crystals usually thick tabular with prominent basal planes and small rhombohedral truncations. Faces of the third order rhombohedron rare. Crystal constants close to those for hematite. Often in thin plates. Usually massive, compact; also in grains or as sand.

Physical Properties. **H.** = $5\frac{1}{2}$–6. **G.** = 4.7. Luster metallic to submetallic. Color iron-black. Streak black to brownish red. May be magnetic without heating. Opaque.

Composition. Ferrous titanate, $FeTiO_3$. Fe = 36.8 per cent, Ti = 31.6 per cent, O = 31.6 per cent. By the introduction of ferric oxide, the ratio between the titanium and iron often varies widely. The excess of ferric oxide may be largely due to minute inclusions of hematite. Magnesium may replace the ferrous iron.

Tests. Infusible. Magnetic after heating. Fine powder fused in the reducing flame with sodium carbonate yields a magnetic mass. After fusion with sodium carbonate it can be dissolved in sulfuric acid, and on the addition of hydrogen peroxide the solution turns yellow.

Diagnostic Features. Ilmenite can be distinguished from hematite by its streak and from magnetite by its lack of magnetism. In doubtful cases, as in intergrowths with magnetite, it is necessary to apply the chemical tests.

Occurrence. Ilmenite occurs as beds and lenticular bodies enveloped in gneiss and other crystalline metamorphic rocks. Frequently found in veins or large masses as a product of magmatic segregation. Associated with magnetite. Also as an accessory mineral in igneous rocks. One of the constituents of black sands, associated with magnetite, rutile, zircon, and monazite.

Found in large quantities at Krägerö and other localities in Norway; in crystals at Miask in the Ilmen Mountains, U.S.S.R. In the United States found at Washington, Connecticut; in Orange County, New York, and with many of the magnetite deposits of the Adirondack region. Also found at Bay St. Paul in Quebec.

Use. As a source of titanium for paint pigment. Cannot be used as an iron ore because of difficulties in smelting it. Moreover, a small amount present in a magnetite body renders it of little value as an ore.

Name. From the Ilmen Mountains, U.S.S.R.

SPINEL — $MgAl_2O_4$

Crystallography. Isometric; hexoctahedral. Usually in octahedral crystals (Fig. 305). In twinned octahedrons (spinel twins) (Fig. 307). Dodecahedron may be present as small truncations (Fig. 306). Other forms rare.

Physical Properties. **H.** = 8. **G.** = 3.5–4.1. Nonmetallic. Luster vitreous. Color various: white, red, lavender, blue, green, brown, black. Streak white. Usually translucent, may be clear and transparent.

Composition. $MgAl_2O_4$. $MgO = 28.2$ per cent, $Al_2O_3 = 71.8$ per cent. The magnesium may be replaced, in part, by ferrous iron or manganese, and the aluminum by ferric iron and chromium. The clear red, nearly pure, magnesium spinel is known as *ruby spinel*. *Pleonaste* is the iron spinel, dark green to black; and *picotite* is the chrome spinel, yellowish to greenish brown.

Tests. Infusible. The finely powdered mineral dissolves completely in the salt of phosphorus bead (proving the absence of silica).

Diagnostic Features. Recognized by its hardness (8), its octahedral crystals, and its vitreous luster. The iron spinel can be distinguished from magnetite by its nonmagnetic character and white streak.

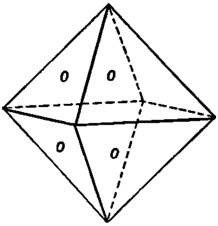


FIG. 305.

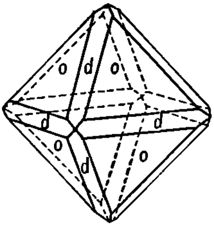


FIG. 306.

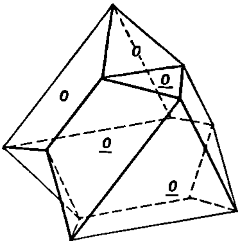


FIG. 307.

Spinel.

Occurrence. Spinel is a common metamorphic mineral occurring imbedded in crystalline limestone, gneisses, and serpentine. Occurs also as an accessory mineral in many basic igneous rocks. Spinel is frequently formed as a contact metamorphic mineral associated with phlogopite, pyrrhotite, chondrodite, and graphite. Found frequently as rolled pebbles in stream sands, where it has been preserved because of its resistant physical and chemical properties. The ruby spinels are found in this way, often associated with the gem corundum, in the sands of Ceylon, Siam, Upper Burma, Madagascar. Ordinary spinel is found in various localities in New York and New Jersey.

Use. When transparent and finely colored is used as a gem. Usually red in color and known as the spinel ruby or *balas ruby*. Some stones are blue in color. The largest cut stone known weighs in the neighborhood of 80 carats. The stones usually are comparatively inexpensive.

Artificial. Synthetic spinel has been made in various colors rivaling the natural stones in beauty. Synthetic spinel is also used as a refractory.

Gahnite — $ZnAl_2O_4$

Zinc Spinel

Crystallography. Isometric; hexoctahedral. Commonly octahedral with faces striated parallel to the edge between the dodecahedron and octahedron (Fig. 308). Less frequently showing well-developed dodecahedrons and cubes.

Physical Properties. H. = 7½–8. **G.** = 4.55. Luster vitreous. Color dark green. Streak grayish. Translucent.

Composition. A zinc spinel, $ZnAl_2O_4$. Ferrous iron and manganese may replace zinc, and ferric iron aluminum.

Tests. Infusible. The fine powder fused with sodium carbonate on charcoal gives a white nonvolatile coating of zinc oxide.

Diagnostic Features. Characterized by crystal form (striated octahedrons) and hardness.

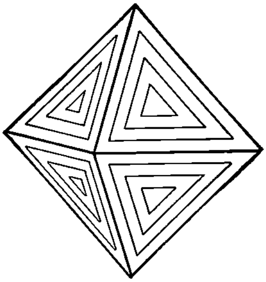


FIG. 308. Gahnite.

Occurrence. Gahnite occurs in zinc deposits and also as a contact mineral in crystalline limestones. Found in large crystals at Bodenmais, Bavaria; in a talcose schist near Falun, Sweden. In the United States found at Charlemont, Massachusetts.

Name. After the Swedish chemist, J. G. Gahn.

MAGNETITE — Fe_3O_4

Crystallography. Isometric; hexoctahedral. Frequently in crystals of octahedral habit (Fig. 309), occasionally twinned. More rarely in dodecahedrons (Fig. 310). Dodecahedrons may be striated parallel to the intersection with the octahedrons (Fig. 311). Other forms rare. Usually granular massive, coarse or fine grained.

Physical Properties. Octahedral parting on some specimens. **H.** = 6. **G.** = 5.18. Luster metallic. Color iron-black. Streak black. Strongly magnetic; may act as a natural magnet, known as *lodestone*. Opaque.

Composition. Fe_3O_4 or $FeFe_2O_4$. Fe = 72.4 per cent, O = 27.6 per cent.

Tests. Infusible. Slowly soluble in HCl and solution reacts for both ferrous and ferric iron.

Diagnostic Features. Characterized chiefly by its strong magnetism, its black color, and its hardness (6). Can be distinguished from magnetic franklinite by streak.

Occurrence. Magnetite is a common ore of iron. It is found disseminated as an accessory mineral through most igneous rocks. In certain types through magmatic segregation becomes one of the chief constituents, and may thus form large ore bodies. Such bodies are often highly titaniferous. Most commonly associated with crystalline metamorphic rocks, also frequently in rocks that are rich in ferromagnesian minerals, such as diorite, gabbro, peridotite. Occurs also in immense beds and lenses, inclosed in old metamorphic rocks. Found in the black sands of the seashore. Occurs as thin plates and dendritic growths between plates of mica. Often intimately associated with corundum, forming the material known as *emery*.

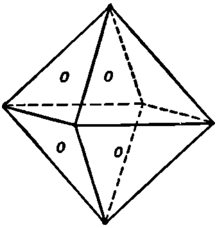


Fig. 309.

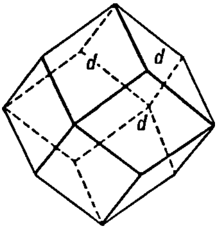


Fig. 310.

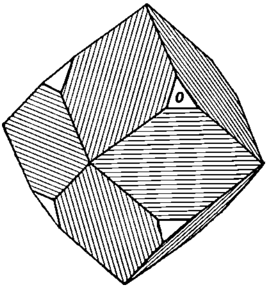


Fig. 311.

The largest magnetite deposits in the world are in northern Sweden at Kiruna and Gellivare, and are believed to have formed by magmatic segregation. Other important foreign deposits are in Norway, Rumania, Ural Mountains. The most powerful natural magnets are found in Siberia, the Harz Mountains, on the Island of Elba, and in the Bushveld complex, Transvaal.

In the United States found in several localities in the Adirondack region in New York; New Jersey; Pennsylvania; Utah. Found as lodestone and in crystals at Magnet Cove, Arkansas.

Use. An important iron ore.

Name. Probably derived from the locality Magnesia, bordering on Macedonia. A fable, told by Pliny, ascribes its name to a shepherd named Magnes, who first discovered the mineral on Mount Ida by noting that the nails of his shoes and the iron ferrule of his staff adhered to the ground.

FRANKLINITE — $(Fe,Zn,Mn)(Fe,Mn)_2O_4$

Crystallography. Isometric; hexoctahedral. Habit strongly octahedral. Dodecahedron as truncations. Other forms rare. Crystals often rounded. Also massive, coarse or fine granular, in rounded grains.

Physical Properties. **H.** = 6. **G.** = 5.15. Luster metallic. Color iron-black. Streak dark brown. Slightly magnetic.

Composition. $(Fe,Zn,Mn)(Fe,Mn)_2O_4$. Shows wide variation in the proportions of the different elements present, but conforms to the general formula, $R''R_2'''O_4$.

Tests. Infusible. Becomes strongly magnetic on heating in the reducing flame. Gives a bluish green color to sodium carbonate bead in the oxidizing flame (manganese). Very fine powder mixed with sodium carbonate and heated intensely on charcoal gives a coating of zinc oxide.

Diagnostic Features. Resembles magnetite but is only slightly attracted by the magnet and has a dark brown streak. Usually identified by its characteristic association with willemite and zincite.

Occurrence. Franklinite, with only minor exceptions, is confined to the zinc deposits at Franklin, New Jersey, which are in the form of large lenses, inclosed in granular limestone. Associated chiefly with zincite and willemite, with which it is often intimately intergrown. (See frontispiece.)

Use. As an ore of zinc and manganese. The zinc is converted into zinc white, and the residue is smelted to form an alloy of iron and manganese, *spiegeleisen*, which is used in the manufacture of steel.

Name. From Franklin, New Jersey.

CHROMITE — $FeCr_2O_4$

Crystallography. Isometric; hexoctahedral. Habit octahedral. Crystals small and rare. Commonly massive, granular to compact.

Physical Properties. **H.** = $5\frac{1}{2}$. **G.** = 4.6. Luster metallic to submetallic; frequently pitchy. Color iron-black to brownish black. Streak dark brown. Subtranslucent.

Composition. $FeCr_2O_4$. $FeO = 32.0$ per cent, $Cr_2O_3 = 68.0$ per cent. The iron may be replaced by magnesium, and the chromium by aluminum and ferric iron.

Tests. Infusible. When finely powdered and fused on charcoal with sodium carbonate gives a magnetic residue. Imparts a green color to the borax and salt of phosphorus beads (chromium).

Diagnostic Features. The submetallic luster usually distinguishes chromite, but the green borax bead is diagnostic.

Occurrence. Chromite is a common constituent of peridotite rocks and the serpentines derived from them. One of the first minerals to separate from a cooling magma; large chromite ore deposits are thought to have been derived by such magmatic differentiation. Associated with olivine, serpentine, corundum.

The important countries for its production are New Caledonia, Southern Rhodesia, Greece, U.S.S.R., and Canada. Found only sparingly in the United States. Pennsylvania, Maryland, North Carolina, and Wyoming have produced it in the past. California is the only important producing state at present (1940). Also found in the Philippine Islands.

Uses. The only ore of chromium. (See page 392.) Chromium is used with various other metals to give hardness to steel, also as a plating material because of its non-corrosive nature. Chromite bricks are used to a considerable extent as linings for metallurgical furnaces, because of their neutral and refractory character. The bricks are usually made of crude chromite and coal tar but sometimes of chromite with kaolin, bauxite, or other materials. Chromium is a constituent of certain green, yellow, orange, and red pigments and of similarly colored dyes.

CHRYSOBERYL — $BeAl_2O_4$

Crystallography. Orthorhombic; dipyramidal. Usually in crystals tabular parallel to macropinacoid, {100}, the faces of which are vertically striated. Commonly twinned, giving pseudohexagonal appearance (Fig. 312).

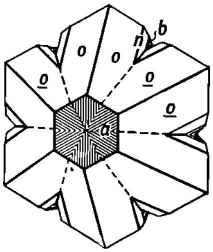


FIG. 312. Chrysoberyl.

Physical Properties. Prismatic {110} cleavage. **H.** = $8\frac{1}{2}$ (unusually high). **G.** = 3.65–3.8. Luster vitreous. Color various shades of green, brown, yellow; may be red by transmitted light.

Alexandrite is an emerald-green variety, but red by transmitted light and generally also by artificial light. *Cat's-eye,* or *cymophane,* is a variety which when polished shows an opalescent luster, and across whose surface plays a long narrow beam of light, changing its position with every movement of the stone. This effect, known as chatoyancy, is best obtained when the stone is cut in an oval or round form (en cabochon). This property of the mineral is thought to be due to numerous minute tubelike cavities, arranged in a parallel position. Chrysoberyl is the true *cat's-eye* and is not to be confused with various minerals possessing similar properties (e.g., quartz).

Composition. Beryllium aluminate, $BeAl_2O_4$. $BeO = 19.8$ per cent, $Al_2O_3 = 80.2$ per cent. $Be = 7.1$ per cent.

Tests. Infusible. Insoluble. The finely powdered mineral is wholly soluble in the salt of phosphorus bead (absence of silica). Mineral, moistened with cobalt nitrate and ignited, turns blue (aluminum).

Diagnostic Features. Characterized by its extreme hardness, its yellowish to emerald-green color, and its twin crystals.

Occurrence. Chrysoberyl is a rare mineral. It occurs in granitic rocks and pegmatites and in mica schists. Frequently in river sands and gravels. The outstanding alluvial gem deposits are found in Brazil and Ceylon; the *alexandrite* variety comes from the Ural Mountains. In the United States chrysoberyl is found rarely of gem quality. It has been found in Oxford County and elsewhere in Maine; Haddam, Connecticut; Greenfield, New York. Recently found in Colorado.

Use. Serves as a gem stone. The ordinary yellowish green stones are inexpensive; the varieties alexandrite and cat's-eye are of considerable value.

Name. *Chrysoberyl* means *golden beryl. Cymophane* is derived from two Greek words meaning *wave* and *to appear,* in allusion to the chatoyant effect of some of the stones. *Alexandrite* was named in honor of Alexander II of Russia.

CASSITERITE — SnO_2

Tin Stone

Crystallography. Tetragonal; ditetragonal-dipyramidal. Common forms are prisms and dipyramids of first and second orders (Fig. 313). Frequently in elbow-shaped twins with a characteristic notch, giving rise to the miner's term *visor tin* (Fig. 314); the twin plane is the dipyramid of the second order,, {011}. Usually massive granular; often in reniform shapes with radiating fibrous appearance, *wood tin.*

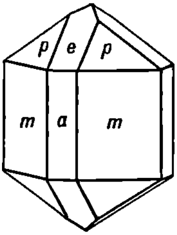


FIG. 313.

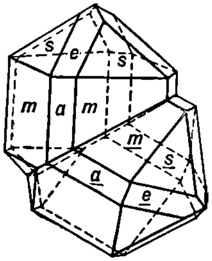


FIG. 314.

Cassiterite.

Physical Properties. H. = 6–7. G. = 6.8–7.1 (unusually high for a mineral with nonmetallic luster). Luster adamantine to submetallic and dull. Color usually brown or black; rarely yellow or white. Streak white. Translucent, rarely transparent.

Composition. Tin dioxide, SnO_2. Sn = 78.6 per cent, O = 21.4 per cent. Small amounts of iron may be present.

Tests. Infusible. Gives globule of tin with coating of white tin oxide when finely powdered mineral is fused on charcoal with the reducing mixture. Insoluble. When fragments of cassiterite are placed in dilute hydrochloric acid together with a little metallic zinc the surface of the cassiterite is reduced and the specimen becomes coated with a dull gray deposit of metallic tin which becomes bright on rubbing.

Diagnostic Features. Recognized by its high specific gravity, adamantine luster, and light streak.

Occurrence. Cassiterite is widely distributed in small amounts but is produced on a commercial scale in only a few localities. It has been noted as an original constituent of igneous rocks and pegmatites, but it is more commonly to be found in veins associated with quartz, in or near granitic rocks. Tin veins usually have minerals which contain fluorine and boron, such as tourmaline, topaz, fluorite, and apatite, and the minerals of the wall rocks are commonly much altered. It is thought, therefore, that the tin veins have been formed through the agency of vapors which carried tin with boron and fluorine. Frequently associated with wolframite. Cassiterite is also found in the form of rolled pebbles in placer deposits, *stream tin.*

Most of the world's supply of tin ore comes from the Malay States, Netherlands East Indies, Bolivia, Siam, Nigeria. Cornwall, England, has produced large amounts of tin ore in the past. In the United States cassiterite is not at present found in sufficient quantities to warrant mining.

Use. Principal ore of tin. Chief use of tin is in coating or "tinning" metals, particularly iron, to form what is known as sheet tin. Tin is also used in various alloys; solder, containing tin and lead; bell-metal and bronze, containing copper and tin. (See page 402.)

Name. From the Greek word meaning tin.

RUTILE — TiO_2

Crystallography. Tetragonal; ditetragonal-dipyramidal. Prismatic crystals with dipyramid terminations common (Fig. 315). Vertically striated. Frequently in elbow twins, often repeated (Figs. 316 and 317). Twinning plane is dipyramid of second order $\{011\}$. Crystals frequently slender acicular. Also compact massive.

Physical Properties. **H.** = 6–6½. **G.** = 4.18–4.25. Luster adamantine to submetallic. Color red, reddish brown to black. Streak pale brown. Usually subtranslucent, may be transparent.

Composition. Titanium dioxide, TiO_2. Ti = 60 per cent, O = 40 per cent. A little iron is usually present and may amount to 10 per cent.

Tests. Infusible. Insoluble. After fusion with sodium carbonate it can be dissolved in sulfuric acid; the solution turns yellow on addition of hydrogen peroxide.

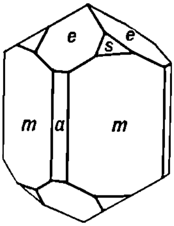


FIG. 315.

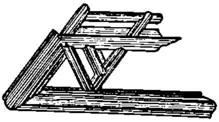


FIG. 316.

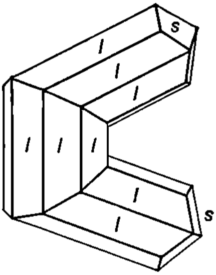


FIG. 317.

Rutile.

Diagnostic Features. Characterized by its peculiar adamantine luster and red color. Lower specific gravity distinguishes it from cassiterite.

Occurrence. Rutile is found in granite, granite pegmatites, gneiss, mica schist, metamorphic limestone, and dolomite. It may be present as an accessory mineral in the rock, or in quartz veins traversing it. Often occurs as slender crystals penetrating quartz. (See Plate XIII, page 276.) Is found in considerable quantities in black sands associated with magnetite, zircon, and monazite.

Notable European localities are: Krägerö, Norway; Yrieix, near Limoges, France; in Switzerland and the Tyrol. In the United States remarkable crystals come from Graves Mountain, Lincoln County, Georgia. Also found in Alexander County, North Carolina, and at Magnet Cove, Arkansas. Has been mined in Amherst and Nelson Counties, Virginia, and derived in commercial quantities from the black sands of northeastern Florida.

Use. Source of titanium. Titanium is used to a small extent in steel and cast iron; for electrodes in arc lights; to give a yellow color to porcelain and false teeth. Titanium oxide is used as a paint pigment.

Name. From the Latin *rutilus*, red, in allusion to the color.

Similar Species. *Octahedrite* or *anatase* (tetragonal) and *brookite* (orthorhombic) are polymorphous forms of TiO_2.

Perovskite, $CaTiO_3$, is an isometric titanium mineral found usually in metamorphic rocks.

PYROLUSITE — MnO_2

Crystallography. Tetragonal; ditetragonal-dipyramidal. Rarely in well-developed crystals, *polianite*. Many crystals pseudomorphous after manganite. Usually in radiating fibers or columns. Also granular massive; often in reniform coats and dendritic shapes (Plate IX).

Physical Properties. Prismatic cleavage {110}, perfect. **H.** = 1–2 (often soiling the fingers). For coarsely crystalline polianite the hardness is 6–6½. **G.** = 4.75. Luster metallic. Color and streak iron-black. Fracture splintery. Opaque.

Dendrites of Pyrolusite on Limestone, Sardinia.

PLATE IX

Composition. Manganese dioxide, MnO_2. Mn = 63.2 per cent, O = 36.8 per cent. Commonly contains a little water.

Tests. Infusible. A small amount of powdered mineral gives in the oxidizing flame a reddish violet bead with borax or a bluish green opaque bead with sodium carbonate. Gives oxygen in the closed tube, which will cause a splinter of charcoal to ignite when placed in tube above the mineral and heated. Only a small amount of water in the closed tube. In hydrochloric acid, chlorine gas evolved.

Diagnostic Features. Characterized by and distinguished from other manganese minerals by its black streak, low hardness, and small amount of water.

Occurrence. Pyrolusite is a secondary mineral. Manganese is dissolved out of the crystalline rocks, in which it is almost always present in small amounts, and redeposited as various minerals, chiefly as pyrolusite. Dendritic coatings of pyrolusite are frequently observed on the surfaces of fractures and coating pebbles. Nodular deposits of pyrolusite are found on the sea bottom. Nests and beds of manganese ores are found inclosed in residual clays, derived from the decay of manganiferous limestones. It is thought that the manganese oxides were originally colloidal, having subsequent to deposition assumed a crystalline form. Also found in veins with quartz and various metallic minerals.

Pyrolusite is the most common manganese ore and is widespread in its occurrence. The chief manganese-producing countries are the U.S.S.R.; Union of South Africa; Brazil; Gold Coast; India; Cuba. In the United States, manganese ores are found in Virginia and West Virginia, Georgia, Arkansas, Tennessee, with the hematite ores of the Lake Superior districts, and in California.

Uses. Most important manganese ore. Manganese is used with iron in the manufacture of *spiegeleisen* and *ferromanganese*, employed in making steel. Also used in various alloys with copper, zinc, aluminum, tin, lead. Pyrolusite is used as an oxidizer in the manufacture of chlorine, bromine, and oxygen; as a disinfectant in potassium permanganate; as a drier in paints; as a decolorizer of glass; and in electric cells and batteries. Manganese is also used as a coloring material in bricks, pottery, and glass.

Name. *Pyrolusite* is derived from two Greek words meaning *fire* and *to wash*, because it is used to free glass through its oxidizing effect of the colors due to iron.

Similar Species. *Alabandite*, MnS, is comparatively rare, associated with other sulfides in veins.

Wad is the name given to manganese ore composed of a mixture of hydrous manganese oxides.

Columbite — $(Fe,Mn)(Cb,Ta)_2O_6$

Crystallography. Orthorhombic; dipyramidal. Commonly in crystals. The habit is short prismatic or thin tabular; often in square prisms because of prominent development of the vertical pinacoids. Terminated by basal plane, pyramids, and domes; frequently complex (Fig. 318). Also in heart-shaped contact twins.

Physical Properties. Cleavage parallel to the brachypinacoid {010}. **H.** = 6. **G.** = 5.3–7.3, varying with the composition, increasing with rise in percentage of tantalum oxide present. Luster submetallic. Color iron-black, frequently iridescent. Streak dark red to black. Subtranslucent.

Composition. An oxide of columbium, tantalum, ferrous iron, and manganese, $(Fe,Mn)(Cb,Ta)_2O_6$, which varies in composition from pure *columbite* $(Fe,Mn)Cb_2O_6$, to pure *tantalite* $(Fe,Mn)Ta_2O_6$. Often contains small amounts of tin and tungsten. A variety known as *manganotantalite* is essentially a tantalite with most of the iron replaced by manganese.

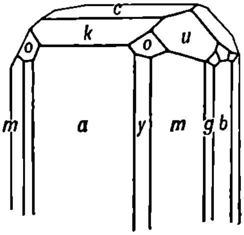


FIG. 318. Columbite.

Tests. Difficultly fusible (5–5½). Fused with borax; the bead dissolved in hydrochloric acid; the solution boiled with tin gives a blue color (columbium). There is no simple test for tantalum. Generally when fused with sodium carbonate gives an opaque bluish green bead (manganese). Fused with sodium carbonate on charcoal yields a magnetic mass.

Diagnostic Features. Recognized usually by its black color, submetallic streak, and high specific gravity. Distinguished from wolframite by having a lower specific gravity and less distinct cleavage; and from tourmaline by its orthorhombic crystal form.

Occurrence. Columbite occurs in granitic rocks and in pegmatite veins, associated with quartz, feldspar, mica, tourmaline, beryl, spodumene, cassiterite, samarskite, wolframite, microlite, monazite.

Notable localities for its occurrence are the west coast of Greenland; near Moss, Norway; Bodenmais, Bavaria; Ilmen Mountains, U.S.S.R.; western Australia (manganotantalite); Madagascar. In the United States found at Standish, Maine; Haddam, Middletown, and Branchville, Connecticut; in Amelia County, Virginia; Mitchel County, North Carolina; Black Hills, South Dakota; near Canon City, Colorado.

Use. Source of the rare elements tantalum and columbium. From 1903 to 1911 tantalum was used in making filaments for incandescent electric lamps. Because of its resistance to acid corrosion tantalum is used in chemical equipment; also used in some tool steels and in electronic tubes. Columbium only recently has had commercial value and is now used as an alloy in weldable high-speed steels.

Name. The name is derived from the acid element that the mineral contains.

Similar Species. *Pyrochlore* and *fergusonite* are oxides of columbium, tantalum, and rare earths found associated with alkalic rocks.

Diaspore — AlO(OH)

Crystallography. Orthorhombic; dipyramidal. Usually in thin crystals, tabular parallel to the brachypinacoid ‖{010}. Bladed; foliated massive.

Physical Properties. Perfect pinacoidal {010} cleavage. **H.** = 6½–7. **G.** = 3.35–3.45. Luster vitreous except on cleavage face, where it is pearly. Color white, gray, yellowish, greenish. Transparent to translucent.

Composition. AlO(OH). Al_2O_3 = 85 per cent, H_2O = 15 per cent.

Tests. Infusible. Insoluble. Fine powder wholly soluble in salt of phosphorus bead (absence of silica). Decrepitates and gives water when heated in the closed tube. Ignited with cobalt nitrate turns blue (aluminum).

Diagnostic Features. Characterized by its good cleavage, its bladed habit, and its hardness (6½–7).

Occurrence. Diaspore is usually a decomposition product of corundum and found associated with that mineral in dolomite and chlorite schist. Occurs similarly in bauxite deposits. Has been noted as an accessory mineral in metamorphic limestones.

Notable localities are the Ural Mountains; Schemnitz, Czechoslovakia; Campolungo in Switzerland. In the United States is found in Chester County, Pennsylvania; at Chester, Massachusetts; with alunite, forming rock masses at Mt. Robinson, Rosita Hills, Colorado.

Name. Derived from a Greek word meaning *to scatter,* in allusion to its decrepitation when heated.

GOETHITE — FeO(OH)

Bog-Iron Ore

Crystallography. Orthorhombic; dipyramidal. Rarely in distinct prismatic, vertically striated crystals. Often flattened parallel to brachypinacoid. In acicular crystals. Also massive, reniform, stalactitic in radiating fibrous aggregates. Foliated. The so-called bog ore is generally loose and porous in texture.

Physical Properties. Perfect cleavage parallel to brachypinacoid, {010}. **H.** = 5–5½. **G.** = 4.37; may be as low as 3.3 for impure material. Luster adamantine to dull; silky in certain fine scaly or fibrous varieties. Color yellowish brown to dark brown. Streak yellowish brown. Subtranslucent.

Composition. FeO(OH). Fe = 62.9 per cent, O = 27.0 per cent, H_2O = 10.1 per cent. Manganese is often present in amounts up to 5 per cent. The massive varieties often contain adsorbed or capillary water.

Tests. Difficultly fusible (5–5½). Becomes magnetic in the reducing flame. In the closed tube gives water and is converted to Fe_2O_3.

Diagnostic Features. Told chiefly by the color of its streak and distinguished from limonite by its cleavage, radial growth, and other evidence of crystallinity. Most of the material formerly classed under limonite is now known to be goethite.

Occurrence. Goethite is one of the commonest minerals, and is typically formed under oxidizing conditions as a weathering product of iron-bearing minerals. It also forms as a direct inorganic or biogenic precipitate from water and is widespread as a deposit in bogs and springs. Goethite with limonite forms the gossan or "iron hat" over metalliferous veins. Large quantities of goethite have been found as residual lateritic mantles resulting from the weathering of serpentine. The very common pseudomorphs of so-called limonite after pyrite probably consist for the most part of goethite.

Deposits known as *bog-iron ore* are formed by the solution, transportation, and reprecipitation of pre-existing iron minerals through the agency of surface waters. Solution is brought about by small amounts of carbonic acid in the water. The iron is transported as a carbonate to the surface and then carried by the streams into marshes and stagnant pools. There the carbonate is changed to the oxide through evaporation of the water and the consequent loss of the carbonic acid, and through the agency of the reducing action of carbonaceous matter. The oxide separates and first collects as an iridescent scum on the surface of the water, and then later sinks to the bottom. This separation is also aided by the so-called iron bacteria which absorb the iron from the water and later deposit it as ferric hydroxide. In this way, under favorable conditions, beds of impure goethite can be formed in the bottom of marshes and bogs. Such deposits are very common but, because of associated foreign materials, are seldom of sufficient purity to be worked commercially. Only recently bog-iron ores have been known to be mostly goethite and were formerly called limonite.

Goethite deposits are also to be found with iron-bearing limestones. The iron content of the limestone may be gradually dissolved by circulating waters, and under favorable conditions may, as goethite, replace the calcium carbonate of the rock. The gradual weathering and solution of the limestone may leave behind the iron content in the form of residual masses of ferric hydroxide, lying in clay above the limestone formation. Such deposits are often of considerable size, and because of their greater purity are much more often mined than the bog-iron ores.

Goethite in some localities constitutes an important ore of iron. It is the principal constituent of the valuable minette ores of Alsace-Lorraine.

Other notable European localities are: Eiserfeld in Westphalia; Přibram, Bohemia; and Cornwall, England. Large deposits of iron-rich laterites composed essentially of goethite are found in the Mayari and Moa districts of Cuba.

In the United States goethite is common in the Lake Superior hematite deposits, and has been obtained in fine specimens at Negaunee, near Marquette, Michigan. Goethite is to be found in iron-bearing limestones along the Appalachian Mountains, from western Massachusetts as far south as Alabama. Such deposits are particularly important in Alabama, Georgia, Virginia, and Tennessee. Finely crystallized material occurs with smoky quartz and microcline in Colorado at Fluorissant and in the Pikes Peak region.

Use. An ore of iron.

Name. In honor of Goethe, the German poet.

Similar Species. *Turgite,* $2Fe_2O_3 \cdot H_2O$, is frequently associated with goethite but distinguished from it by the red streak.

MANGANITE — $MnO(OH)$

Crystallography. Orthorhombic; dipyramidal. Crystals usually long prismatic with obtuse terminations, deeply striated vertically. Often twinned. Crystals often grouped in bundles or in radiating masses; also columnar.

Physical Properties. Perfect cleavage parallel to brachypinacoid, {010}. **H.** = 4. **G.** = 4.3. Luster metallic. Color steel-gray to iron-black. Streak dark brown. Opaque.

Composition. $MnO(OH)$. Mn = 62.4 per cent, O = 27.3 per cent, H_2O = 10.3 per cent.

Tests. Infusible. A small amount of the powdered mineral gives a bluish green bead with sodium carbonate. Much water when heated in the closed tube.

Diagnostic Features. Told chiefly by its black color, prismatic crystals, hardness (4), and brown streak. The last two will serve to distinguish it from pyrolusite.

Occurrence. Manganite is found associated with other manganese oxides and has a similar origin. It frequently alters to pyrolusite. Found often in veins associated with the granitic igneous rocks, both filling cavities and as a replacement of the neighboring rocks. Barite and calcite are frequent associates.

Occurs at Ilfeld, Harz Mountains, in fine crystals; also at Ilmenau, Thuringia; Cornwall, England. In the United States at Negaunee, Michigan. In Nova Scotia.

Use. A minor ore of manganese.

Limonite — $FeO(OH) \cdot nH_2O$

Brown Hematite. Bog-Iron Ore

Crystallography. Amorphous. In mammillary to stalactitic masses; also concretionary, nodular, earthy.

Physical Properties. **H.** = 5–5½. Finely divided limonite may have an apparent hardness as low as 1. **G.** = 3.6–4. Luster vitreous. Color dark brown to black. Streak yellowish brown. Subtranslucent.

Composition. Largely $FeO(OH) \cdot nH_2O$ with some $Fe_2O_3 \cdot nH_2O$. Often impure with small amounts of hematite, clay minerals, and manganese oxides. The water content of limonite varies widely, and it is probable that the mineral is essentially an amorphous form of goethite with adsorbed and capillary water.

Tests. Difficultly fusible (5–5½). Strongly magnetic after heating in the reducing flame. Much water in the closed tube (15 per cent).

Diagnostic Features. Characterized chiefly by its yellow-brown streak, and distinguished from goethite by its vitreous appearance and the absence of cleavage.

Occurrence. Limonite is always of secondary origin, formed through the alteration or solution of previously existing iron minerals. It may form in place as the result of direct oxidation or an inorganic or biogenic precipitation in water-lain deposits. Limonite and goethite are the chief constituents of the gossan or " iron hat " which is often the oxidized surface expression of sulfide veins. The principal mineral of most occurrences formerly listed under limonite is now known to be goethite. It is impossible to separate the localities of the two minerals on a mineralogical basis. (See goethite, page 205.) In addition to indicating the amorphous nature of the material, the name limonite may conveniently be retained as a field term to refer to natural hydrous iron oxides whose real identity is uncertain.

Limonite is the coloring material of yellow clays and soils, and mixed with fine clay makes what is known as *yellow ocher.* Limonite is commonly associated in its occurrence with goethite, hematite, turgite, pyrolusite, calcite, siderite.

Use. As a pigment, yellow ocher.

Name. Derived from the Greek word meaning *meadow,* in allusion to its occurrence in bogs.

BAUXITE*

Crystallography. A mixture. Pisolitic, in round concretionary grains; also massive, earthy, claylike.

Physical Properties. **H.** = 1–3. **G.** = 2–2.55. Luster dull to earthy. Color white, gray, yellow, red. Translucent.

Composition. A mixture of hydrous aluminum oxides of indefinite composition. Some bauxites approach closely the composition of *gibbsite*, $Al(OH)_3$, but most are a mixture, and usually contain iron. As a result, bauxite has been discredited as a mineral species and in a rigid classification should be used only as a rock name. The principal constituents of the rock bauxite are *gibbsite*, *boehmite*, and *diaspore* any one of which may be dominant. *Cliachite* is the name proposed for the very fine-grained amorphous constituent of bauxite.

Tests. Infusible. Insoluble. Assumes a blue color when moistened with cobalt nitrate and then ignited (aluminum). Gives water in the closed tube.

Diagnostic Features. Can usually be recognized by its pisolitic character.

Occurrence. Bauxite is of secondary origin, commonly produced under subtropical to tropical climatic conditions by the prolonged weathering of aluminum-bearing rocks. Also may be derived from the weathering of clay-bearing limestones. It has apparently originated as a colloidal precipitate. It may occur in place as a direct derivative of the original rock, or it may have been transported and deposited in a sedimentary formation. In the tropics deposits known as *laterites*, consisting largely of hydrous aluminum and ferric oxides, are found in the residual soils. These vary widely in composition and purity but may become valuable as sources of aluminum and iron.

Occurs over a large area in the south of France, an important district being at Baux, near Arles, France. Large quantities are produced in Dutch Guiana and British Guiana and shipped to the United States. In the United States the chief deposits are found in Georgia, Alabama, and Arkansas where bauxite was formed by the alteration of a nepheline syenite.

Use. The ore of aluminum. (See page 388.) Used in the manufacture of aluminum salts, artificial abrasives, and bauxite brick.

Name. From its occurrence at Baux, France.

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* Bauxite has been discredited as a mineral species, but the name has been retained here since it has become so firmly fixed as the name of the important commercial substance.

Brucite — $Mg(OH)_2$

Crystallography. Rhombohedral; scalenohedral. Crystals usually tabular with prominent basal planes, which may show small rhombohedral truncations. Commonly foliated, massive.

Physical Properties. Perfect basal {0001} cleavage. Folia flexible but not elastic. Sectile. **H.** = 2½. **G.** = 2.39. Luster on base pearly, elsewhere vitreous to waxy. Color white, gray, light green. Transparent to translucent.

Composition. Magnesium hydroxide, $Mg(OH)_2$. MgO = 69.0 per cent, H_2O = 31.0 per cent. Iron and manganese may be present.

Tests. Infusible. Glows before the blowpipe. Gives water in the closed tube. Easily soluble in hydrochloric acid, and after solution has been made ammoniacal the addition of sodium phosphate gives a white granular precipitate of ammonium magnesium phosphate (test for magnesium).

Diagnostic Features. Recognized by its foliated nature, light color, and pearly luster on cleavage face. Distinguished from talc by its greater hardness and lack of greasy feel, and from mica by being inelastic.

Occurrence. Brucite is found associated with serpentine, dolomite, magnesite, chromite, as a decomposition product of magnesium silicates, especially serpentine. It is also found in crystalline limestone.

Notable foreign localities for its occurrence are at Unst, one of the Shetland Islands, and Aosta, Italy. In the United States found at Tilly Foster Iron Mine, Brewster, New York; at Wood's Mine, Texas, Pennsylvania; near Luning, Nevada.

Name. In honor of the early American mineralogist, Archibald Bruce.

PSILOMELANE — $H_4R_2Mn_8O_{20}$

Crystallography. Orthorhombic. Massive, botryoidal, stalactitic. Appears amorphous.

Physical Properties. **H.** = 5–6. **G.** = 3.7–4.7. Luster submetallic. Color black. Streak brownish black. Opaque.

Composition. The ideal formula is $H_4R_2Mn_8O_{20}$, where R is chiefly Ba but also includes Mn, Mg, Ca, Ni, Co, and Cu.

Tests. Infusible. A small amount of mineral fused with sodium carbonate gives an opaque bluish green bead. Gives much water in the closed tube.

Diagnostic Features. Distinguished from the other manganese oxides by its greater hardness and lack of crystal structure, and from limonite by its black streak.

Occurrence. Psilomelane occurs usually with pyrolusite, and its origin and associations are similar to those of that mineral.

Use. An ore of manganese.

Name. Derived from two Greek words meaning *smooth* and *black,* in allusion to its appearance.

HALIDES

The halides are compounds of the metals with the halogen elements, fluorine, chlorine, bromine, and iodine.

Halides

Halite	$NaCl$
Sylvite	KCl
Cerargyrite	$AgCl$
Cryolite	Na_3AlF_6
Fluorite	CaF_2
Atacamite	$Cu_2Cl(OH)_3$
Carnallite	$KMgCl_3 \cdot 6H_2O$

HALITE — $NaCl$

Rock Salt. Common Salt.

Crystallography. Isometric; hexoctahedral. Habit cubic (Fig. 319). Some crystals hopper-shaped. Other forms very rare. Found in crystals or granular crystalline masses showing cubical cleavage, known as *rock salt.* Also massive, granular to compact.

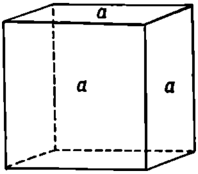


FIG. 319. Halite.

Physical Properties. Perfect cubic {100} cleavage. H. = 2½. G. = 2.16. Luster transparent to translucent. Colorless or white, or when impure may have shades of yellow, red, blue, purple. Salty taste. Diathermanous.

Composition. Sodium chloride, NaCl. Na = 39.3 per cent, Cl = 60.7 per cent. Commonly contains impurities, such as calcium and magnesium sulfates and calcium and magnesium chlorides.

Tests. Fusible at 1½, giving strong yellow flame of sodium. With copper oxide in salt of phosphorus bead gives azure-blue copper chloride flame. After intense ignition, residue gives alkaline reaction to moistened test paper. Readily soluble in water; solution made acid with nitric acid gives with silver nitrate a heavy white precipitate of silver chloride.

Diagnostic Features. Characterized by its cubic cleavage and taste, and distinguished from sylvite by its yellow flame color and by less bitter taste.

Occurrence. Halite is a common and widely disseminated mineral, occurring often in extensive beds and irregular masses, precipitated from sea water and interstratified in rocks of all ages, in such a manner as to form a true rock mass. Associated with gypsum, sylvite, anhydrite, calcite, clay, sand. Occurs also dissolved in the waters of salt springs, salt seas, and the ocean.

The deposits of salt have been formed by the gradual evaporation and ultimate drying up of inclosed bodies of salt water. The salt beds formed in this way have subsequently been covered by other sedimentary deposits and gradually buried beneath the rock strata formed from them. Salt beds range from a few feet up to 100 feet in thickness and have been found at great depths. The history of the formation of these salt beds is as follows: River waters contain a small but appreciable amount of various soluble salts. When these waters are collected in a sea which has no outlet, or in other words, a sea where the evaporation equals or exceeds the amount of water flowing in, there is a gradual concentration in the sea of the salts brought into it by the rivers. The sea water, therefore, in time becomes heavily charged with soluble salts, particularly sodium chloride. When the points of concentration of the various salts held in solution are reached, they will be deposited progressively upon the sea bottom, commencing with the most insoluble. This process may be interrupted by seasons of flood in which the sea water becomes freshened beyond the concentration point. Silt materials may be brought in at such times and deposited upon the bottom and so form beds of clay alternating with those of salt. Another theory of origin postulates that a body of sea water was separated from the ocean by the gradual growth of a sand bar, with the subsequent slow evaporation and concentration of the inclosed water. Such deposits of salt are now to be found buried in rock strata of all ages. At the present time similar deposits are being formed in the Great Salt Lake and the Dead Sea.

Important foreign countries for the production of salt are Austria; Poland; Czechoslovakia; Bavaria; Prussia; Spain; U.S.S.R.; Great Britain.

In the United States salt is produced, on a commercial scale, in some fifteen states, either from rock-salt deposits or by evaporation of saline waters. Beds of rock salt are found in New York State from the Oatka Valley in Wyoming County east to Morrisville, Madison County, and south of this line wherever wells have been driven deep enough to reach the beds. The important producing localities are near Syracuse, Ithaca, Watkins, and Ludlowville, and at various places in Wyoming, Genesee, and Livingston Counties. These beds continue into Michigan where salt is produced in Saginaw, Bay, Midland, Isabella, Detroit, Wayne, Manistee and Mason Counties. Notable deposits are also found in Ohio, Kansas, New Mexico. Salt is obtained by the evaporation of saline waters in California, Utah, and Texas.

In Louisiana and Texas salt is produced extensively from *salt domes.* A salt dome is a nearly vertical pipelike mass of salt that appears to have punched its way upward to the surface from an underlying salt bed. Anhydrite, gypsum, and native sulfur are commonly associated with salt domes. Hundreds of salt domes have been located by geophysical prospecting in a search for petroleum, frequently associated with them.

Use. The chief uses of salt are for culinary and preservative purposes. It furnishes the sodium for the manufacture of soda ash (sodium carbonate), which is used in glass making, soap making, bleaching, etc., and in the preparation of sodium salts in general. Salt is employed also in the extraction of gold by the chlorination process. (See page 406.)

Name. Halite comes from the Greek word meaning *salt.*

SYLVITE — KCl

Crystallography. Isometric; hexoctahedral. Cube and octahedron frequently in combination (Fig. 320). Usually in granular crystalline masses showing cubic cleavage; compact.

Physical Properties. Perfect cubic {100} cleavage. **H.** = 2. **G.** = 1.99. Transparent when pure. Colorless or white; also shades of blue, yellow, or red from impurities. Readily soluble in water. Salty taste but more bitter than that of halite.

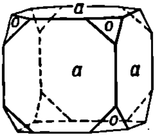


Fig. 320. Sylvite.

Composition. Potassium chloride, KCl. K = 52.4 per cent, Cl = 47.6 per cent. May contain sodium chloride.

Tests. Fusible at 1½, giving violet flame of potassium, which may be obscured by yellow flame due to sodium present. The yellow sodium flame may be filtered out by means of a blue filter and the violet of the potassium rendered visible. After intense ignition, residue gives alkaline reaction on moistened test paper. Readily soluble in water; solution made acid with nitric acid gives with silver nitrate a heavy precipitate of silver chloride.

Diagnostic Features. Distinguished from halite by the violet flame color of potassium and its more bitter taste.

Occurrence. Sylvite has the same origin, mode of occurrence, and associations as halite (page 212) but is much more rare. It remains in the mother liquor after precipitation of halite and is one of the last salts to be precipitated.

Found in some quantity and frequently well crystallized, associated with the salt deposits at Stassfurt, Prussia; from Kalusz in Galicia. In the United States found in large amount in the Permian salt deposits near Carlsbad, New Mexico, and in western Texas.

Use. The chief source of potassium compounds which are extensively used as fertilizers.

Name. Potassium chloride is the *sal digestivus Sylvii* of early chemistry, whence the name for the species.

Other Potassium Salts. Other potassium minerals commonly associated with sylvite and found in Germany and Texas in sufficient amount to make them valuable as sources of potassium salts are *carnallite,* $KMgCl_3 \cdot 6H_2O$ (see page 219); *kainite,* $MgSO_4 \cdot KCl \cdot 3H_2O$; *polyhalite,* $K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$.

CERARGYRITE — AgCl

Horn Silver

Crystallography. Isometric; hexoctahedral. Habit cubic but crystals rare. Usually massive, resembling wax; often in plates and crusts.

Physical Properties. H. = 2–3. G. = 5.5±. Sectile, can be cut with a knife like horn. Transparent to translucent. Color pearl-gray to colorless. Rapidly darkens to violet-brown on exposure to light.

Composition. Silver chloride, AgCl. Ag = 75.3 per cent, Cl = 24.7 per cent. Some varieties contain mercury.

Tests. Fusible at 1. Before the blowpipe on charcoal gives a globule of silver. Insoluble in nitric acid, but slowly soluble in ammonium hydroxide. With copper oxide in salt of phosphorus bead gives azure-blue copper chloride flame.

Diagnostic Features. Distinguished chiefly by its horny or waxlike appearance and its sectility.

Occurrence. Cerargyrite is an important secondary ore of silver. It is to be found only in the upper, enriched zone of silver veins where descending waters containing small amounts of chlorine have acted upon the oxidized products of the primary silver ores of the vein. Found associated with other silver minerals and with native silver, cerussite, and secondary minerals in general.

Notable amounts have been found in New South Wales, Peru, Chile, Bolivia, and Mexico. In the United States cerargyrite was an important mineral in the mines at Leadville and elsewhere in Colorado, at the Comstock Lode in Nevada, in crystals at the Poorman's Lode in Idaho.

Use. A silver ore.

Name. Cerargyrite is derived from two Greek words meaning *horn* and *silver,* in allusion to its hornlike appearance and characteristics.

Similar Species. Other closely related silver minerals less common than cerargyrite, but formed under similar conditions, are *embolite,* Ag(Cl,Br); *bromyrite,* AgBr; *iodobromite,* Ag(Cl,Br,I); *iodyrite,* AgI.

CRYOLITE — Na_3AlF_6

Crystallography. Monoclinic; prismatic. Prominent forms are prism and base. Crystals rare, usually cubic in aspect, and in parallel groupings growing out of massive material. Usually massive.

Physical Properties. Parting in three directions nearly at right angles. **H.** = $2\frac{1}{2}$. **G.** = 2.95–3.0. Luster vitreous to greasy. Colorless to snow-white. Transparent to translucent. A low index of refraction gives the mineral an appearance of watery snow or of paraffin. Index of refraction near that of water, and thus powdered mineral almost disappears when immersed in water.

Composition. A fluoride of sodium and aluminum, Na_3AlF_6. Na = 32.8 per cent, Al = 12.8 per cent, F = 54.4 per cent.

Tests. Fusible at $1\frac{1}{2}$ with strong yellow sodium flame. After intense ignition, residue gives alkaline reaction on moistened test paper. Fused in a bulb tube with potassium disulfate, cryolite evolves hydrofluoric acid and gives a volatile white ring of silica. (See page 117.)

Diagnostic Features. Characterized by pseudocubic parting, white color, and peculiar luster; and for the Greenland cryolite, the association of siderite, galena, and chalcopyrite.

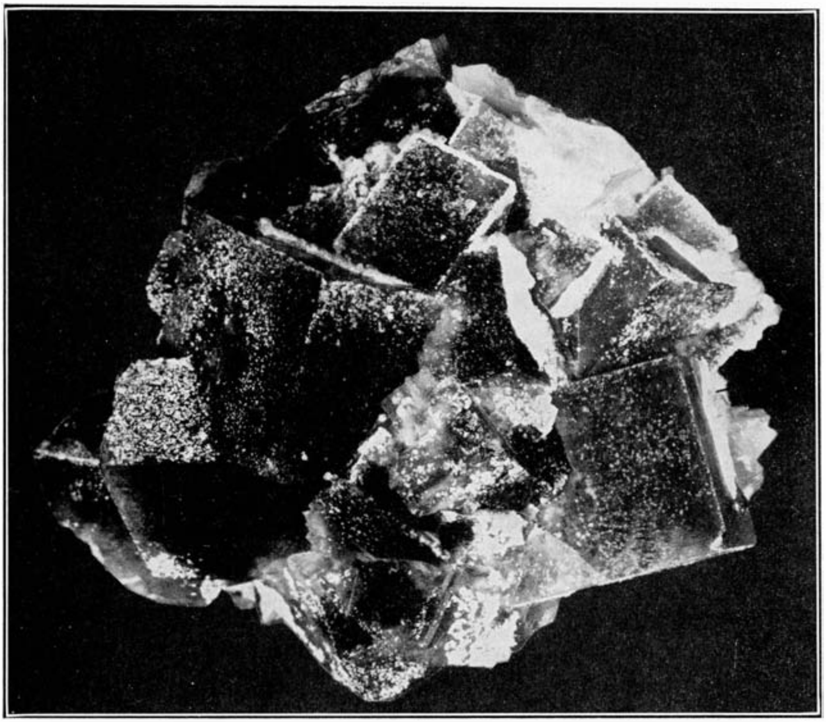
Occurrence. The only important deposit of cryolite is at Ivigtut, on the west coast of Greenland. Here it is found in a large veinlike mass in granite. Usually associated with the cryolite are siderite, galena, sphalerite, and chalcopyrite; and less commonly quartz, wolframite, fluorite, cassiterite, molybdenite, arsenopyrite, columbite. In the United States, found at the foot of Pikes Peak, Colorado.

Use. Cryolite is used for the manufacture of sodium salts, of certain kinds of glass and porcelain, and as a flux for cleansing metal surfaces. It was early used as a source of aluminum. When aluminum was produced from bauxite ore, cryolite was used as a flux in the electrolytic process. Today most of the sodium aluminum fluoride used in the aluminum industry is produced artificially.

Name. Name is derived from two Greek words meaning *frost* and *stone,* in allusion to its icy appearance.

FLUORITE — CaF_2

Crystallography. Isometric; hexoctahedral. Habit cubic (Figs. 321 and 323), often in twinned cubes (Plate X and Fig. 322). Other forms are rare, but examples of all the forms of the hexoctahedral class have been observed; the tetrahexahedron (Fig. 324) and hexoctahedron (Fig. 325) are characteristic. Usually in crystals or in cleavable masses. Also massive; coarse or fine granular; columnar.



Fluorite Crystals Coated with Quartz, Northumberland, England.
PLATE X

Physical Properties. Perfect octahedral {111} cleavage. **H.** = 4. **G.** = 3.18. Transparent to translucent. Luster vitreous. Color varies widely; most commonly light green, yellow, bluish green, or purple; also colorless, white, rose, blue, brown. The color in some fluorite results from the presence of a hydrocarbon. A single crystal may show varying bands of color; the massive variety is also often banded in color. The phenomenon of fluorescence (see page 80) is shown by some varieties of fluorite and hence receives its name.

Composition. Calcium fluoride, CaF_2. Ca = 51.1 per cent, F = 48.9 per cent.

Tests. Fusible at 3, and residue gives alkaline reaction to moistened turmeric paper. Gives a reddish flame (calcium). When it is mixed with potassium disulfate and heated in a bulb tube, hydrofluoric acid is evolved which etches the glass, and a white deposit of silica forms upon the walls of the tube (see page 117).

Diagnostic Features. Determined usually by its cubic crystals and octahedral cleavage; also vitreous luster and usually fine coloring, and by the fact that it can be scratched with a knife.

Occurrence. Fluorite is a common and widely distributed mineral. Usually found either in veins in which it is the chief mineral or as a gangue mineral with metallic ores, especially those of lead and tin. Common in dolomites and limestone and has been observed also as a minor accessory mineral in various igneous rocks and pegmatites. Associated with many different minerals, as calcite, dolomite, gypsum, celestite, barite, quartz, galena, sphalerite, cassiterite, topaz, tourmaline, apatite.

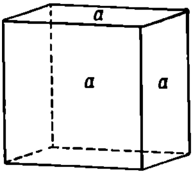


Fig. 321.

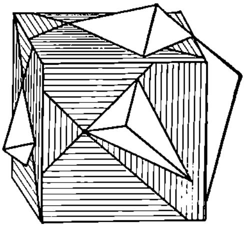


Fig. 322.

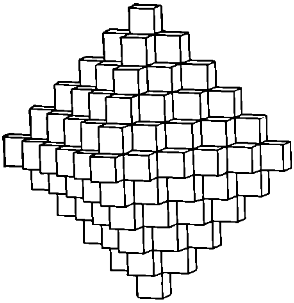


Fig. 323.

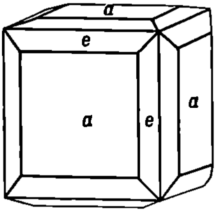


Fig. 324.

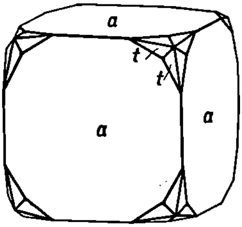


Fig. 325.

Fluorite.

Fluorite is found in quantity in England, chiefly from Cumberland, Derbyshire, and Durham; the first two localities are famous for their magnificent crystallized specimens. Found commonly in the mines of Saxony. Fine specimens come from Switzerland, the Tyrol, Bohemia, Norway. The most important deposits in the United States are in southern Illinois near Rosiclare and Cave-in-Rock, and in the adjacent part of Kentucky. At Rosiclare fluorite which is without crystal form occurs in limestone, in fissure veins which in places are 40 feet in width. Twenty miles away at Cave-in-Rock the fluorite is in coarsely crystalline aggregates lining flat-lying open spaces.

Use. Fluorite is used mainly as a flux in the making of steel, in the manufacture of opalescent glass, in enameling cooking utensils, for the preparation of hydrofluoric acid, and occasionally as an ornamental material for vases and dishes.

Name. From the Latin *fluere,* meaning to flow, since it melts more easily than other minerals with which it was, in the form of cut stones, confused.

Atacamite — $Cu_2Cl(OH)_3$

Crystallography. Orthorhombic; dipyramidal. Commonly slender prismatic in habit, with vertical striations. Also tabular parallel to brachypinacoid. Usually in confused crystalline aggregates; fibrous; granular. As " sand."

Physical Properties. Cleavage perfect parallel to brachypinacoid {010}. **H.** = 3–3½. **G.** = 3.75–3.77. Luster adamantine to vitreous. Color various shades of green. Transparent to translucent.

Composition. Basic copper chloride, $Cu_2Cl(OH)_3$. Cu = 59.5 per cent, Cl = 13.0 per cent, H_2O = 12.7 per cent.

Tests. Fusible at 3–4, giving the azure-blue flame of copper chloride without the use of hydrochloric acid. Fused on charcoal with sodium carbonate gives globule of copper. Nitric acid solution with silver nitrate gives white precipitate of silver chloride; with ammonia in excess gives blue solution. Gives acid water in the closed tube.

Diagnostic Features. Characterized by its green color and granular crystalline aggregates. Distinguished from malachite by its lack of effervescence in acids, and from brochantite and antlerite by its azure-blue copper chloride flame.

Occurrence. Atacamite is a comparatively rare copper mineral. Found originally as sand in the province of Atacama in Chile. Occurs in arid regions as a secondary mineral in the oxidized zone of copper deposits. Is found with other copper ores in various localities in Chile, Bolivia, Mexico, and in some of the copper districts of South Australia. In the United States occurs sparingly in the copper districts of Arizona.

Use. A minor ore of copper.

Name. From the province of Atacama, Chile.

Carnallite — $KMgCl_3 \cdot 6H_2O$

Crystallography. Orthorhombic. Crystals rare. Usually massive, granular.

Physical Properties. **H.** = 1. **G.** = 1.6. Luster nonmetallic, shining, greasy. Color milk-white, often reddish, due to included hematite. Transparent to translucent. Taste bitter. Deliquescent.

Composition. A hydrous chloride of potassium and magnesium, $KMgCl_3 \cdot 6H_2O$. KCl = 26.81 per cent, $MgCl_2$ = 34.19 per cent, H_2O = 39.0 per cent.

Tests. Fusible at 1–1½ with violet flame. After ignition gives an alkaline reaction on moistened test paper. Gives much water in the closed tube. Easily and completely soluble in water; on addition of nitric acid and silver nitrate gives a white precipitate of silver chloride. Acid solution neutralized with ammonia and sodium phosphate added gives a white precipitate of ammonium magnesium phosphate.

Diagnostic Features. Carnallite is distinguished from associated salts by lack of cleavage and its deliquescent nature.

Occurrence. Carnallite is found associated with halite, sylvite, etc., in the salt deposits at Stassfurt, Prussia. It is also found to a lesser extent in the potash deposits of western Texas and eastern New Mexico.

Use. A source of potassium compounds and magnesium. (See page 397.)

Name. In honor of Rudolph von Carnall (1804–1874).

CARBONATES, NITRATES, AND BORATES

Carbonates

	Calcite	$CaCO_3$
	Dolomite	$CaMg(CO_3)_2$
CALCITE GROUP	Magnesite	$MgCO_3$
	Siderite	$FeCO_3$
	Rhodochrosite	$MnCO_3$
	Smithsonite	$ZnCO_3$
	Aragonite	$CaCO_3$
ARAGONITE GROUP	Witherite	$BaCO_3$
	Strontianite	$SrCO_3$
	Cerussite	$PbCO_3$
	Malachite	$Cu_2CO_3(OH)_2$
	Azurite	$Cu_3(CO_3)_2(OH)_2$

Nitrates

Soda niter	$NaNO_3$
Niter	KNO_3

Borates

Boracite	$Mg_7Cl_2B_{16}O_{30}$
Borax	$Na_2B_4O_7 \cdot 10H_2O$
Kernite	$Na_2B_4O_7 \cdot 4H_2O$
Ulexite	$NaCaB_5O_9 \cdot 8H_2O$
Colemanite	$Ca_2B_6O_{11} \cdot 5H_2O$

CARBONATES

The important anhydrous carbonates fall into two isostructural groups, the *calcite group* and the *aragonite group.* Aside from the minerals of these groups the basic copper carbonates, azurite and malachite, are the only carbonates of importance.

Calcite Group

The calcite group consists of rhombohedral carbonates of calcium, magnesium, ferrous iron, manganese, and zinc. With the exception of dolomite, all the members of the group crystallize in the scalenohedral class. Dolomite crystallizes in the rhombohedral class. All the minerals show a perfect rhombohedral cleavage, the angle between the cleavage faces varying from 72° to 75°. The calcite group forms one of the most marked and important groups of isostructural minerals.

CALCITE — $CaCO_3$

Crystallography. Rhombohedral; scalenohedral. Crystals are extremely varied in habit, often highly complex. Over 300 different forms have been described. Three important habits: (1) prismatic, in long or short prisms, in which the prism faces are prominent, with basal pinacoid or rhombohedral terminations (Figs. 330 and 331); (2) rhombohedral, in which rhombohedral forms predominate, both low and steep rhombohedrons, the unit (cleavage) form is not common (Figs. 326–329); (3) scalenohedral, in which the scalenohedrons predominate (Plate XI), often with prism faces and rhombohedral truncations (Figs. 332–335). The most common scalenohedron is $\{21\bar{3}1\}$. All possible combinations and variations of these types are found.

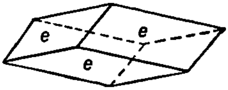


Fig. 326.

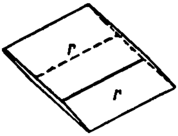


Fig. 327.

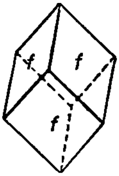


Fig. 328.

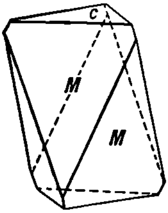


Fig. 329.

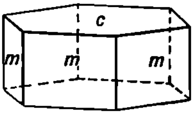


Fig. 330.

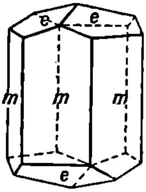


Fig. 331.

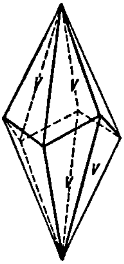


Fig. 332.

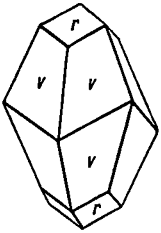


Fig. 333.

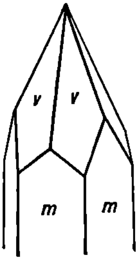


Fig. 334.

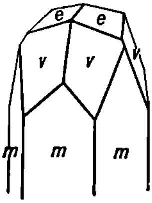


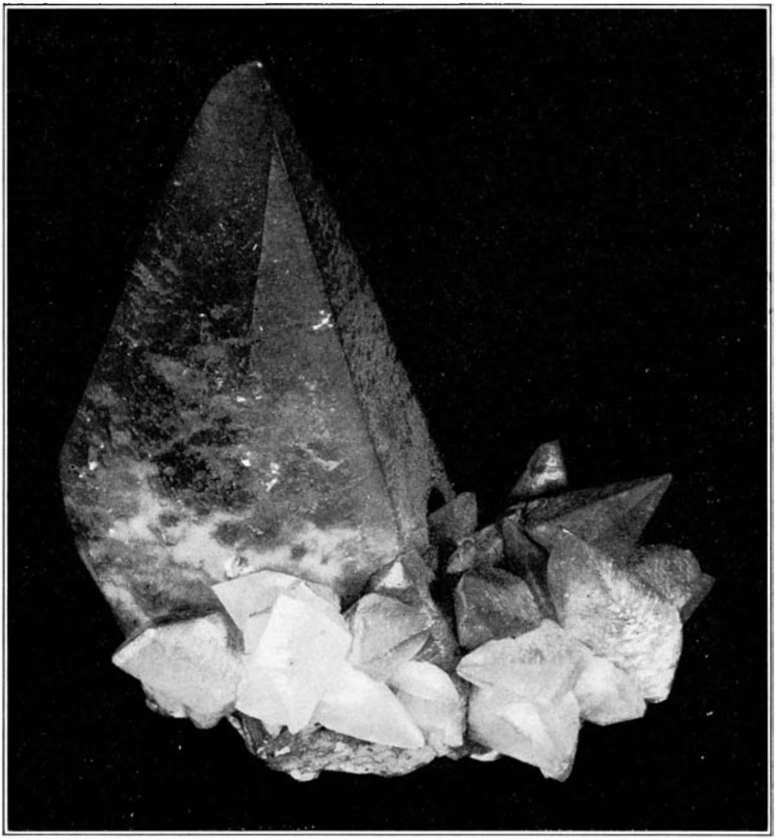
Fig. 335.

Calcite.

Twinning with the twin plane the negative rhombohedron, $\{01\bar{1}2\}$, very common (Fig. 336); often produces twinning lamellae which may, as in crystalline limestones, be of secondary origin. This twinning may be produced artificially (see page 63). Twins with the basal pinacoid, $\{0001\}$, the twin plane common (Figs. 337 and 338). Twinning on the unit rhombohedron, $\{10\bar{1}1\}$, less common (Fig. 339).

Calcite is usually in crystals or in coarse to fine granular aggregates. Also fine-grained to compact, earthy, and in stalactitic forms.

Physical Properties. Perfect cleavage parallel to unit rhombohedron $\{10\bar{1}1\}$ (cleavage angle = 75°). **H.** = 3. **G.** = 2.72. Luster vitreous to earthy. Color usually white or colorless, but may be variously tinted, gray, red, green, blue, yellow. Also, when impure, brown to black. Transparent to translucent. Shows strong double refraction (page 85), hence the name *doubly refracting spar*. The chemically pure and optically clear, colorless variety is known as *Iceland spar* because of its occurrence in Iceland.



Calcite Crystals, Joplin, Missouri.

PLATE XI.

Composition. Calcium carbonate, $CaCO_3$. $CaO = 56.0$ per cent, $CO_2 = 44.0$ per cent. Small amounts of magnesium, ferrous iron, manganese, and zinc may replace the calcium.

Tests. Infusible. After intense ignition, residue gives alkaline reaction to moistened test paper. Fragment moistened with hydrochloric acid and heated gives orange-red flame. Fragments effervesce freely in cold dilute hydrochloric acid. Concentrated solution gives precipitate of calcium sulfate when a few drops of sulfuric acid are added; no precipitate will form if solution is dilute.

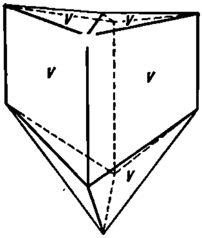


FIG. 336. Calcite Twinned on the Negative Rhombohedron.

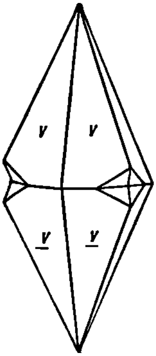


FIG. 337. Calcite Twinned on the Base.

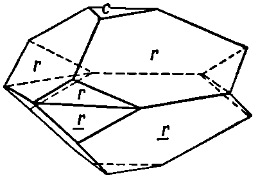


FIG. 338. Calcite Twinned on the Base.

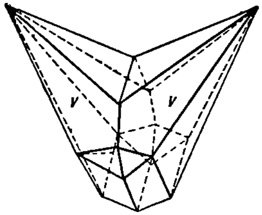


FIG. 339. Calcite Twinned on the Unit Rhombohedron.

Diagnostic Features. Distinguished by its softness (3), its perfect cleavage, light color, vitreous luster. Distinguished from dolomite by the fact that fragments of calcite effervesce freely in cold hydrochloric acid, whereas those of dolomite do not. Distinguished from aragonite by having lower specific gravity and rhombohedral cleavage.

Occurrence. *As a Rock Mineral.* Calcite is one of the most common and widely diffused of minerals. It occurs as enormous and widespread sedimentary rock masses in which it is the predominant mineral; and in some rocks, the limestones, it is the only mineral present. Crystalline metamorphosed limestones are known as *marbles*. *Chalk* is a fine-grained pulverulent deposit of calcium carbonate. Calcite is an important constituent of calcareous marls and calcareous sandstones. The limestone rocks have, in great part, been formed by the deposition on a sea bottom of great thicknesses of calcareous material in the form of shells and skeletons of sea animals. A smaller proportion of these rocks have been formed directly by precipitation of calcium carbonate.

As Cave Deposits, etc. Calcareous waters evaporating in limestone caves often deposit calcite in the form of stalactites, stalagmites, and incrustations. Such deposits are often beautiful and spectacular. The calcite is usually semi-translucent and of light yellow colors. Both hot and cold calcareous spring waters may form a deposit of calcite known as *travertine*, or *tufa*, around their mouths. Many deposits of cellular travertine are to be found in limestone regions. The deposit at Mammoth Hot Springs, Yellowstone Park, is more spectacular than most, but of similar origin.

Siliceous Calcites. Calcite crystals may inclose considerable amounts of quartz sand (up to 60 per cent) and form what are known as sandstone crystals. Such occurrences are found at Fontainebleau, France (Fontainebleau limestone), and in the Bad Lands, South Dakota.

Calcite occurs as a secondary mineral in igneous rocks as a product of decomposition of lime silicates. It is found lining the amygdaloidal cavities in lavas. It occurs in many sedimentary and metamorphic rocks in greater or less proportion. It is the cementing material in light-colored sandstones. Calcite is also one of the most common of vein minerals, occurring as a gangue material, with all sorts of metallic ores.

It would be quite impossible to specify all the important districts for the occurrence of calcite in its various forms. Some of the more notable localities in which finely crystallized calcite is found are as follows: Andreasberg in the Harz Mountains; various places in Saxony; in Cumberland, Derbyshire, Durham, Cornwall, and Lancashire, England; Iceland; Guanajuato, Mexico. In the United States at Joplin, Missouri; Lake Superior copper district; Rossie, New York.

Use. The most important use for calcite is for the manufacture of cements and lime for mortars. (See page 382.) Limestone when heated to about 1,000° F. loses its carbonic acid and is converted into quicklime, CaO. This, when mixed with water (slaked lime), swells, gives off much heat, and finally by absorption of carbon dioxide from the air hardens or, as commonly termed, "sets." Quicklime when mixed with sand forms the common mortar used in building.

The greatest consumption of limestone is in the manufacture of cements. The particular type known as Portland cement is most widely used. It is composed of about 75 per cent calcium carbonate (limestone), 13 per cent of silica, and 5 per cent of alumina. Small amounts of magnesium carbonate and iron oxide are also present. The silica and alumina are contributed by clay or shale which is mixed with the limestone before " burning." When water is mixed with cement, hydrous calcium aluminum silicates are formed. Certain limestones have various clayey materials as impurities in the correct proportions and are known as *cement rocks.* Cements made from such rocks have the valuable property of hardening under water and are known as hydraulic cements.

Chalk is used as a fertilizer, for whiting and whitewash, for crayons, etc. It is found in many places in Europe, the chalk cliffs of Dover being famous.

Limestone is largely used as a building material; it is obtained in the United States chiefly from Indiana. Limestone is extensively used as a flux for smelting various metallic ores. A fine-grained limestone is used in lithographing.

Marbles are used very extensively as ornamental and building material. The most important marble quarries in the United States are found in Vermont, New York, Georgia, Tennessee.

Iceland spar is valuable for optical instruments in the form of the Nicol prism to produce polarized light.

Name. From the Latin word, *calx*, meaning burnt lime.

DOLOMITE — $CaMg(CO_3)_2$

Crystallography. Rhombohedral; rhombohedral class. Crystals are usually the unit rhombohedron (Fig. 340). Faces often curved, some so acutely as to form " saddle-shaped " crystals (Fig. 341). Other forms rare. In coarse, granular, cleavable masses to fine-grained and compact.

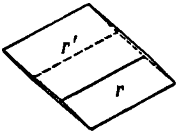


FIG. 340.

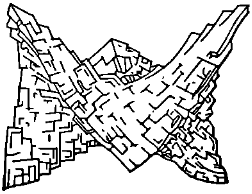


FIG. 341.

Dolomite.

Physical Properties. Perfect rhombohedral cleavage $\{10\bar{1}1\}$ (cleavage angle = 73° 45′). **H.** = $3\frac{1}{2}$–4. **G.** = 2.85. Luster vitreous; pearly in some varieties, *pearl spar.* Color usually some shade of pink, flesh color; may be colorless, white, gray, green, brown, and black. Transparent to translucent.

Composition. Carbonate of calcium and magnesium, $CaMg(CO_3)_2$. $CaO = 30.4$ per cent, $MgO = 21.7$ per cent, $CO_2 = 47.9$ per cent. In ordinary dolomite the proportion of $CaCO_3$ to $MgCO_3$ is as 1 : 1. Small amounts of ferrous carbonate frequently replace some of the magnesium carbonate. When considerable iron is present the mineral is called *ankerite.* Manganese may also be present.

Tests. Infusible. After intense ignition a fragment will give an alkaline reaction to moistened test paper. In cold dilute hydrochloric acid large fragments only slowly attacked, but powder readily soluble with effervescence. Large fragments soluble with effervescence in hot hydrochloric acid. Solution oxidized by nitric acid and then made ammoniacal (may precipitate ferric hydroxide) will with ammonium oxalate give a white precipitate of calcium oxalate; filtrate with sodium phosphate gives granular white precipitate of ammonium magnesium phosphate.

Diagnostic Features. Crystallized variety told by its curved rhombohedral crystals and usually by its flesh-pink color. The massive rock variety is distinguished from limestone by the less vigorous reaction with hydrochloric acid.

Occurrence. Dolomite occurs chiefly in widely extended rock masses as dolomitic limestone and the crystallized equivalent, dolomitic marble. Occurrence same as for calcite rocks. Often intimately mixed with calcite. Dolomite as a rock mass is thought to be secondary in origin, having been formed from ordinary limestone by the replacement of calcium by magnesium. Occurs also as a vein mineral, chiefly in the lead and zinc veins that traverse limestone.

Found in large rock strata in the dolomite region of southern Tyrol; in crystals from the Binnenthal, Switzerland; Traversella in Piedmont; northern England; Guanajuato, Mexico. In the United States is found as masses of sedimentary rock in many of the middle-western states, and in crystals in the Joplin, Missouri, district.

Use. As a building and ornamental stone. For the manufacture of certain cements. For the manufacture of magnesia used in the preparation of refractory linings of the converters in the basic steel process.

Name. In honor of the French chemist, Dolomieu (1750–1801).

Similar Species. *Ankerite,* $CaCO_3 \cdot (Mg,Fe,Mn)CO_3$, is a subspecies intermediate between calcite, dolomite, and siderite.

MAGNESITE — $MgCO_3$

Crystallography. Rhombohedral; scalenohedral. Rarely in crystals. Usually in white compact earthy masses; less frequently in cleavable granular masses, coarse to fine.

Physical Properties. Perfect rhombohedral $\{10\bar{1}1\}$ cleavage (cleavage angle = 72° 36′). **H.** = $3\frac{1}{2}$–5. **G.** = 3.0–3.2. Luster vitreous. Color white, gray, yellow, brown. Transparent to translucent.

Composition. Magnesium carbonate, $MgCO_3$. MgO = 47.6 per cent, CO_2 = 52.4 per cent. Iron and calcium may be present in small amounts.

Tests. Infusible. After intense ignition gives a faint alkaline reaction on moistened test paper. Scarcely acted upon by cold, but dissolves with effervescence in hot hydrochloric acid. Solution, after the precipitation of any iron and calcium, gives in the presence of an excess of ammonia, with sodium phosphate, a white granular precipitate of ammonium magnesium phosphate.

Diagnostic Features. Cleavable varieties are distinguished from dolomite only by the higher specific gravity and absence of abundant calcium. The white massive variety resembles chert and is distinguished from it by inferior hardness.

Occurrence. Magnesite is commonly in veins derived from the alteration of serpentine through the action of waters containing carbonic acid. Such magnesites are compact and commonly colloidal, and often contain opaline silica. Crystallized cleavable magnesite can be considered as a sedimentary type formed from limestones or dolomites by the replacement of calcium by magnesium.

Notable deposits of the sedimentary type of magnesite are at Satka in the Ural Mountains; and at Styria, Austria. The most famous deposit of the colloidal type is on the Island of Eubœa, Greece.

In the United States the compact variety is found in serpentine veins in the Coast Range, California, and large masses of the sedimentary type are in Stevens County, Washington.

Use. Magnesite is chiefly used in the preparation of magnesite bricks for refractory linings in metallurgical furnaces. Also used in the preparation of magnesium salts (Epsom salts, magnesia, etc.).

SIDERITE — $FeCO_3$

Spathic Iron. Chalybite

Crystallography. Rhombohedral; scalenohedral. Crystals usually unit rhombohedrons (same as cleavage form), frequently with curved faces. Concretionary. In globular concretions. Usually cleavable granular. May be botryoidal, compact, and earthy.

Physical Properties. Perfect rhombohedral $\{10\bar{1}1\}$ cleavage (cleavage angle = 73° 0′). **H.** = $3\frac{1}{2}$–4. **G.** = 3.85±. Luster vitreous. Color usually light to dark brown. Transparent to translucent.

Composition. Ferrous carbonate, $FeCO_3$. FeO = 62.1 per cent, CO_2 = 37.9 per cent. Fe = 48.2 per cent. Manganese, magnesium, and calcium may be present in small amounts.

Tests. Difficultly fusible (4½–5). Becomes strongly magnetic on heating. Heated in the closed tube decomposes and gives a black magnetic residue. Soluble in hot hydrochloric acid with effervescence; solution gives with potassium ferricyanide a dark blue precipitate (test for ferrous iron).

Diagnostic Features. Distinguished from other carbonates by its color and high specific gravity, and from sphalerite by its rhombohedral cleavage.

Occurrence. Siderite is frequently found as *clay ironstone*, impure by admixture with clay materials, in concretions with concentric layers. As *black-band ore* it is found, contaminated by carbonaceous material, in extensive stratified formations lying in shales and commonly associated with coal measures. These ores have been mined extensively in Great Britain in the past as the chief source of iron, but at present are mined only in North Staffordshire and Scotland. Clay ironstone is also abundant in the coal measures of western Pennsylvania and eastern Ohio, but it is not used to any great extent as an ore. Siderite is also formed by the replacement action of ferrous solutions upon limestones, and if such deposits are extensive they may be of economic value. The most notable occurrence of this type is in Styria, Austria, where siderite is mined on a large scale. Siderite, in its crystallized form, is a common vein mineral associated with various metallic ores, as silver minerals, pyrite, chalcopyrite, tetrahedrite, galena. When siderite predominates in such veins it may be mined, as in southern Westphalia, Germany.

Use. An ore of iron. Important in Great Britain and Austria, but of very subordinate value in the United States.

Name. From the Greek word meaning *iron.* The original name was *spherosiderite,* given to the concretionary variety and subsequently shortened to siderite to apply to the entire species. *Spathic ore* is a common name. *Chalybite,* used by some mineralogists, was derived from the Chalybes, who lived on the Black Sea, and were in ancient times workers in iron.

RHODOCHROSITE — $MnCO_3$

Crystallography. Rhombohedral; scalenohedral. Only rarely in crystals of the unit rhombohedron; frequently with curved faces. Usually cleavable massive; granular to compact.

Physical Properties. Perfect rhombohedral $\{10\bar{1}1\}$ cleavage (cleavage angle = 73° 0′). **H.** = 3½–4½. **G.** = 3.45–3.6. Luster vitreous.

Color usually some shade of rose-red; may be light pink to dark brown. Transparent to translucent.

Composition. Manganese carbonate, $MnCO_3$. $MnO = 61.7$ per cent, $CO_2 = 38.3$ per cent. Iron is usually present, replacing a part of the manganese, and some analyses report calcium, magnesium, zinc.

Tests. Infusible. Soluble in hot hydrochloric acid with effervescence. In the oxidizing flame gives reddish violet color to borax bead and blue-green color to sodium carbonate bead.

Diagnostic Features. Told usually by its pink color, rhombohedral cleavage, and hardness (4). Distinguished by its hardness from rhodonite ($MnSiO_3$, **H.** = $5\frac{1}{2}$–$6\frac{1}{2}$).

Occurrence. Rhodochrosite is a comparatively rare mineral, occurring in veins with ores of silver, lead, and copper, and with other manganese minerals. Found in the silver mines of Rumania and Saxony. In the United States found at Branchville, Connecticut; Franklin, New Jersey; Butte, Montana. In good crystals at Alicante, Lake County; Alma, Park County, and elsewhere in Colorado.

Use. A minor ore of manganese. Mined to a considerable extent at Butte, Montana.

Name. Derived from two Greek words meaning *rose* and *color,* in allusion to its rose-pink color.

SMITHSONITE — $ZnCO_3$

Dry-Bone Ore

Crystallography. Rhombohedral; scalenohedral. Rarely in small rhombohedral or scalenohedral crystals. Usually reniform, botryoidal, or stalactitic, and in crystalline incrustations or in honeycombed masses known as *dry-bone ore.* Also granular to earthy.

Physical Properties. Perfect rhombohedral $\{10\bar{1}1\}$ cleavage, which is seldom observed. **H.** = 5 (unusually high for a carbonate). **G.** = 4.35–4.40. Luster vitreous. Color usually dirty brown. May be white, green, blue, pink. The yellow variety contains cadmium and is known as *turkey-fat ore.* Translucent.

Composition. Zinc carbonate, $ZnCO_3$. $ZnO = 64.8$ per cent, $CO_2 = 35.2$ per cent. Iron and manganese replace a part of the zinc; also, less commonly, calcium, magnesium, and cadmium.

Tests. Infusible. Soluble in cold hydrochloric acid with effervescence. A fragment heated in the reducing flame gives bluish green streaks in the flame, due to the burning of the volatilized zinc. Heated in the reducing flame on charcoal gives a nonvolatile coating of zinc oxide, yellow when hot, white when cold; if coating is moistened with cobalt nitrate and again heated it turns green.

Diagnostic Features. Distinguished by its effervescence in acids, its tests for zinc, its hardness (5), and its high specific gravity.

Occurrence. Smithsonite is a zinc ore of secondary origin, usually found with zinc deposits lying in limestone rocks. Associated with sphalerite, galena, hemimorphite, cerussite, calcite, limonite. Often found in pseudomorphs after calcite. *Dry-bone ore* is a honeycombed mass, with the appearance of dried bone, whose texture has resulted from the manner of deposition of the mineral. Some hemimorphite, the silicate of zinc, is included under the term. Found in places in translucent green or greenish blue material which is used for ornamental purposes. Laurium, Greece, is noted for this ornamental smithsonite; and Sardinia for yellow stalactites with concentric banding. In the United States smithsonite occurs as an ore in the zinc deposits of Missouri, Arkansas, Wisconsin, Virginia. Fine greenish blue material has been found at Kelly, New Mexico.

Use. An ore of zinc. A minor use is for ornamental purposes.

Name. Named in honor of James Smithson (1754–1829), who founded the Smithsonian Institution at Washington. English mineralogists formerly called the mineral calamine.

Similar Species. *Hydrozincite,* a basic zinc carbonate, occurs as a secondary mineral in zinc deposits.

Aragonite Group

The aragonite group consists of a series of carbonates of calcium, strontium, barium, and lead, which crystallize in the orthorhombic system with closely related crystal constants and similar habits of crystallization. All of them may appear in twin crystals which are pseudohexagonal in character. The members of the group are: *aragonite, strontianite, witherite,* and *cerussite.* These orthorhombic carbonates form an important isostructural group.

ARAGONITE — $CaCO_3$

Crystallography. Orthorhombic; dipyramidal. Three habits of crystallization are common. (1) Acicular pyramidal; consisting of a prism terminated by a combination of a very steep dipyramid and brachydome (Fig. 342). Usually in radiating groups of large to very small crystals. (2) Tabular; consisting of prominent brachypinacoid faces modified by a prism and a low brachydome (Fig. 343). Often twinned with a prism face as the twinning plane (Fig. 344). (3) In pseudohexagonal twins (Fig. 345). This type shows a hexagonal-like prism terminated by a basal plane, and is formed by an intergrowth of three individuals twinned on the prism face with basal planes in common. The crystals are distinguished from true hexagonal forms by noting that the basal plane is striated in three different directions, and also by the fact that, because the prism angle of the simple crystals is not exactly 60°, but 63° 48′, the composite prism faces for the twin will often show slight re-entrant angles. Also found in reniform, columnar, and stalactitic aggregates.

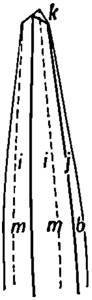


FIG. 342.

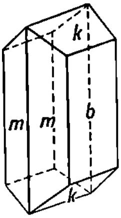


FIG. 343.

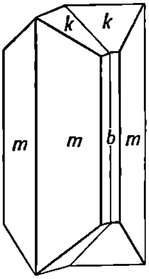


FIG. 344.

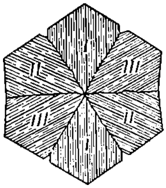


FIG. 345.

Aragonite.

Physical Properties. Imperfect cleavage parallel to brachypinacoid, {010} and prism {110}. Luster vitreous. Colorless, white, pale yellow, and variously tinted. Transparent to translucent. **H.** = $3\frac{1}{2}$–4. **G.** = 2.95 (harder and higher specific gravity than calcite).

Composition. Calcium carbonate, like calcite, $CaCO_3$. CaO = 56.0 per cent, CO_2 = 44.0 per cent. May contain a little strontium or lead, rarely zinc.

Tests. Infusible. Decrepitates. After intense ignition the powder gives an alkaline reaction on moistened test paper. Fragments fall to powder (change to calcite) when heated at low redness in the closed tube. Chemical tests same as for calcite (page 224).

Diagnostic Features. Distinguished from calcite by its higher specific gravity and lack of rhombohedral cleavage. Cleavage fragments of columnar calcite are terminated by a cross cleavage which is lacking in aragonite. Distinguished from witherite and strontianite by being infusible, of lower specific gravity, and in lacking a distinctive flame color.

Alteration. Paramorphs of calcite after aragonite are common. Calcium carbonate secreted by molluscs as aragonite is usually changed to calcite on the outside of the shell.

Occurrence. Aragonite is less stable than calcite and much less common in its occurrence. Found as a hot-spring deposit. Experiments have shown that carbonated waters containing calcium more often deposit aragonite when they are hot and calcite when they are cold. The pearly layer of many shells is aragonite. Aragonite is most commonly found associated with beds of gypsum and deposits of iron ore where it may occur in forms resembling coral, and is called *flos ferri*, flower of iron. Found lining amygdaloidal cavities in basalt.

Notable localities for the various crystalline types are as follows: Pseudohexagonal twin crystals are found in Aragon, Spain; Bastennes, in the south of France; and at Girgenti, Sicily. The tabular type of crystals is found near Bilin, Bohemia. The acicular type is found at Alston Moor and Cleator Moor, Cumberland, England. Flos ferri is found in the Styrian iron mines. In the United States pseudohexagonal twins are found at Lake Arthur, New Mexico. The flos ferri variety occurs in the Organ Mountains, New Mexico, and in Bisbee, Arizona.

Name. From Aragon, Spain, where the pseudohexagonal twins were first recognized.

WITHERITE — $BaCO_3$

Crystallography. Orthorhombic; dipyramidal. Crystals always twinned, forming pseudohexagonal pyramids by the intergrowth of three individuals terminated by brachydomes. Crystals sometimes doubly terminated; often deeply striated horizontally and by a series of re-entrant angles have the appearance of one pyramid capping another. Also botryoidal to globular; columnar or granular.

Physical Properties. Poor cleavage parallel to brachypinacoid $\{010\}$ and prism $\{110\}$. **H.** $= 3\frac{1}{2}$. **G.** $= 4.3$. Luster vitreous. Colorless, white, gray. Translucent.

Composition. Barium carbonate, $BaCO_3$. $BaO = 77.7$ per cent, $CO_2 = 22.3$ per cent.

Tests. Fusible at $2\frac{1}{2}$–3, giving a yellowish green flame (barium). After intense ignition gives an alkaline reaction on moistened test paper. Soluble in cold hydrochloric acid with effervescence. All solutions, even the very dilute, give precipitate of barium sulfate with sulfuric acid (difference from calcium and strontium).

Diagnostic Features. Witherite is characterized by high specific gravity and effervescence in acid. It can be distinguished from strontianite by the flame test and from barite by its effervescence in acid.

Occurrence. Witherite is a comparatively rare mineral, most frequently found in veins associated with galena. Found in England in fine crystals near Hexham in Northumberland and Alston Moor in Cumberland. Occurs at Leogang in Salzburg. In the United States found near Lexington, Kentucky; in a large vein with barite at El Portal, Yosemite Park, California. Also at Thunder Bay, Lake Superior, Ontario.

Use. A minor source of barium.

Name. In honor of D. W. Withering (1741–1799), who discovered and first analyzed the mineral.

STRONTIANITE — $SrCO_3$

Crystallography. Orthorhombic; dipyramidal. Crystals usually acicular, radiating like type (1) under aragonite. Twinning also frequent, giving pseudohexagonal forms. Also columnar; fibrous and granular.

Physical Properties. Good prismatic {110} cleavage. **H.** = $3\frac{1}{2}$–4. **G.** = 3.7. Luster vitreous. Color white, gray, yellow, green. Transparent to translucent.

Composition. Strontium carbonate, $SrCO_3$. SrO = 70.1 per cent, CO_2 = 29.9 per cent. A little calcium may be present.

Tests. Infusible, but on intense ignition swells and throws out fine branches and gives a crimson flame (strontium), and residue gives alkaline reaction on moistened test paper. Effervesces in hydrochloric acid, and the medium dilute solution will give precipitate of strontium sulfate on addition of a few drops of sulfuric acid; no precipitate will form in the very dilute solution (difference from calcium and barium).

Diagnostic Features. Characterized by high specific gravity and effervescence in hydrochloric acid. Can be distinguished from witherite and aragonite by flame test; from celestite by poorer cleavage and effervescence in acid.

Occurrence. Strontianite is a comparatively rare mineral found in veins in limestones or marls, and less frequently in igneous rocks. In some metallic veins. Occurs in commercial deposits in Westphalia, Germany; at Schoharie, New York.

Use. Source of strontium. Strontium has no great commercial use; used in fireworks, in the separation of sugar from molasses, and in various strontium compounds.

Name. From Strontian in Argyllshire, Scotland, where it was originally found.

CERUSSITE — $PbCO_3$

Crystallography. Orthorhombic; dipyramidal. Crystals common of varied habit, and show many forms. Often tabular parallel to brachypinacoid (Fig. 346). Frequently twinned (Fig. 347); may form reticulated groups with the plates crossing each other at 60° angles.

May be pyramidal in habit; also twinned in pseudohexagonal pyramids, frequently with deep re-entrant angles in the prism zone. Also in granular crystalline aggregates; fibrous; granular massive; compact; earthy.

Physical Properties. Prismatic {110} cleavage. **H.** = 3–3½. **G.** = 6.55 (high for a mineral with nonmetallic luster). Luster adamantine. Colorless, white, or gray. Transparent to subtranslucent.

Composition. Lead carbonate, $PbCO_3$. PbO = 83.5 per cent, CO_2 = 16.5 per cent.

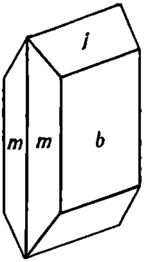


FIG. 346.

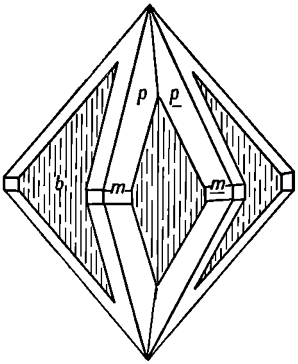


FIG. 347.

Cerussite.

Tests. Fusible at 1½. With sodium carbonate on charcoal gives globule of lead and yellow to white coating of lead oxide. Soluble in warm dilute nitric acid with effervescence. In the closed tube usually decrepitates and is changed to lead oxide, which is dark yellow when hot.

Diagnostic Features. Recognized by its high specific gravity, white color, and adamantine luster. Crystal form and effervescence in nitric acid serve to distinguish it from anglesite.

Occurrence. Cerussite is an important and widely distributed lead ore of secondary origin, formed by the action of carbonated waters on galena in the upper zone of lead veins. Associated with the primary minerals galena and sphalerite, and various secondary minerals such as anglesite, pyromorphite, smithsonite, limonite.

Notable localities for its occurrence are Ems in Nassau; Mies, Bohemia; Nerchinsk, Siberia; on the island of Sardinia; in Tunis; at Tsumeb, Otavi, Southwest Africa; Broken Hill, New South Wales. In the United States found at Phoenixville, Pennsylvania; Leadville, Colorado; various districts in Arizona; from the Organ Mountains, New Mexico; in the Coeur d'Alene District in Idaho.

Use. An important ore of lead.

Name. From the Latin word meaning *white lead.*

Similar Species. *Phosgenite,* a chlorocarbonate of lead $Pb_2Cl_2CO_3$, tetragonal in crystallization, is a rare anhydrous carbonate.

MALACHITE — $Cu_2CO_3(OH)_2$

Green Copper Carbonate

Crystallography. Monoclinic; prismatic. Crystals usually slender prismatic but seldom distinct. Crystals may be pseudomorphous after azurite. Usually in radiating fibers forming botryoidal or stalactitic masses. Often granular or earthy.

Physical Properties. Perfect basal {001} cleavage, but rarely seen. **H.** = $3\frac{1}{2}$–4. **G.** = 3.9–4.03. Luster adamantine to vitreous in crystals; often silky in fibrous varieties; dull in earthy type. Color bright green. Translucent.

Composition. Basic carbonate of copper, $Cu_2CO_3(OH)_2$. CuO = 71.9 per cent, CO_2 = 19.9 per cent, H_2O = 8.2 per cent. Cu = 57.4 per cent.

Tests. Fusible at 3, giving a green flame. With fluxes on charcoal gives copper globule. Soluble in hydrochloric acid with effervescence, yielding a green solution. Solution turns deep blue with excess of ammonia. Much water in the closed tube.

Diagnostic Features. Recognized by its bright green color and botryoidal forms, and distinguished from other green copper minerals by its effervescence in acid.

Occurrence. Malachite is an important and widely distributed copper ore of secondary origin. Found in the oxidized portions of copper veins associated with azurite, cuprite, native copper, iron oxides, and the various sulfides of copper and iron. Usually occurs in copper veins that lie in limestone.

Notable localities for its occurrence are at Nizhne Tagil in the Ural Mountains; at Chessy, near Lyons, France, associated with azurite; from Tsumeb, Southwest Africa; from Rhodesia; South Australia. In the United States, an important copper ore in the southwestern copper districts; at Bisbee, Morenci, and other localities in Arizona; and in New Mexico.

Use. An ore of copper. Has been used to some extent as an ornamental material for vases, veneer for table tops, etc.

Name. Derived from the Greek word for *mallows,* in allusion to its green color.

AZURITE — $Cu_3(CO_3)_2(OH)_2$

Chessylite. Blue Copper Carbonate

Crystallography. Monoclinic; prismatic. Habit varied. Crystals frequently complex in habit and distorted in development. Also in radiating spherical groups.

Physical Properties. **H.** = $3\frac{1}{2}$–4. **G.** = 3.77. Luster vitreous. Color intense azure-blue. Transparent to translucent.

Composition. A basic carbonate of copper, $Cu_3(CO_3)_2(OH)_2$. CuO = 69.2 per cent, CO_2 = 25.6 per cent, H_2O = 5.2 per cent. Cu = 55.3 per cent.

Tests. Same as for malachite (page 236).

Diagnostic Features. Characterized chiefly by its azure-blue color and effervescence in hydrochloric acid.

Occurrence. Azurite has the same origin and associations as malachite, but is much more frequently in crystals. Found in fine crystals at Chessy, near Lyons, France; Tsumeb, Southwest Africa; in Rumania; Laurium, Greece; Siberia; Broken Hill, New South Wales. In the United States at Copper Queen Mine, Bisbee, and Morenci, Arizona. Widely distributed with copper ores. Not so common as malachite.

Use. An ore of copper.

Name. Named in allusion to its color.

Rare Hydrous Carbonates. *Aurichalcite,* a basic carbonate of zinc and copper, pale green to blue, in monoclinic acicular crystals. *Gay-Lussite,* $CaCO_3 \cdot Na_2CO_3 \cdot 5H_2O$, monoclinic; *trona,* $3Na_2O \cdot 4CO_3 \cdot 5H_2O$, monoclinic; both found in saline lake deposits.

NITRATES

Soda Niter — $NaNO_3$

Crystallography. Rhombohedral; scalenohedral. Homeomorphous with calcite. Has similar crystal constants, cleavage, optical properties, etc., to calcite. If a cleavage block of calcite is placed in a crystallizing solution of sodium nitrate, small rhombohedrons of the latter will form with parallel orientation on the calcite. Usually massive, as an incrustation or in beds.

Physical Properties. Perfect rhombohedral $\{10\bar{1}1\}$ cleavage. **H.** = 1–2. **G.** = 2.29. Luster vitreous. Colorless or white, also reddish brown, gray, yellow. Transparent to translucent. Taste cooling. Deliquescent.

Composition. Sodium nitrate, $NaNO_3$. Na_2O = 36.5 per cent, N_2O_5 = 63.5 per cent.

Tests. Fusible at 1, giving a strong yellow sodium flame. After intense ignition gives an alkaline reaction on moistened test paper. Easily and completely soluble in water. Heated in the closed tube with potassium disulfate gives off red vapors of nitrous oxide.

Diagnostic Features. Distinguished by its cooling taste and its strong deliquescence.

Occurrence. Because of its solubility in water soda niter is found only in arid and desert regions. Found in large quantities in the provinces of Tarapaca and Antofagasta, northern Chile, and the neighboring parts of Bolivia. Occurs over immense areas as a salt (caliche) bed interstratified with sand, beds of common salt, gypsum, etc. In the United States has been noted in Humboldt County, Nevada, and in San Bernardino County, California.

Use. In Chile it is quarried, purified, and used as a source of nitrates.

Niter — KNO_3

Saltpeter

Crystallography. Orthorhombic; prismatic. Usually as thin encrustations or as silky acicular crystals.

Physical Properties. Perfect domal cleavage, {011}. **H.** = 2. **G.** = 2.09–2.14. Luster vitreous. Color white. Translucent.

Composition. Potassium nitrate, KNO_3. $K_2O = 46.5$ per cent, $N_2O_5 = 53.5$ per cent.

Tests. Fusible at 1, giving violet flame (potassium). After ignition gives alkaline reaction on moistened test paper. Heated in the closed tube with potassium disulfate gives red fumes of nitrous oxide. Easily soluble in water. Saline and cooling taste.

Diagnostic Features. Characterized by its cooling taste; distinguished from soda niter by the potassium test and by being non-deliquescent.

Occurrence. Niter is found as delicate crusts, as an efflorescence, on surfaces of earth, walls, rocks, etc. Found as a constituent of certain soils. Also in the loose soil of limestone caves. Not as common as soda niter, but produced from soils in Spain, Italy, Egypt, Arabia, Persia, and India.

Use. Used as a source of nitrogen compounds.

BORATES

Boracite — $Mg_7Cl_2B_{16}O_{30}$

Crystallography. Orthorhombic structure at ordinary temperatures, but crystals show isometric, hextetrahedral forms. The cube, tetrahedron, and dodecahedron are usually present in combination (Figs. 348 and 349). If boracite is heated to 265° C. the structure reverts to isometric as required by the crystal form. Crystals usually isolated and disseminated in other minerals. Also massive.

Physical Properties. **H.** = 7. **G.** = 2.9–3.0. Luster vitreous. Colorless, white, gray, green. Transparent to translucent.

Composition. $Mg_7Cl_2B_{16}O_{30}$. MgO = 31.4 per cent, Cl = 7.9 per cent, B_2O_3 = 62.5 per cent, deduct (O = Cl) 1.8 = 100.

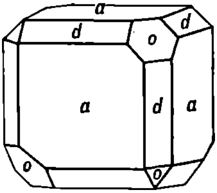


FIG. 348.

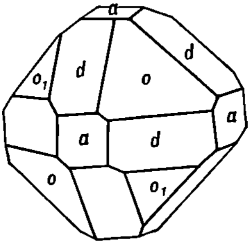


FIG. 349.

Boracite.

Tests. Fusible at 2 with green flame color (boron). Soluble in hydrochloric acid. Turmeric paper moistened with a solution of the mineral and then dried at 100° C. turns reddish brown (boron).

Diagnostic Features. Boracite is characterized by its high hardness, isometric crystals, and test for boron.

Occurrence. Boracite occurs associated with beds of halite, anhydrite, and gypsum, as one of the products formed by the evaporation of bodies of salt water. It is found at Stassfurt and other localities in Germany. In the United States it has been observed in the insoluble residues of salt wells in Louisiana.

BORAX — $Na_2B_4O_7 \cdot 10H_2O$

Crystallography. Monoclinic; prismatic. Prismatic crystals, some large. Also as massive cellular material or encrustations.

Physical Properties. Perfect cleavage parallel to orthopinacoid, {100}. **H.** = 2–2½. **G.** = 1.7±. Luster vitreous. Colorless or white. Translucent. Sweetish-alkaline taste. Clear crystals effloresce and turn white.

Composition. Hydrous sodium borate, $Na_2B_4O_7 \cdot 10H_2O$. Na_2O = 16.2 per cent, B_2O_3 = 36.6 per cent, H_2O = 47.2 per cent.

Tests. Fusible at 1–1½ with much swelling and gives strong yellow flame (sodium). Fused with boron flux gives the bright green flame of boron. Readily soluble in water. Turmeric paper, moistened with a dilute hydrochloric acid solution of the mineral, turns reddish brown when dried at 100° C. Much water in the closed tube.

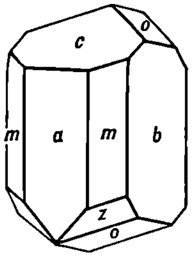


FIG. 350. Borax.

Diagnostic Features. Characterized by its crystals and tests for boron.

Occurrence. Borax is the most widespread of the borate minerals. It is formed as a deposit from the evaporation of salt lakes, and as an efflorescence on the surface of the ground in arid regions. The deposits in Tibet have furnished large amounts of borax, which has been exported to Europe in the crude state under the name of *tincal.* This was the first borax to reach western civilization. Obtained from brines and hot springs in northern Italy. In the United States was first found in Lake County, California, and later in the desert region of southeastern California, in Death Valley, Inyo County, and in San Bernardino County. Occurs also in the adjacent parts of Nevada. Borax is associated with the other minerals deposited in similar manner, such as ulexite, hanksite, halite, gypsum, colemanite, and various rare borates.

Use. Borax is used for washing and cleansing; as an antiseptic and preservative; in medicine; as a solvent for metallic oxides in soldering and welding; and as a flux in various smelting and laboratory operations.

Name. Borax comes from an Arabic name for the substance.

KERNITE — $Na_2B_4O_7 \cdot 4H_2O$

Rasorite

Crystallography. Monoclinic; prismatic. Usually in coarse cleavable aggregates.

Physical Properties. Perfect cleavage parallel to the basal pinacoid {001}, and orthopinacoid {100}. Cleavage fragments are thus elongated parallel to the *b* crystallographic axis. **H.** = 3. **G.** = 1.95. Luster vitreous to pearly. Colorless to white; colorless specimens become a chalky white on long exposure to the air.

Composition. Hydrous sodium borate, $Na_2B_4O_7 \cdot 4H_2O$. Na_2O = 22.7 per cent, B_2O_3 = 51.0 per cent, H_2O = 26.3 per cent.

Tests. Before the blowpipe swells and then fuses (at 1½) to a clear glass. Slowly soluble in cold water.

Diagnostic Features. Characterized by the long splintery cleavage fragments and low specific gravity.

Occurrence. The only locality at which kernite is found is on the Mohave Desert at Kramer, California. Here associated with borax in a bedded series of Tertiary clays it is present by the million tons. This deposit of sodium borates is 4 miles long, 1 mile wide, and 100 feet thick, and lies from 350 to 800 feet beneath the surface. The kernite is believed to have formed from borax by recrystallization caused by increased temperature and pressure.

Use. The chief source of borax at the present time.

Name. From Kern County, California, where the mineral is found.

ULEXITE — $NaCaB_5O_9 \cdot 8H_2O$

Cotton-Balls

Crystallography. Triclinic; pinacoidal. Usually in rounded masses, loose in texture, consisting of fine fibers which are acicular or capillary crystals.

Physical Properties. **H.** = 1. **G.** = 1.96. Luster silky. Color white. Tasteless.

Composition. A hydrous sodium and calcium borate, $NaCaB_5O_9 \cdot 8H_2O$. Na_2O = 7.7 per cent, CaO = 13.8 per cent, B_2O_3 = 43.0 per cent, H_2O = 35.5 per cent.

Tests. Fusible at 1, with intumescence to a clear blebby glass, coloring the flame deep yellow. Moistened with sulfuric acid gives momentarily the green flame of boron. Gives much water in closed tube. Soluble in hydrochloric acid.

Diagnostic Features. The soft " cotton-balls " with silky luster are characteristic of ulexite.

Occurrence. Ulexite crystallizes in arid regions from brines which have concentrated in inclosed basins, as in playa lakes. Usually associated with borax. It occurs abundantly in the dry planes of northern Chile and in Argentina. In the United States it has been found abundantly in certain of the inclosed basins of Nevada and California.

Use. A source of borax.

Name. In honor of the German chemist, G. L. Ulex, who discovered the mineral.

COLEMANITE — $Ca_2B_6O_{11} \cdot 5H_2O$

Crystallography. Monoclinic; prismatic. In short prismatic crystals, highly modified. Cleavable massive to granular and compact.

Physical Properties. Perfect cleavage parallel to the clinopinacoid {010}. **H.** = 4–4½. **G.** = 2.42. Luster vitreous. Colorless to white. Transparent to translucent.

Composition. Hydrous calcium borate, $Ca_2B_6O_{11}·5H_2O$. CaO = 27.2 per cent, B_2O_3 = 50.9 per cent, H_2O = 21.9 per cent.

Tests. Fusible at $1\frac{1}{2}$. Before the blowpipe exfoliates, crumbles, and gives green flame (boron). Water in the closed tube.

Diagnostic Features. Characterized by one direction of highly perfect cleavage and exfoliation on heating.

Occurrence. Colemanite deposits are interstratified with lake bed deposits of Tertiary age. Ulexite is usually associated, and the colemanite is believed to have originated by its alteration. Found only in California in Los Angeles, Ventura, San Bernardino, and Inyo Counties.

Use. A source of borax which, at the time of the discovery of kernite, yielded over half of the world's supply.

Name. In honor of William T. Coleman, merchant of San Francisco, who marketed the product of the colemanite mines.

PHOSPHATES, ARSENATES, AND VANADATES

This mineral class, composed mostly of phosphates, is very large, but most of its members are so rare that they need not be mentioned here. Of the minerals listed below apatite is the only one that can be considered common.

Phosphates, Arsenates, and Vanadates

	Monazite	$(Ce,La,Di)PO_4$
	Triphylite	$LiFePO_4$
Apatite Group	Apatite	$Ca_5(F,Cl)(PO_4)_3$
	Pyromorphite	$Pb_5Cl(PO_4)_3$
	Mimetite	$Pb_5Cl(AsO_4)_3$
	Vanadinite	$Pb_5Cl(VO_4)_3$
	Collophanite	$Ca_3(PO_4)_2 \cdot H_2O$
	Amblygonite	$LiAlFPO_4$
	Lazulite	$MgAl_2(OH)_2(PO_4)_2$
	Scorodite	$FeAsO_4 \cdot 2H_2O$
	Wavellite	$Al_3(OH)_3(PO_4)_2 \cdot 5H_2O$
	Turquois	$Al_2(OH)_3PO_4 \cdot H_2O + x Cu$
	Vivianite	$Fe_3(PO_4)_2 \cdot 8H_2O$
	Erythrite	$Co_3(AsO_4)_2 \cdot 8H_2O$

Monazite — $(Ce,La,Di)PO_4$

Crystallography. Monoclinic; prismatic. Crystals rare and usually small, often flattened parallel to the orthopinacoid, or elongated parallel to the *b* crystal axis. Usually in granular masses, frequently as sand.

Physical Properties. Parting parallel to basal pinacoid {001}. **H.** = 5-5½. **G.** = 5.0-5.3. Luster resinous. Color yellowish to reddish brown. Translucent.

Composition. A phosphate of the rare-earth metals, essentially $(Ce,La,Di)PO_4$, usually with some thorium silicate, $ThSiO_4$. Ce_2O_3 varies from 25 to 35 per cent.

Tests. Infusible. Insoluble in hydrochloric acid. After fusion with sodium carbonate, dissolve in nitric acid and add solution to excess of ammonium molybdate solution; a yellow precipitate forms (test for a phosphate). Decomposed by heating with concentrated sulfuric acid; solution after dilution with water and filtering gives with ammonium oxalate a precipitate of the oxalates of the rare earths.

Diagnostic Features. In large specimens may be distinguished from zircon by crystal form and inferior hardness, and from sphene by crystal form and higher specific gravity. On doubtful specimens it is usually well to make the chemical phosphate test.

Occurrence. Monazite is a comparatively rare mineral occurring as an accessory mineral in granites, gneisses, aplites, and pegmatites, and as rolled grains in the sands derived from the decomposition of such rocks. It is concentrated in sands because of its resistance to chemical attack and because of its high specific gravity, and is thus associated with other resistant and heavy minerals such as magnetite, ilmenite, rutile, zircon.

The bulk of the world's supply of monazite comes from sands in the provinces of Minas Geraes and Bahia, Brazil, and from the coast of India. Found in the United States in North Carolina, both in gneiss and in the stream sands, and in certain beach sands of Florida.

Use. Monazite is the chief source of thorium oxide, which it contains in amounts varying from 1 to 20 per cent; commercial monazite usually contains between 3 and 9 per cent. Thorium oxide is used in the manufacture of mantles for incandescent gas lights.

Name. The name *monazite* is derived from a Greek word meaning *to be solitary,* in allusion to the rarity of the mineral.

Triphylite — $LiFePO_4$

Crystallography. Orthorhombic. Crystals rare. Commonly in cleavable masses. Also compact.

Physical Properties. Cleavage parallel to base {001} and brachypinacoid {010}. **H.** = $4\frac{1}{2}$–5. **G.** = 3.42–3.56. Luster vitreous to resinous. Color bluish gray in triphylite to salmon-pink or clove-brown with the increased amount of manganese. May be stained black by manganese oxide. Translucent.

Composition. Phosphate of lithium and ferrous iron, $LiFePO_4$. Completely isomorphous with *lithiophilite,* $LiMnPO_4$.

Tests. Fusible at $2\frac{1}{2}$, giving red lithium flame. Triphylite becomes magnetic on heating in the reducing flame. Some manganese is usually present, and therefore it gives an opaque bluish green bead with sodium carbonate. Soluble in nitric acid, and when the solution is added to an excess of a solution of ammonium molybdate gives yellow precipitate (test for phosphoric acid).

Diagnostic Features. Characterized by two cleavages at right angles, resinous luster, and association.

Occurrence. Triphylite is a rare mineral occurring in pegmatite dikes associated with other phosphates, spodumene, and beryl. Notable localities are Rabenstein, Bavaria, and Finland. In the United States found at Huntington, Massachusetts; Peru, Maine; Grafton, New Hampshire. Lithiophilite is found at Branchville, Connecticut.

Name. From the Greek words meaning *three* and *a tribe* because it contains the three bases, iron, lithium, and manganese.

APATITE — $Ca_5(F,Cl)(PO_4)_3$

Crystallography. Hexagonal; dipyramidal. Commonly in crystals of long prismatic habit; some short prismatic or tabular. Usually terminated by prominent pyramid of first order and frequently a basal plane (Figs. 351 and 352). Some crystals show faces of the third-order pyramid and may have a very complex development (Fig. 353). Also in massive granular to compact masses.

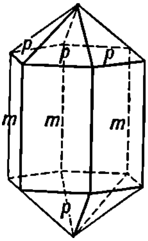


FIG. 351.

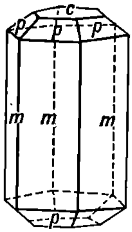


FIG. 352.

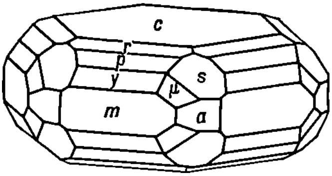


FIG. 353.

Apatite.

Physical Properties. Cleavage poor parallel to basal pinacoid {0001}. **H.** = 5 (can just be scratched by a knife). **G.** = 3.15–3.20. Luster vitreous to subresinous. Color usually some shade of green or brown; also blue, violet, colorless. Transparent to translucent.

Composition. Calcium fluophosphate, $Ca_5F(PO_4)_3$, *fluorapatite;* more rarely $Ca_5Cl(PO_4)_3$, *chlorapatite,* or an isomorphous mixture of the two.

Tests. Difficultly fusible (5–5½). Soluble in acids. Gives a yellow precipitate of ammonium phosphomolybdate when dilute nitric acid solution is added to large excess of ammonium molybdate solution. Concentrated hydrochloric acid solution gives white precipitate of calcium sulfate when a few drops of sulfuric acid are added.

Diagnostic Features. Recognized usually by its crystals, color, and hardness. Distinguished from beryl by the prominent pyramidal terminations of its crystals and by its being softer than a knife.

Occurrence. Apatite is widely disseminated as an accessory constituent in all classes of rocks — igneous, sedimentary, and metamorphic. It is also found in pegmatite and other veins, probably of hydrothermal origin. Found in titaniferous magnetite bodies. Occasionally concentrated into large deposits or veins associated with alkalic rocks.

Apatite occurs in large amounts along the southern coast of Norway, between Langesund and Arendal, where it is found in veins and pockets associated with gabbro. It is distributed through the magnetite iron ore at Kiruna, Sweden. Apatite occurs in commercial amount in Ontario and Quebec, Canada. It is found there in crystals and masses inclosed in crystalline calcite and in veins and irregular nests along the contact of the limestone with igneous rocks.

The world's largest deposit of apatite is located on the Kola Peninsula, near Kirovsk, U.S.S.R. It is found there in a great lens between two types of alkalic rocks. The apatite is in granular aggregates intimately associated with nepheline.

Finely crystallized apatite occurs at various localities in the Tyrol; in Switzerland; Jumilla, Spain. In the United States at Auburn, Maine; St. Lawrence County, New York; Alexander County, North Carolina; San Diego County, California.

Use. Apatite has been used extensively for fertilizer, but phosphate rock (see page 249) has now largely taken its place. The deposit on the Kola Peninsula is the only one at present of importance. Transparent varieties of apatite of fine color are occasionally used for gem material. The mineral is too soft, however, to allow of its extensive use for this purpose.

Name. From the Greek word *to deceive*, since the gem varieties were confused with other minerals.

Pyromorphite — $Pb_5Cl(PO_4)_3$

Crystallography. Hexagonal; dipyramidal. Prismatic crystals with basal plane. Rarely shows pyramid truncations. Often in rounded barrel-shaped forms. Sometimes cavernous, the crystals being hollow prisms. Also in parallel groups. Frequently globular, reniform, fibrous, and granular.

Physical Properties. H. = $3\frac{1}{2}$–4. G. = 6.5–7.1. Luster resinous to adamantine. Color usually various shades of green, brown, yellow; more rarely orange-yellow, gray, white. Subtransparent to translucent.

Composition. Lead chlorophosphate, $Pb_5Cl(PO_4)_3$. $PbO = 82.2$ per cent, $Cl = 2.6$ per cent, $P_2O_5 = 15.7$ per cent. The phosphorus is often replaced by arsenic, and the species grades into mimetite.

Tests. Fusible at 2. Gives a lead globule with sodium carbonate. When fused alone on charcoal gives a globule which on cooling appears to show crystal forms. Faint white sublimate of lead chloride when heated in the closed tube. A few drops of the nitric acid solution added to ammonium molybdate solution gives a yellow precipitate of ammonium phosphomolybdate.

Diagnostic Features. Characterized by its crystal form, high luster, and high specific gravity.

Occurrence. Pyromorphite is a mineral formed by secondary action and found in the upper oxidized portions of lead veins, associated with other lead minerals.

Notable localities for its occurrence are the lead mines of Poullaouen and Huelgoat, Brittany; at Ems in Nassau; at Zschopau, Saxony; Přibram, Bohemia; Beresovsk, Ural Mountains; in Cumberland and at Leadhills, Scotland. In the United States found at Phoenixville, Pennsylvania; Davidson County, North Carolina; Idaho.

Use. A subordinate ore of lead.

Name. Derived from two Greek words meaning *fire* and *form,* in allusion to the crystalline form it assumes on cooling from fusion.

Mimetite — $Pb_5Cl(AsO_4)_3$

Crystallography. Hexagonal; dipyramidal. Crystals prismatic, showing basal plane and pyramids. Usually in rounded barrel- to globular-shaped forms. Also in rounded crystals, mammillary crusts. Nearly identical to pyromorphite in appearance.

Physical Properties. H. = $3\frac{1}{2}$. **G.** = 7–7.2. Luster resinous to adamantine. Colorless, yellow, orange, brown. Subtransparent to translucent.

Composition. Lead chloroarsenate, $Pb_5Cl(AsO_4)_3$. PbO = 74.9 per cent, Cl = 2.4 per cent, As_2O_5 = 23.2 per cent. Phosphorus replaces the arsenic in part, and calcium, the lead.

Tests. Fusible at $1\frac{1}{2}$. Gives globule of lead when fused with sodium carbonate on charcoal. A fragment placed in the closed tube and heated in contact with a splinter of charcoal gives deposit of metallic arsenic on walls of tube.

Diagnostic Features. Difficult to distinguish from pyromorphite without a blowpipe or chemical test.

Occurrence. Mimetite is a comparatively rare mineral of secondary origin, occurring in the upper, oxidized portion of lead veins. Notable localities for its occurrence are in Cornwall and Cumberland, England; Johanngeorgenstadt, Saxony; Nerchinsk, Siberia. In the United States found at Phoenixville, Pennsylvania; Eureka, Utah.

Use. A minor ore of lead.

Name. Derived from the Greek for *imitator,* in allusion to its resemblance to pyromorphite.

Vanadinite — $Pb_5Cl(VO_4)_3$

Crystallography. Hexagonal; dipyramidal. Prism with base. May have small pyramidal faces, rarely the pyramid of the third order. In rounded crystals; in some cases cavernous. Also in globular forms. As incrustations.

Physical Properties. **H.** = 3. **G.** = 6.7–7.1. Luster resinous to adamantine. Color ruby-red, brown, yellow. Transparent to translucent.

Composition. Lead chlorovanadate, $Pb_5Cl(VO_4)_3$. PbO = 78.7 per cent, Cl = 2.5 per cent, V_2O_5 = 19.4 per cent. Phosphorus and arsenic may be present in small amount replacing vanadium. In the variety *endlichite*, intermediate between vanadinite and mimetite, the proportion of V_2O_5 to As_2O_5 is nearly 1 : 1.

Tests. Fusible at $1\frac{1}{2}$. Gives globule of lead on charcoal when fused with sodium carbonate. Gives an amber color in the oxidizing flame to salt of phosphorus bead (vanadium). Dilute nitric acid solution gives with silver nitrate a white precipitate of silver chloride. Endlichite gives in the closed tube the reaction for arsenic (see under mimetite).

Diagnostic Features. Characterized by crystal form, high luster, and high specific gravity; distinguished from pyromorphite and mimetite by color.

Occurrence. Vanadinite is a rare mineral of secondary origin found in the upper oxidized portion of lead veins. Found in fine crystals near Oudjda, Morocco, and Grootfontein, Southwest Africa. In the United States occurs in various districts in Arizona and New Mexico.

Use. Source of vanadium and minor ore of lead. Vanadium is obtained chiefly from other ores, such as *patronite,* a substance of indefinite composition formerly thought to be the sulfide; the vanadate, *carnotite;* and a vanadium mica, *roscoelite.* Vanadium is used chiefly as a steel-hardening metal. Metavanadic acid, HVO_3, is used as a yellow pigment, known as vanadium bronze. Vanadium oxide is used as a mordant in dyeing.

COLLOPHANITE — $Ca_3(PO_4)_2 \cdot H_2O$

Crystallography. Amorphous. Massive, concretionary, banded.

Physical Properties. Conchoidal fracture. **H.** = 2–5. **G.** = 2.6–2.9. Color white, gray, brown. Luster earthy.

Composition. Essentially hydrous calcium phosphate, $Ca_3(PO_4)_2 \cdot H_2O$. It also contains small amounts of calcium carbonate, sulfate, and fluoride.

Tests. Fusible with difficulty. In the closed tube turns dark and yields water. Effervesces slightly in nitric acid. A few drops of a nitric acid solution added to ammonium molybdate solution give a yellow precipitate of ammonium phosphomolybdate. An alkaline solution yields a white precipitate (calcium) on the addition of ammonium oxalate.

Diagnostic Features. Collophanite lacks properties which can be considered diagnostic. It resembles limestone but is harder. Dense varieties resemble chalcedony and opal but are softer. For certain identification a test should be made for phosphorus.

Occurrence. Collophanite is an important constituent of the rock *phosphorite* or *phosphate rock.* Bone is calcium phosphate, and large bodies of phosphorite are derived from the accumulation of animal remains. Collophanite is also found in coral limestones which have been covered by beds of guano and by infiltration of the overlying salts the limestone has been converted into a phosphate rock.

Commercial deposits of phosphorite are to be found in northern France, Belgium, Spain, and especially in northern Africa in Tunisia, Algeria, and Morocco. In the United States high-grade phosphate deposits are found in western middle Tennessee and in Wyoming and Idaho. Nodular deposits of phosphate rock are found at intervals all along the Atlantic coast from North Carolina to Florida, the chief deposits being in the latter state.

Use. Rock phosphate is extensively mined and used as a source of phosphorus in fertilizer. It is treated with sulfuric acid and changed to superphosphate to render it more soluble in the dilute acids that exist in the soil.

Name. From the two Greek words meaning *glue* and *to appear,* in allusion to its appearance.

AMBLYGONITE — $LiAlFPO_4$

Crystallography. Triclinic; pinacoidal. Usually in coarse, cleavable masses. Crystals small and rare.

Physical Properties. Cleavage perfect parallel to base {001}, and imperfect parallel to macropinacoid {100}. **H.** = 6. **G.** = 3.0–3.1. Luster vitreous, pearly on basal cleavage. Color white to pale green or blue. Translucent.

Composition. Lithium aluminum fluophosphate, $LiAlFPO_4$. Li_2O = 10.1 per cent, Al_2O_3 = 34.4 per cent, F = 12.9 per cent, P_2O_5 = 47.9 per cent. Hydroxyl is isomorphous with the fluorine, and sodium in small amounts often replaces the lithium.

Tests. Fusible at 2 with intumescence, giving a red flame (lithium). Insoluble in acids. After fusion with sodium carbonate and dissolving in nitric acid, solution with excess of ammonium molybdate solution gives yellow precipitate (test for phosphate).

Diagnostic Features. Cleavage fragments may be confused with feldspar, but are much more easily fusible and yield a red flame.

Occurrence. Amblygonite is a rare mineral found in pegmatite veins with spodumene, tourmaline, lepidolite, apatite. Found at Montebras, France. In the United States occurs at Hebron, Paris, Auburn, and Peru, Maine; Pala, California; Black Hills, South Dakota.

Use. A source of lithium.

Name. From the two Greek words meaning *blunt* and *angle*, in allusion to the angle between the cleavages.

LAZULITE — $MgAl_2(OH)_2(PO_4)_2$

Crystallography. Monoclinic; prismatic. Crystals showing steep pyramids rare. Usually massive, granular to compact.

Physical Properties. Indistinct prismatic {110} cleavage. **H.** = 5–5½. **G.** = 3.0–3.1. Luster vitreous. Color azure-blue. Translucent.

Composition. A basic magnesium aluminum phosphate, $MgAl_2(OH)_2(PO_4)_2$, with varying amounts of ferrous iron replacing the magnesium.

Tests. Infusible. Before the blowpipe swells, loses its color, and falls to pieces. In the closed tube whitens and yields water. Insoluble. After fusion with sodium carbonate, a nitric acid solution added to an excess of ammonium molybdate solution gives a yellow precipitate of ammonium phosphomolybdate.

Diagnostic Features. If crystals are lacking, lazulite is difficult to distinguish from other blue minerals without a chemical or blowpipe test.

Occurrence. Lazulite is a rare mineral. It is usually found in metamorphic sandstones associated with kyanite, andalusite, corundum, rutile. Notable localities for its occurrence are Salzburg, Austria; Krieglach, Styria; Horrsjoberg, Sweden. In the United States found with corundum on Crowder's Mountain, Gaston County, North Carolina; with rutile on Graves Mountain, Lincoln County, Georgia; with andalusite in the White Mountains, Inyo County, California.

Use. A minor gem stone.

Name. Derived from an Arabic word meaning *heaven*, in allusion to the color of the mineral.

Scorodite — $FeAsO_4{\cdot}2H_2O$

Crystallography. Orthorhombic; dipyramidal. Usually in pyramidal crystals, resembling octahedrons; also prismatic. Crystals in irregular groups and aggregates. Also earthy and compact.

Physical Properties. H. = 3½–4. G. = 3.1–3.3. Luster vitreous to adamantine. Color pale green to liver-brown. Translucent.

Composition. A hydrous ferric arsenate, $FeAsO_4 \cdot 2H_2O$. Fe_2O_3 = 34.6 per cent, As_2O_5 = 49.8 per cent, H_2O = 15.6 per cent.

Tests. Fusible at 2. Magnetic when heated in the reducing flame. Heated intensely with splinter of charcoal in the closed tube gives arsenical mirror. Water in the closed tube. Soluble in hydrochloric acid, and reacts for ferric iron.

Diagnostic Features. No outstanding diagnostic property, but crystal habit, luster, and test for arsenic are usually sufficient to identify the mineral.

Occurrence. Scorodite occurs in oxidized portions of metallic veins as an alteration of arsenic-containing minerals. It is also deposited by certain hot springs. Notable localities are: Adun Chilon Mountains, Siberia; Laurium, Greece; Lolling, Carinthia; Cornwall, England. In the United States scorodite occurs at several localities in Nevada, notably at Eureka and Tintic districts; and as a deposit of hot springs at Yellowstone National Park.

Name. From the Greek word meaning *garlic,* in allusion to the odor obtained on heating.

Wavellite — $Al_3(OH)_3(PO_4)_2 \cdot 5H_2O$

Crystallography. Orthorhombic; dipyramidal. Crystals rare. Usually in radiating spherulitic and globular aggregates.

Physical Properties. Good cleavage parallel to brachypinacoid {010} and macrodome {101}. H. = 3½–4. G. = 2.33. Luster vitreous. Color white, yellow, green, and brown. Translucent.

Composition. A hydrous basic aluminum phosphate, $Al_3(OH)_3(PO_4)_2 \cdot 5H_2O$. Al_2O_3 = 38.0 per cent, P_2O_5 = 35.2 per cent, H_2O = 26.8 per cent. Some fluorine may be present replacing the hydroxyl.

Tests. Infusible, but on heating swells and splits into fine particles. Insoluble. Yields much water in the closed tube. Decomposed by fusion with sodium carbonate and dissolved in nitric acid gives yellow precipitate when solution is added to excess of ammonium molybdate (test for phosphoric acid). When moistened with cobalt nitrate and then ignited assumes a blue color (aluminum).

Diagnostic Features. Characterized almost invariably by radiating globular aggregates.

Occurrence. Wavellite is a rare mineral of secondary origin. Frequently in bedded ore bodies, especially limonite and phosphorite. Although it occurs in many localities it never is found in quantity. In the United States wavellite occurs in a number of localities in Pennsylvania and near Avant, Arkansas.

Name. After Dr. William Wavel, who discovered the mineral.

Turquois — $Al_2(OH)_3PO_4 \cdot H_2O + x Cu$

Crystallography. Triclinic; pinacoidal. Rarely in minute crystals, usually cryptocrystalline. Massive compact, reniform, stalactitic. In thin seams, incrustations and disseminated grains.

Physical Properties. **H.** = 6. **G.** = 2.6–2.8. Luster waxlike. Color blue, bluish green, green. Transmits light on thin edges.

Composition. A basic hydrous phosphate of aluminum, $Al_2(OH)_3PO_4 \cdot H_2O$. Excluding CuO reported in chemical analyses of turquois, the percentages of the oxides are: $Al_2O_3 = 46.8$, $P_2O_5 = 32.6$, $H_2O = 20.6$. The mineral is colored by small amounts of copper whose role in the composition is not well understood.

Tests. Infusible. When moistened with hydrochloric acid and heated gives blue copper chloride flame. Soluble in hydrochloric acid. Solution gives a yellow precipitate with an excess of ammonium molybdate solution (test for a phosphate). Gives a momentary green flame. In the closed tube turns dark and gives water.

Diagnostic Features. Turquois can be easily recognized by its color. It is harder than chrysocolla, the only common mineral which it resembles.

Occurrence. Turquois is a mineral of secondary origin, usually found in the form of small veins and stringers traversing more or less decomposed volcanic rocks. The famous Persian deposits are found in trachyte near Nishâpûr in the province of Khorasan. In the United States it is found in a much altered trachytic rock in the Los Cerillos Mountains, near Santa Fe, and elsewhere in New Mexico. Turquois has also been found in Arizona, Nevada, and California.

Use. As a gem stone. It is always cut in round or oval forms. Much turquois is cut which is veined with the various gangue materials, and such stones are sold under the name of *turquois matrix.*

Name. Turquois is French and means *Turkish,* the original stones having come into Europe from the Persian locality through Turkey.

Vivianite — $Fe_3(PO_4)_2 \cdot 8H_2O$

Crystallography. Monoclinic; prismatic. Prismatic crystals, vertically striated; often in radiating groups. Also nodular and earthy.

Physical Properties. Perfect clinopinacoidal {010} cleavage. **H.** = $1\frac{1}{2}$–2. **G.** = 2.58–2.68. Luster vitreous; pearly on cleavage face.

Colorless when unaltered; blue to green when altered. Transparent when fresh, becoming translucent on exposure.

Composition. Hydrous ferrous phosphate, $Fe_3(PO_4)_2 \cdot 8H_2O$. $FeO = 43.0$ per cent, $P_2O_5 = 28.3$ per cent, $H_2O = 28.7$ per cent.

Tests. Fusible at 2 to a magnetic globule. Nitric acid solution added to an excess of ammonium molybdate solution gives yellow precipitate (test for phosphate). Water in the closed tube.

Diagnostic Features. Usually altered, and in this state characterized by blue to green color. Cleavage lamellae flexible.

Occurrence. Vivianite is a rare mineral of secondary origin, associated with pyrrhotite and pyrite in copper and tin veins. Found also in beds of clay; may be associated with limonite; often in cavities of fossils.

Name. In honor of the eighteenth century English mineralogist, J. G. Vivian, the discoverer of the mineral.

Erythrite — $Co_3(AsO_4)_2 \cdot 8H_2O$

Cobalt Bloom

Crystallography. Monoclinic; prismatic. Crystals prismatic and vertically striated. Usually as crusts in globular and reniform shapes. Also pulverulent and earthy.

Physical Properties. Perfect cleavage parallel to the clinopinacoid $\{010\}$. **H.** $= 1\frac{1}{2}$–$2\frac{1}{2}$. **G.** $= 2.95$. Luster adamantine to vitreous, pearly on cleavage. Color crimson to pink. Translucent.

Composition. Hydrous cobalt arsenate, $Co_3(AsO_4)_2 \cdot 8H_2O$. $CoO = 37.5$ per cent, $As_2O_5 = 38.4$ per cent, $H_2O = 24.1$ per cent. Cobalt may be partly replaced by nickel.

Tests. Fusible at 2 to a gray bead. When heated on charcoal gives arsenical odor. Imparts a deep blue to the borax bead (cobalt). Soluble in hydrochloric acid giving a red solution.

Diagnostic Features. The association of erythrite with other cobalt minerals and its pink color are usually sufficient to distinguish it from all other minerals.

Occurrence. Erythrite is a rare secondary mineral which occurs as an alteration product of cobalt arsenides. It is rarely present in large amounts and usually forms as crusts or fine aggregates filling cracks. Notable localities are at Schneeberg, Saxony, and Cobalt, Ontario.

Use. Although erythrite has no economic importance it is used by the prospector as a guide to other cobalt minerals and associated native silver.

Name. From the Greek word meaning *red.*

Similar Species. *Annabergite* or *nickel bloom,* $Ni_3(AsO_4)_2 \cdot 8H_2O$, is a similar nickel compound. It is light green in color.

SULFATES AND CHROMATES

A large number of minerals belong to this class but only a few of them are common. The class can be divided into (1) the anhydrous sulfates and (2) the hydrous sulfates.

Sulfates

ANHYDROUS	Glauberite	$Na_2Ca(SO_4)_2$
	Barite	$BaSO_4$
	Celestite	$SrSO_4$
	Anglesite	$PbSO_4$
	Anhydrite	$CaSO_4$
	Crocoite	$PbCrO_4$
HYDROUS AND BASIC	Antlerite	$Cu_3(OH)_4SO_4$
	Polyhalite	$K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$
	Gypsum	$CaSO_4 \cdot 2H_2O$
	Epsomite	$MgSO_4 \cdot 7H_2O$
	Chalcanthite	$CuSO_4 \cdot 5H_2O$
	Alunite	$KAl_3(OH)_6(SO_4)_2$

Glauberite — $Na_2Ca(SO_4)_2$

Crystallography. Monoclinic; prismatic. Crystals thin, tabular parallel to base.

Physical Properties. Basal {001} cleavage. **H.** = $2\frac{1}{2}$–3. **G.** = 2.7–2.85. Luster vitreous. Color pale yellow or gray. Taste slightly saline.

Composition. A sodium and calcium sulfate, $Na_2Ca(SO_4)_2$. Na_2O = 22.3 per cent, CaO = 20.1 per cent, SO_3 = 57.6 per cent.

Tests. Fusible at $1\frac{1}{2}$–2, giving yellow flame (sodium). After ignition, gives an alkaline reaction on moistened test paper. Soluble in hydrochloric acid, and solution with barium chloride gives white precipitate of barium sulfate. On long exposure deliquesces and falls to pieces.

Diagnostic Features. Characterized by its thin tabular crystals, good cleavage and association.

Occurrence. Glauberite is a rare mineral occurring in saline deposits formed by the evaporation of salt lakes, and is thus associated with other salts such as thenardite, halite, polyhalite.

Found at Salzburg, Austria; near Stassfurt, Germany. In the United States found in Yavapai County, Arizona, and at Borax Lake, San Bernardino County, California.

Name. Glauberite is so named because Glauber's salt (sodium sulfate) is present in it.

BARITE GROUP

The sulfates of barium, strontium, lead, and calcium form an isostructural group. They crystallize in the orthorhombic system with closely related crystal constants and similar habits. The members of the group are: *barite, celestite, anglesite, anhydrite.*

BARITE — $BaSO_4$

Barytes. Heavy Spar

Crystallography. Orthorhombic; dipyramidal. Crystals usually tabular parallel to base; often diamond-shaped because of the presence of a short prism (Fig. 354). Both macro- and brachydomes usually present, either beveling the corners of the diamond-shaped crystals (Fig. 355) or, if the prism faces are wanting, beveling the edges of the tables and forming rectangular prismatic crystals elongated parallel to either the brachy- or macro-axis (Figs. 356 and 357). Crystals may be very complex. Frequently in divergent groups of tabular crystals forming " crested barite " or " barite roses." Also coarsely laminated; granular, earthy.

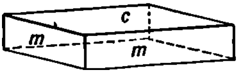


FIG. 354.

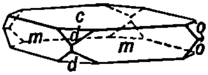


FIG. 355.

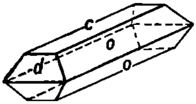


FIG. 356.

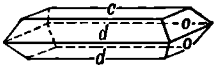


FIG. 357.

Barite.

Physical Properties. Perfect cleavage parallel to base {001} and prism {110}. **H.** = 3–3½. **G.** = 4.5 (heavy for a nonmetallic mineral). Luster vitreous; on some specimens pearly on base. Colorless, white, and light shades of blue, yellow, red. Transparent to translucent.

Composition. Barium sulfate, $BaSO_4$. BaO = 65.7 per cent, SO_3 = 34.3 per cent. Strontium and calcium sulfates present in some specimens.

Tests. Fusible at 4, giving yellowish green barium flame. After ignition gives an alkaline reaction on moistened test paper. Fused with reducing mixture gives a residue, which, when moistened, produces a dark stain of silver sulfide on a clean silver surface.

Diagnostic Features. Recognized by its high specific gravity and characteristic cleavage and crystals.

Occurrence. Barite is a common mineral of wide distribution. It occurs usually as a gangue mineral in metallic veins, associated especially with ores of silver, lead, copper, cobalt, manganese, and antimony. It is found in veins in limestone with calcite, or as residual masses in clay overlying limestone. Also in sandstone with copper ores. In places acts as a cement in sandstone. Deposited occasionally as a sinter by waters from hot springs.

Notable localities for the occurrence of barite crystals are in Westmoreland, Cornwall, Cumberland, and Derbyshire, England; Felsobanya and other localities, Rumania; in Saxony and Bohemia. In the United States at Cheshire, Connecticut; Dekalb, New York; Fort Wallace, New Mexico. Massive barite, occurring usually as veins, nests, and irregular bodies in limestones, has been quarried in the United States in Georgia, Tennessee, Missouri, and Arkansas. At El Portal, California, at the entrance to Yosemite Park, barite is found in a vein with witherite.

Use. The chief source of barium. (See page 233.) The largest use of barium is in the chemical *lithopone*, an intimate combination of barium sulfide and zinc sulfate, which is used in the paint industry and to a lesser extent in floor coverings and textiles. Precipitated barium sulfate, "blanc fixe," is used as a filler in paper and cloth, in cosmetics, as a paint pigment, and for barium meals in medical radiology. Crushed barite is used extensively in making a sludge of high specific gravity to support tools during drilling operations of deep wells.

Name. From the Greek word meaning *heavy*, in allusion to its high specific gravity.

CELESTITE — $SrSO_4$

Crystallography. Orthorhombic; dipyramidal. Crystals resemble closely those of barite. Commonly tabular parallel to the base or prismatic parallel to the brachy- or macro-axis with prominent development of the domes (Fig. 358). Crystals which are elongated parallel to the brachy-axis are frequently terminated in front by four faces in nearly equal development, consisting of two faces of the prism and two of the macrodome (Fig. 359). Also radiating fibrous; granular.

Physical Properties. Perfect cleavage parallel to base $\{001\}$ and prism $\{110\}$. **H.** = 3–3½. **G.** = 3.95–3.97. Luster vitreous to pearly. Colorless, white, often faintly blue or red. Transparent to translucent.

Composition. Strontium sulfate, $SrSO_4$. $SrO = 56.4$ per cent, $SO_3 = 43.6$ per cent.

Tests. Fuses at $3\frac{1}{2}$–4 and colors the flame crimson (strontium). After ignition gives an alkaline reaction on moistened test paper. Fused with sodium carbonate gives a residue, which, when moistened, produces on a clean silver surface a dark stain of silver sulfide.

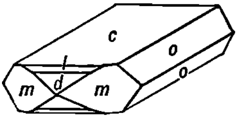


Fig. 358.

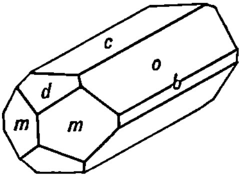


Fig. 359.

Celestite.

Diagnostic Features. Closely resembles barite but of lower specific gravity. A flame test may be necessary to differentiate the two species positively.

Occurrence. Celestite is found usually disseminated through limestone or sandstone, or in nests and lining cavities in such rocks. Associated with calcite, dolomite, gypsum, halite, sulfur, fluorite.

Notable localities for its occurrence are with the sulfur deposits of Sicily; at Bex, Switzerland; Yate, Gloucestershire, England; Herrengrund, Slovakia. Found in the United States at Clay Center, Ohio; Put-in-Bay, Lake Erie; Mineral County, West Virginia; Lampasas, Texas; Inyo County, California.

Use. Used in the preparation of nitrate of strontium for fireworks and other strontium salts used in the refining of beet sugar.

Name. Derived from *cœlestis*, in allusion to the faint blue color of the first specimens described.

ANGLESITE — $PbSO_4$

Crystallography. Orthorhombic; dipyramidal. Frequently in crystals with habit often similar to that of barite but much more varied. Crystals may be prismatic parallel to any one of the crystal axes and frequently show many forms, with a complex development. Also massive, granular to compact. Frequently earthy, in concentric layers which may have a nucleus of galena.

Physical Properties. Imperfect cleavage parallel to base {001} and prism {110}. Fracture conchoidal. **H.** = 3. **G.** = 6.2–6.4 (unusually high). Luster adamantine when pure and crystalline, dull when earthy. Colorless, white, gray, pale shades of yellow. May be colored dark gray by impurities. Transparent to translucent.

Composition. Lead sulfate, $PbSO_4$. PbO = 73.6 per cent, SO_3 = 26.4 per cent.

Tests. Fusible at $1\frac{1}{2}$. On charcoal with sodium carbonate reduced to a lead globule with yellow to white coating of lead oxide; the residue, when moistened, produces on a clean silver surface a dark stain of silver sulfide.

Diagnostic Features. Recognized by its high specific gravity, its adamantine luster, and frequently by its association with galena. Distinguished from cerussite in that it will not effervesce in nitric acid.

Occurrence. Anglesite is a common lead mineral of secondary origin. It is formed through the oxidation of galena, either directly to the sulfate as is shown by concentric layers of anglesite surrounding a core of unaltered galena, or by an intermediate solution and subsequent recrystallization. Found in the upper, oxidized portions of lead veins, associated with galena, cerussite, sphalerite, smithsonite, hemimorphite, and iron oxides.

Notable localities for its occurrence are Monte Poni, Sardinia; Island of Anglesey, Wales; Derbyshire; Leadhills, Scotland. From Sidi-Amor-ben-Salem, Tunis; near Otavi, Southwest Africa; Broken Hill, New South Wales; Dundas, Tasmania. Is found in crystals at Los Lamentos, Chihuahua, Mexico, imbedded in sulfur. Occurs in the United States at Phoenixville, Pennsylvania; Tintic District, Utah; Coeur d'Alene District, Idaho.

Use. A minor ore of lead.

Name. Named from the original locality on Island of Anglesey.

ANHYDRITE — $CaSO_4$

Crystallography. Orthorhombic; dipyramidal. Crystals rare; when observed are thick tabular, also prismatic parallel to the macro-axis. Usually in crystalline masses, with rectangular cleavage. Also fibrous, granular, massive.

Physical Properties. Distinct cleavage parallel to the three pinacoids {100}, {010}, {001} yields rectangular blocks. **H.** = 3–$3\frac{1}{2}$. **G.** = 2.89–2.98. Luster vitreous to pearly on cleavage. Color white; may have a faint gray, blue, or red tinge. Transparent to translucent.

Composition. Anhydrous calcium sulfate, $CaSO_4$. CaO = 41.2 per cent, SO_3 = 58.8 per cent.

Tests. Fusible at 3. After ignition gives an alkaline reaction on moistened test paper. Moistened with hydrochloric acid and ignited gives orange-red flame of calcium. Soluble in hot hydrochloric acid and dilute solution with barium chloride gives white precipitate of barium sulfate. When fused with reducing mixture gives a residue which, when moistened with water, darkens silver.

Diagnostic Features. Anhydrite is characterized by its three cleavages at right angles. It is distinguished from calcite by its higher specific gravity and from gypsum by its hardness. Some massive varieties are very difficult to recognize, and one should test for the sulfate radical.

Alteration. By the absorption of moisture anhydrite changes to gypsum, and in places large masses of anhydrite have thus been altered.

Occurrence. Anhydrite occurs in much the same manner as gypsum and is often associated with that mineral but is not nearly so common. Found in beds associated with salt deposits and in limestone rocks. Found in some amygdaloidal cavities in basalt.

Notable foreign localities are: Wieliczka, Poland; Aussee, Styria; Stassfurt, Prussia; Berchtesgaden, Bavaria; Hall near Innsbruck, Tyrol; Bex, Switzerland. In the United States found in Lockport, New York; West Paterson, New Jersey; Nashville, Tennessee. Found in large beds in Nova Scotia.

Name. Anhydrite is from the Greek meaning *without water*, as compared with the more common calcium sulfate, gypsum, which contains much water.

Crocoite — $PbCrO_4$

Crystallography. Monoclinic; prismatic. Commonly in slender prismatic crystals, vertically striated and columnar aggregates. Also granular.

Physical Properties. Imperfect prismatic {110} cleavage. **H.** = $2\frac{1}{2}$-3. **G.** = 5.9–6.1. Luster adamantine. Color bright hyacinth red. Streak orange-yellow. Translucent.

Composition. Lead chromate, $PbCrO_4$. $PbO = 68.9$ per cent, $CrO_3 = 31.1$ per cent.

Tests. Fusible at $1\frac{1}{2}$. Fused with sodium carbonate on charcoal gives a lead globule. With borax gives a green (chromium) bead in the oxidizing flame.

Diagnostic Features. Characterized by its color, high luster, and high specific gravity. Crocoite may be confused with wulfenite, lead molybdate, but can be distinguished from it by its redder color, lower specific gravity, and crystal form.

Occurrence. Crocoite is a rare mineral found in the oxidized zones of lead deposits in those regions where lead veins have traversed rocks containing chromite. Notable localities are: Dundas, Tasmania; Beresovsk near Sverdlovsk, Ural Mountains; Rézbánya, Rumania. In the United States is found in small quantities in the Vulture District, Arizona.

Use. Not abundant enough to be of commercial value, but of historic interest since the element chromium was first discovered in crocoite.

Name. From the Greek meaning *saffron,* in allusion to the color.

Antlerite — $Cu_3(OH)_4SO_4$

Crystallography. Orthorhombic; dipyramidal. Slender prismatic crystals, vertically striated, often acicular. May be tabular (Figs. 360 and 361). Also in parallel aggregates, reniform, massive.

Physical Properties. Perfect pinacoidal {010} cleavage. **H.** = 3½–4. **G.** = 3.9±. Luster vitreous. Color emerald to blackish green. Transparent to translucent.

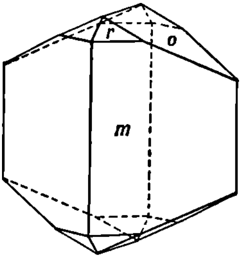


Fig. 360.

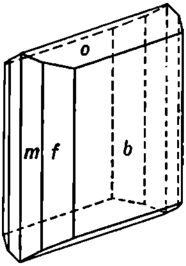


Fig. 361.

Antlerite.

Composition. A basic sulfate of copper, $Cu_3(OH)_4SO_4$. CuO = 67.3 per cent, SO_3 = 22.5 per cent, H_2O = 10.2 per cent.

Tests. Fusible at 3½. Yields a copper globule when fused with sodium carbonate on charcoal. Hydrochloric acid solution with barium chloride gives white precipitate of barium sulfate. Yields water in the closed tube and, at a high temperature, sulfuric acid.

Diagnostic Features. Antlerite is characterized by its green color, {010} cleavage, and associations. It will not effervesce in hydrochloric acid and can thus be distinguished from malachite. It is impossible to distinguish antlerite from atacamite or brochantite by inspection. A positive test for chlorine will identify atacamite, but one must use optical properties to distinguish antlerite from brochantite.

Occurrence. Antlerite is found in the oxidized portions of copper veins, especially in arid regions. Until recently it has been considered a rare mineral, but it is now definitely recognized as the chief ore mineral at Chuquicamata, Chile, the world's largest copper mine. It may form directly as a secondary mineral on chalcocite, or the copper may go into solution and later be deposited as antlerite filling cracks. In the United States is found at Bisbee, Arizona, and near Black Mountain, Nevada. Also found at Kennecott, Alaska.

Use. An ore of copper.

Name. From the Antler mine, Arizona, from which locality it was originally described.

Similar Species. *Brochantite*, $Cu_4(OH)_6SO_4$, is similar in all its properties to antlerite, and although more widespread, is nowhere abundant. Until recently it was considered to be the chief ore mineral at Chuquicamata, Chile.

Polyhalite — $K_2Ca_2Mg(SO_4)_4{\cdot}2H_2O$

Crystallography. Triclinic; pinacoidal. Twinned crystals very rare. Usually in compact granular, fibrous, or lamellar masses.

Physical Properties. Distinct cleavage parallel to macropinacoid $\{100\}$. **H.** = $2\frac{1}{2}$–3. **G.** = 2.78. Color flesh- or brick-red. Luster resinous. Translucent. Taste bitter.

Composition. A hydrous sulfate of potassium, calcium, and magnesium, $K_2Ca_2Mg(SO_4)_4{\cdot}2H_2O$, which yields the following percentages: K_2O = 15.6, CaO = 18.6, MgO = 6.7, SO_3 = 53.1, H_2O = 6.0.

Tests. Fusible at $1\frac{1}{2}$, giving a violet flame color (potassium). Gives water in the closed tube. Readily soluble in hydrochloric acid, and solution made ammoniacal will, on the addition of ammonium oxalate, give a white precipitate of calcium oxalate. Filtrate with sodium phosphate gives white precipitate of ammonium magnesium phosphate.

Diagnostic Features. Characterized by its red color, but not readily distinguished by inspection from other, associated and similar appearing minerals.

Occurrence. Polyhalite occurs in bedded deposits associated with halite, sylvite, carnallite, etc. Notable localities are at Stassfurt, Germany, and Salzburg, Austria. In the United States is found associated with other potassium and magnesium salts in the Permian basin of western Texas and eastern New Mexico.

Use. A source of potassium.

Name. From the two Greek words meaning *many* and *salt,* in allusion to the several component salts present.

GYPSUM — $CaSO_4 \cdot 2H_2O$

Crystallography. Monoclinic; prismatic. Crystals are of prismatic habit (Figs. 362 and 363); tabular parallel to clinopinacoid; diamond-shaped, with edges beveled by prism and pyramid faces (Fig. 364). Other forms rare. Twins common with the orthopinacoid the twin plane (Fig. 365) often resulting in swallowtail twins. Cleavable massive; foliated; granular massive. *Satin spar* is a fibrous gypsum with silky luster. *Alabaster* is the fine-grained massive variety. *Selenite* is a variety which yields broad colorless and transparent cleavage folia.

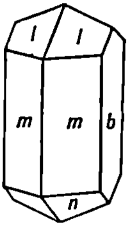


FIG. 362.

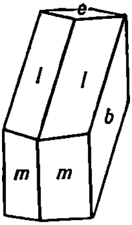


FIG. 363.

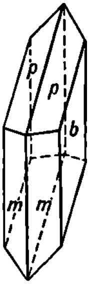


FIG. 364.

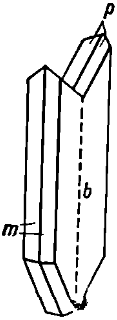


FIG. 365.

Gypsum.

Physical Properties. Cleavage in three directions; perfect parallel to clinopinacoid {010}, yielding easily thin folia; with conchoidal surface parallel to orthopinacoid {100}; with fibrous fracture parallel to the negative hemipyramid $\{\bar{1}11\}$. **H.** = 2 (can be scratched by the finger nail). **G.** = 2.32. Luster usually vitreous; also pearly and silky. Colorless, white, gray; various shades of yellow, red, brown, from impurities. Transparent to translucent.

Composition. Hydrous calcium sulfate, $CaSO_4 \cdot 2H_2O$. CaO = 32.5 per cent, SO_3 = 46.6 per cent, H_2O = 20.9 per cent.

Tests. Fusible at 3. After intense ignition, residue gives alkaline reaction on moistened test paper. Soluble in hot dilute hydrochloric acid, and solution with barium chloride gives white precipitate of barium sulfate. In the closed tube turns white and yields much water. Fused with reducing mixture gives a residue which, when moistened with water, darkens silver.

Diagnostic Features. Characterized by its softness and its three directions of unequal cleavage. Its solubility in acid and the presence of much water distinguish it from anhydrite.

Occurrence. Gypsum is a common mineral widely distributed in sedimentary rocks, often as thick beds. It frequently occurs interstratified with limestones and shales, and is usually found as a layer underlying beds of rock salt, having been deposited there as one of the first minerals to crystallize on the evaporation of salt waters. May recrystallize in veins, forming *satin spar*. Occurs also as lenticular bodies or scattered crystals in clays and shales. Frequently formed by the alteration of anhydrite and under these circumstances may show folding because of increased volume. Found in volcanic regions, especially where limestones have been acted upon by sulfur vapors. Also, is common as a gangue mineral in metallic veins. Associated with many different minerals, the more common ones being halite, anhydrite, dolomite, calcite, sulfur, pyrite, quartz.

Gypsum is the most common sulfate, and extensive deposits are found in many localities throughout the world. In the United States commercial deposits are found in many states, but the chief producers are located in New York, Michigan, Iowa, Texas, Nevada, and California. Gypsum is found in large deposits in Arizona and New Mexico in the form of wind-blown sand.

Use. Gypsum is used chiefly for the production of plaster of Paris. In the manufacture of this material, the gypsum is ground and then heated, until about 75 per cent of the water has been driven off. This plaster, when mixed with water, slowly absorbs the water, crystallizes, and thus hardens or "sets." Plaster of Paris is used extensively for "staff," the material from which temporary exposition buildings are built, for gypsum lath, wall board, and for molds and casts of all kinds. Gypsum is employed in making adamant plaster for interior use. Serves as land plaster, for a fertilizer. Uncalcined gypsum is used as a retarder in Portland cement. Satin spar and alabaster are cut and polished for various ornamental purposes but are restricted in their uses because of their softness.

Name. From the Greek name for the mineral, but more especially for the calcined mineral.

Epsomite — $MgSO_4 \cdot 7H_2O$

Epsom Salt

Crystallography. Orthorhombic; disphenoidal. Rarely in crystals. Usually in botryoidal masses and delicately fibrous crusts.

Physical Properties. Perfect cleavage parallel to the brachypinacoid $\{010\}$. **H.** = 2–2½. **G.** = 1.75. Luster vitreous to earthy. Colorless to white. Transparent to translucent. Taste very bitter.

Composition. Hydrous magnesium sulfate, $MgSO_4 \cdot 7H_2O$. MgO = 16.3 per cent, SO_3 = 32.5 per cent, H_2O = 51.2 per cent.

Tests. In the closed tube gives much acid water, and liquefies in its water of crystallization. Soluble in water.

Diagnostic Features. Characterized by its mode of occurrence in delicate fibrous and capillary aggregates, its easy solubility in water, and bitter taste.

Occurrence. Epsomite is usually deposited as an efflorescence on the rocks in mine workings and on the walls of caves. More rarely it is found in lake deposits; associated with other soluble salts as at Stassfurt, Germany. In the United States it is found on the floors of limestone caves in Kentucky, Tennessee, and Indiana, and in abandoned mines in California and Colorado. Found in lake deposits in Stevens County, Washington.

Use. The mineral epsomite has little use in itself, for commercial epsom salt is manufactured from other magnesium minerals.

Name. Epsomite was named from the original locality of Epsom, England.

Chalcanthite — $CuSO_4 \cdot 5H_2O$

Blue Vitriol

Crystallography. Triclinic; pinacoidal. Found in crystals commonly tabular parallel to a pyramid face. Also massive, stalactitic, and reniform; may have fibrous appearance.

Physical Properties. **H.** = $2\frac{1}{2}$. **G.** = 2.12–2.30. Luster vitreous. Color deep azure-blue. Transparent to translucent. Taste metallic.

Composition. Hydrous copper sulfate, $CuSO_4 \cdot 5H_2O$. CuO = 31.8 per cent, SO_3 = 32.1 per cent, H_2O = 36.1 per cent.

Tests. Fusible at 3. Gives copper globule when fused with sodium carbonate on charcoal. Soluble in water. Dilute hydrochloric acid solution gives with barium chloride a precipitate of barium sulfate. Turns white and gives much water in the closed tube.

Diagnostic Features. Characterized by its blue color, metallic taste, and solubility in water.

Occurrence. Chalcanthite is a rare mineral, found only in arid regions as a secondary mineral, occurring near the surface in copper veins, and derived from the original copper sulfides by oxidation. Often deposited on iron from the waters in copper mines.

Chalcanthite is found abundantly at Chuquicamata and other localities in Chile where it has served as an important ore mineral. Other occurrences are unimportant.

Use. A minor ore of copper. The artificial blue vitriol is used in calico printing, in galvanic cells, as an insecticide, and for industrial purposes.

Name. From two Greek words meaning *brass* and *flower.*

Alunite — $KAl_3(OH)_6(SO_4)_2$

Alumstone

Crystallography. Rhombohedral; scalenohedral. Crystals usually rhombohedrons resembling cubes (rhombohedron angle = 90° 50′). May be tabular parallel to the base {0001}. Commonly massive or disseminated.

Physical Properties. Imperfect basal {0001} cleavage. **H.** = 4. **G.** = 2.6–2.8. Color white, gray or reddish. Transparent to translucent.

Composition. Basic potassium aluminum sulfate, $KAl_3(OH)_6(SO_4)_2$. K_2O = 11.4 per cent, Al_2O_3 = 37.0 per cent, SO_3 = 38.6 per cent, H_2O = 13.0 per cent. Sodium may replace potassium in part, giving *natro-alunite.*

Tests. Infusible and decrepitates before the blowpipe, giving a potassium flame. Heated with cobalt nitrate solution turns a fine blue color. In the closed tube gives acid water. Soluble in sulfuric acid.

Diagnostic Features. Alunite is usually massive and in that form is difficult to distinguish by inspection from rocks such as limestone and dolomite, and other massive minerals such as anhydrite and granular magnesite. A positive test for acid water will serve to distinguish alunite from similar appearing minerals.

Occurrence. Alunite is usually formed by sulfuric acid solutions acting on rocks rich in potash feldspar. Found in smaller amounts about volcanic fumeroles. In the United States it is found at Red Mountain in the San Juan district, Colorado; Goldfield, Nevada; Marysvale, Utah.

Use. In the production of alum. Recently at Marysvale, Utah, alunite has been mined and treated in such a way as to recover aluminum and potassium from the mineral.

Name. From the Latin meaning *alum.*

Similar Species. *Jarosite,* $KFe_3(OH)_6(SO_4)_2$, like alunite in most properties.

TUNGSTATES, MOLYBDATES, AND URANATES

Wolframite	$(Fe,Mn)WO_4$
Scheelite	$CaWO_4$
Wulfenite	$PbMoO_4$
Uraninite	

WOLFRAMITE — $(Fe,Mn)WO_4$

Crystallography. Monoclinic; prismatic. Crystals commonly tabular parallel to the orthopinacoid (Fig. 366), giving bladed forms. Prism zone vertically striated. In bladed, lamellar, or columnar forms. Massive granular.

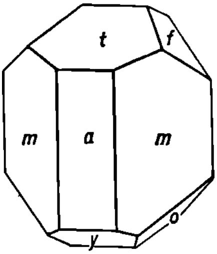


FIG. 366. Wolframite.

Physical Properties. Perfect cleavage parallel to clinopinacoid {010}. **H.** = 5–5½. **G.** = 7.0–7.5. Luster submetallic to resinous. Color black in *ferberite* to brown in *huebnerite.* Streak from nearly black to brown.

Composition. Ferrous and manganous tungstate, $(Fe,Mn)WO_4$, which is an isomorphous mixture of *ferberite,* $FeWO_4$, and *huebnerite,* $MnWO_4$. The percentage of WO_3 is 76.3 in ferberite and 76.6 in huebnerite.

Tests. Fusible at 3–4 to a magnetic globule. Insoluble in acids. Fused with sodium carbonate, dissolves in hydrochloric acid, tin added and solution boiled gives a blue color (tungsten). In the oxidizing flame with sodium carbonate gives bluish green bead (manganese).

Diagnostic Features. The dark color, one direction of perfect cleavage, and high specific gravity serve to distinguish wolframite from other minerals.

Occurrence. Wolframite is a comparatively rare mineral formed at high temperatures and found usually in quartz veins and pegmatite dikes, associated with granites. More rarely in sulfide veins. Commonly found with cassiterite and associated also with scheelite, bismuth, quartz, pyrite, galena, sphalerite, arsenopyrite.

Found in fine crystals from Schlaggenwald and Zinnwald, Bohemia, and in the various tin districts of Saxony and Cornwall. Important deposits occur in China, Burma, New South Wales, Bolivia. Nearly half of the world's supply of tungsten comes, as wolframite, from China. Wolframite occurs in the United States in the Black Hills, South Dakota. Ferberite has been mined extensively in Boulder County, Colorado. Huebnerite is found near Silverton, Colorado; Mammoth District, Nevada; Black Hills, South Dakota.

Use. Chief ore of tungsten. (See page 404.) Tungsten is used as a hardening metal in the manufacture of high-speed tool steel. Also as a filament in incandescent electric lights and radio tubes. Sodium tungstate is used in fireproofing cloth and as a mordant in dyeing. In recent years considerable tungsten as the carbide has been used as an abrasive.

Name. Wolframite is derived from an old word of German origin.

SCHEELITE — $CaWO_4$

Crystallography. Tetragonal; dipyramidal. Crystals usually simple dipyramids of the first order. The second order dipyramid closely resembles the octahedron in angles. Faces of the dipyramid of third order are small and rare. Also massive granular.

Physical Properties. Cleavage parallel to dipyramid of second order {011}. **H.** = 4½–5. **G.** = 5.9–6.1 (unusually high for a mineral with non-metallic luster). Luster vitreous to adamantine. Color white, yellow, green, brown. Translucent; some specimens transparent. Most scheelite will fluoresce.

Composition. Calcium tungstate, $CaWO_4$. CaO = 19.4 per cent, WO_3 = 80.6 per cent. Molybdenum is usually present, replacing a part of the tungsten.

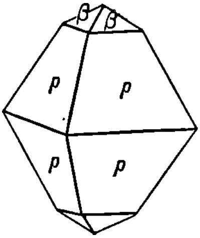


FIG. 367. Scheelite.

Tests. Difficultly fusible (5). Decomposed by boiling in hydrochloric acid, leaving a yellow residue of tungstic oxide, which, when tin is added to the solution and boiling continued, turns first blue and then brown. Sodium phosphate bead blue in the reducing flame.

Diagnostic Features. Recognized by its high specific gravity and crystal form. The test for tungsten may be necessary for identification.

Occurrence. Scheelite is found in pegmatite dikes and high-temperature ore veins which are associated with granitic rocks. Associated with cassiterite, topaz, fluorite, apatite, molybdenite, wolframite. Found in places with gold. Occurs in connection with the tin deposits of Bohemia, Saxony, and Cornwall; in quantity in New South Wales and Queensland. In the United States scheelite is mined near Mill City and Mina, Nevada; near Atolia, San Bernardino County, California; and in lesser amounts in Arizona, Utah, and Colorado.

Use. A subordinate ore of tungsten, wolframite furnishing the greater amount.

Name. After K. W. Scheele, the discoverer of tungsten.

WULFENITE — $PbMoO_4$

Crystallography. Tetragonal; dipyramidal. Crystals usually square tabular in habit with prominent base (Fig. 368). Some crystals very thin. Edges of tables beveled with faces of low second-order dipyramid (Fig. 369). More rarely pyramidal in habit. Dipyramid of third order in small faces and very rare. Also massive granular, coarse to fine.

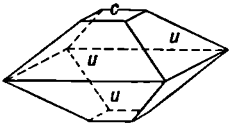


FIG. 368.

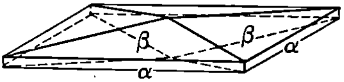


FIG. 369.

Wulfenite.

Physical Properties. H. = 3. G. = 6.8±. Luster vitreous to adamantine. Color yellow, orange, red, gray, white. Streak white. Transparent to subtranslucent.

Composition. Lead molybdate, $PbMoO_4$. $PbO = 60.7$ per cent, $MoO_3 = 39.3$ per cent. Calcium may replace some of the lead.

Tests. Fusible at 2. Gives a lead globule when fused with sodium carbonate on charcoal. With salt of phosphorus in the reducing flame gives green bead; in the oxidizing flame, yellowish green when hot to almost colorless when cold. If powdered mineral is moistened with concentrated sulfuric acid and evaporated almost to dryness in a porcelain crucible the residue will show a deep blue color on cooling (molybdenum).

Diagnostic Features. Wulfenite is characterized by its tabular crystals, orange to yellow color, high luster, and association with other lead minerals. Distinguished from crocoite by test for molybdenum.

Occurrence. Wulfenite is found in the oxidized portion of lead veins with other secondary lead minerals, especially vanadinite and pyromorphite. Found in the United States at Phoenixville, Pennsylvania; in a number of places in Utah, Nevada, Arizona, and New Mexico. Found in beautiful crystals at Red Cloud, Arizona.

Use. A minor source of molybdenum. Molybdenite is the chief ore.

Name. After X. F. Wulfen, Austrian mineralogist.

Uraninite

Pitchblende

Crystallography. Isometric. In octahedrons, also with dodecahedrons; less often showing cube faces. Crystals rare. Usually massive and botryoidal.

Physical Properties. **H.** = 5½. **G.** = 9–9.7 (unusually high). Luster submetallic to pitchlike, dull. Color black. Streak brownish black.

Composition. A complex oxide of uranium with small amounts of lead and the rare elements, radium, thorium, yttrium, nitrogen, helium, argon. It is the mineral in which the gas helium was first discovered on the earth, having been previously noted in the gases surrounding the sun by means of the sun's spectrum. In it, also, radium was first discovered.

Tests. Infusible. Imparts to the salt of phosphorus bead in the oxidizing flame a yellowish green and in the reducing flame a green color. Soluble in dilute sulfuric acid with the slight evolution of helium gas. Water in the closed tube.

Diagnostic Features. Characterized chiefly by its pitchy luster, high specific gravity, color, and streak.

Occurrence. Uraninite occurs either as a primary constituent of granitic rocks and pegmatites or as a secondary mineral with ores of silver, lead, copper. Found under the latter condition at Johanngeorgenstadt, Marienberg, and Schneeberg in Saxony; at Joachimsthal and Přibram in Bohemia; Rezbânya in Rumania; Cornwall, England. The two places in which active mining of uraninite is being carried on are Katanga and Canada. Some of the Canadian supply has come from Wilberforce, Ontario, but the present source is the mines on the shores of Great Bear Lake, Northwest Territory. In the United States it is found in isolated crystals in pegmatite veins at Middletown, Glastonbury, and Branchville, Connecticut. In the mica mines of Mitchell County, North Carolina. A narrow vein of it has been mined near Central City, Gilpin County, Colorado.

Use. The chief interest in the mineral lies in the fact that it is the commercial source of radium. This element is found in uraninite in extremely small percentages, and it is necessary to subject a large amount of the mineral to a chemical concentration in order to produce a gram of a radium salt. Roughly, 750 tons of ore must be mined in order to furnish 12 tons of concentrates; chemical treatment of these concentrates yields about 1 gram of a radium salt. Over 5 tons of uranium salts are obtained in producing 1 gram of radium. Uranium itself has only a limited use. Experiments have been made using uranium in steel, but such steel is not yet commercial because of its relatively high cost. However, uranium is added to copper to yield an alloy which is extremely efficient both as an electrical and heat conductor and, in addition, is unusually resistant to corrosion. In the form of various compounds it has a limited use in coloring glass and porcelain, in photography, and as a chemical reagent.

SILICATES

The silicate mineral class is of greater importance than any other, for about 25 per cent of the known minerals and nearly 40 per cent of the common ones are silicates. With a few minor exceptions all the igneous rock-forming minerals are silicates, and they thus constitute well over 90 per cent of the earth's crust.

The classification of the silicates has long been a subject of controversy, and many different schemes have been proposed. The classification used here is that developed by Bragg and Bragg from a study of the crystal structures, and follows in its details the arrangement of Berman. The fundamental unit of structure of all the silicates is a tetrahedron made up of a silicon atom in the center and oxygen atoms at the four corners. The different types of silicates arise from the various ways in which these tetrahedrons are related to each other. There are relatively few ways in which the tetrahedrons can be joined together. They are:

1. Three-dimensional networks.
2. Sheet structures.
3. Chain structures.
4. Ring structures.
5. Double tetrahedral structures.
6. Independent tetrahedral groups.

Silicates

THREE-DIMENSIONAL NETWORKS

SILICA GROUP	Quartz	SiO_2
	Tridymite	
	Cristobalite	
	Opal	$SiO_2 \cdot nH_2O$
FELDSPAR GROUP	Orthoclase	$KAlSi_3O_8$
	Microcline	$KAlSi_3O_8$
	Plagioclase series	
	Albite	$NaAlSi_3O_8$
	Oligoclase	
	Andesine	
	Labradorite	
	Bytownite	
	Anorthite	$CaAl_2Si_2O_8$
FELDSPATHOID GROUP	Leucite	$KAlSi_2O_6$
	Nepheline	$(Na,K)(Al,Si)_2O_4$
	Sodalite	$Na_4Al_3Si_3O_{12}Cl$
	Lazurite	$Na_{4-5}Al_3Si_3O_{12}S$

	Scapolite	
ZEOLITE FAMILY	Heulandite	$(Ca,Na,K)_6Al_{10}(Al,Si)Si_{29}O_{80}\cdot 25H_2O$
	Stilbite	$(Ca,Na,K)_3Al_5(Al,Si)Si_{14}O_{40}\cdot 30H_2O$
	Chabazite	$(Ca,Na,K)_7Al_{12}(Al,Si)_2Si_{26}O_{80}\cdot 40H_2O$
	Natrolite	$Na_2Al_2Si_3O_{10}\cdot 2H_2O$
	Analcime	$NaAlSi_2O_6\cdot H_2O$

SHEET STRUCTURES

	Cordierite	$Mg_2Al_4Si_5O_{18}$
	Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$
	Kaolinite	$Al_2Si_2O_5(OH)_4$
	Talc	$Mg_3Si_4O_{10}(OH)_2$
	Sepiolite	$Mg_2Si_3O_8\cdot 2H_2O$
	Serpentine	$Mg_3Si_2O_5(OH)_4$
	Garnierite	$(Ni,Mg)SiO_3\cdot nH_2O$
	Apophyllite	$Ca_4K(Si_4O_{10})_2F\ 8H_2O$
	Chlorite	$(Mg,Fe)_5(Al,Fe^{\prime\prime\prime})_2Si_3O_{10}(OH)_8$
	Margarite	$CaAl_4Si_2O_{10}(OH)_2$
	Prehnite	$Ca_2Al_2Si_3O_{10}(OH)_2$
MICA GROUP	Muscovite	$KAl_3Si_3O_{10}(OH)_2$
	Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$
	Phlogopite	$KMg_2Al_2Si_3O_{10}(OH)_2$
	Lepidolite	$K_2Li_3Al_4Si_7O_{21}(OH,F)_3$

CHAIN STRUCTURES

AMPHIBOLE GROUP	Anthophyllite	$(Mg,Fe)_7Si_8O_{22}(OH)_2$
	Tremolite-actinolite series	
	Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$
	Actinolite	$Ca(Mg,Fe)_5Si_8O_{22}(OH)_2$
	Hornblende series	
	Hornblende	$Ca_2Na(Mg,Fe^{\prime\prime})_4(Al,Fe^{\prime\prime\prime},Ti)_3Si_6O_{22}(O,OH)_2$
	Arfvedsonite	$Na_3Mg_4AlSi_8O_{22}(OH,F)_2$
PYROXENE GROUP	Enstatite series	
	Enstatite	$MgSiO_3$
	Hypersthene	$(Mg,Fe)_2Si_2O_6$
	Diopside series	
	Diopside	$CaMgSi_2O_6$
	Augite	$Ca(Mg,Fe,Al)(Al,Si)_2O_6$
	Aegirite	$NaFe^{\prime\prime\prime}Si_2O_6$
	Jadeite	$NaAlSi_2O_6$
	Spodumene	$LiAlSi_2O_6$

Rhodonite	$MnSiO_3$
Wollastonite	$CaSiO_3$
Pectolite	$Ca_2NaSi_3O_8(OH)$
Chrysocolla	$CuSiO_3 \cdot 2H_2O$

Ring Structures

Tourmaline	$WX_3B_3Al_3(AlSi_2O_9)_3(O,OH,F)_4$
Beryl	$Be_3Al_2Si_6O_{18}$

Double Tetrahedral Structures

Hemimorphite	$Zn_4Si_2O_7(OH)_2 \cdot H_2O$
Danburite	$CaB_2Si_2O_8$

Independent Tetrahedral Groups

	Olivine	$(Mg,Fe)_2SiO_4$
	Phenacite	Be_2SiO_4
	Willemite	Zn_2SiO_4
	Chondrodite	$Mg_5(SiO_4)_2(OH,F)_2$
	Garnet	$R_3''R_2'''(SiO_4)_3$
	Idocrase	$Ca_{10}Al_4(Mg,Fe)_2Si_9O_{34}(OH)_4$
Epidote Group	Epidote	$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$
	Clinozoisite	$Ca_2Al_3(SiO_4)_3(OH)$
	Allanite	$R_2''R_3'''(SiO_4)_3(OH)$
	Zircon	$ZrSiO_4$
	Datolite	$CaBSiO_4(OH)$
	Topaz	$Al_2SiO_4(F,OH)_2$
	Axinite	$H(Ca,Mn,Fe)_3Al_2B(SiO_4)_4$
	Andalusite	Al_2SiO_5
	Sillimanite	Al_2SiO_5
	Kyanite	Al_2SiO_5
	Staurolite	$Fe''Al_5Si_2O_{12}(OH)$
	Sphene	$CaTiSiO_5$
	Dumortierite	$Al_8BSi_3O_{19}(OH)$

SILICA GROUP

Although it is a marked departure from conventional mineral classifications, the silica minerals are here grouped with the silicates rather than with the oxides. This is done because structurally they bear a close resemblance to the silicates. The silica minerals show in their structures the same silicon-oxygen tetrahedra as are found in the silicates. Moreover, their physical properties — hardness, specific gravity, luster, color — resemble those of the silicates more than they do those of the oxides.

By means of thermal studies it has been shown that there are several polymorphous forms of silica. The most common of these is quartz, which exists in two modifications depending on the temperature of formation. Low-temperature, or α-quartz, forms below 573° C., whereas high-temperature, or β-quartz, forms between 573° and 870° C. Between 870° and 1,470° *tridymite* is the stable form, and above 1,470° *cristobalite* is stable. When β-quartz cools, it inverts to α-quartz at 573° C., and thus no β-quartz exists at ordinary temperatures. The inversion of tridymite and cristobalite, however, to lower-temperature forms is extremely slow, and these minerals can exist indefinitely as unstable forms. On cooling, however, tridymite passes through two inversion points, one at 163° C., the other at 117° C. Tridymite at room temperatures is thus a paramorph after high-temperature tridymite, and many of the properties of the two modifications are different. Cristobalite, on cooling, likewise inverts to a low-temperature form, with crystallographic and physical properties differing from those of the high-temperature form.

QUARTZ — SiO_2

Crystallography. α-Quartz rhombohedral; trigonal-trapezohedral. β-Quartz hexagonal; trapezohedral. Crystals commonly prismatic, with prism faces horizontally striated. Terminated usually by a combination of positive and negative rhombohedrons, which often are so equally developed as to give the effect of a hexagonal dipyramid (Fig. 370). In some crystals one rhombohedron predominates or occurs alone (Fig. 371). The prism faces may be wanting, and the combination of the two

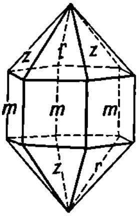


FIG. 370.

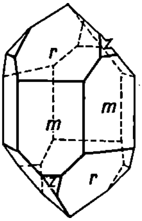


FIG. 371.

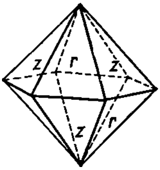


FIG. 372.

Quartz.

rhombohedrons gives what appears to be a doubly terminated hexagonal dipyramid (known as a quartzoid) (Fig. 372). Some crystals much distorted, but the recognition of the prism faces by their horizontal striations will assist in the orientation of the crystal. The trapezohedral faces are to be occasionally observed as small truncations between a prism face and that of an adjoining rhombohedron either to the right or left, forming what are known as right- or left-handed crystals (Figs. 373 and 374). Crystals are often elongated in tapering and sharply pointed forms, owing to an oscillatory combination between the faces of the different rhombohedrons and those of the prism (Plate XII). Some crystals twisted and bent. Crystals showing the higher symmetry of β-quartz are rare.

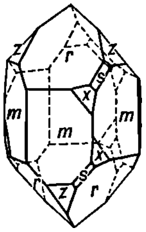


FIG. 373. Right-Handed Quartz.

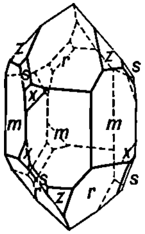


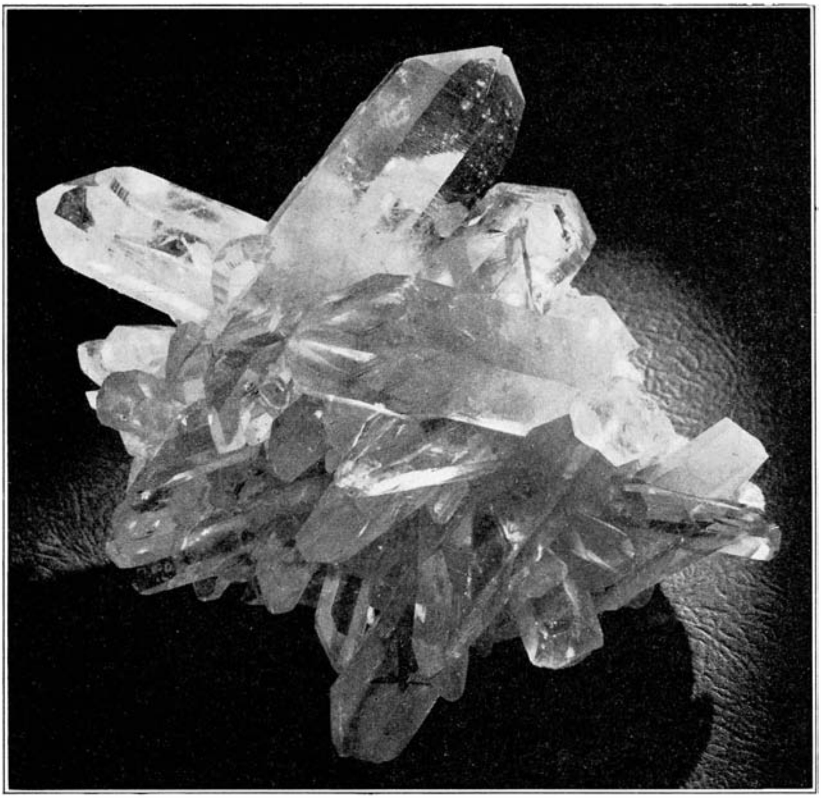
FIG. 374. Left-Handed Quartz.

Crystals frequently twinned (see page 63). The twins are usually so intimately intergrown that they can be determined only by the irregular position of the trapezohedral faces, by etching the crystal, or by the pyroelectric phenomena that they show. The size of crystals varies from individuals weighing a ton to finely crystalline coatings, forming " drusy " surfaces. Also common in massive forms of great variety. From coarse- to fine-grained crystalline to flintlike or cryptocrystalline, giving rise to many variety names (see below). May form in concretionary masses.

Physical Properties. H. = 7. G. = 2.65. Fracture conchoidal. Luster vitreous, in some specimens greasy, splendent. Usually colorless or white, but frequently colored by various impurities and may then be any color. The color gives rise to several varieties (see below). Transparent to translucent. Possesses strong piezoelectric and pyroelectric properties.

Composition. SiO_2. Si = 46.7 per cent, O = 53.3 per cent. Usually nearly pure.

Tests. Infusible. Insoluble. Yields a clear glass when the finely powdered mineral is fused with an equal volume of sodium carbonate. Soluble in hydrofluoric acid.



Courtesy of Ward's Natural Science Establishment, Inc.

Quartz Crystals, Hot Springs, Arkansas.

PLATE XII

Diagnostic Features. Characterized by its glassy luster, conchoidal fracture, and crystal form. Distinguished from calcite by its high hardness. May be confused with some varieties of beryl.

Varieties. A great many different forms of quartz exist to which varietal names have been given. The more important varieties, with a brief description of each, follow.

Coarsely Crystalline Varieties

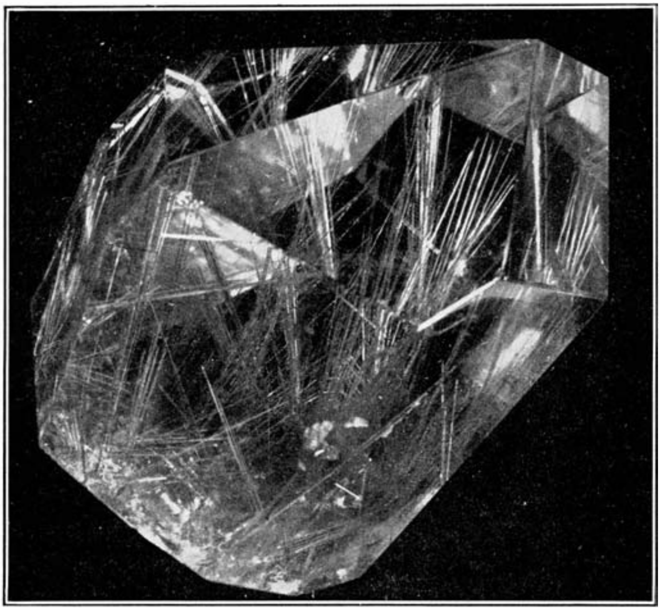
1. *Rock Crystal.* Colorless quartz, commonly in distinct crystals.
2. *Amethyst.* Quartz colored purple or violet, often in crystals.
3. *Rose Quartz.* Coarsely crystalline, but without crystal form, color a rose-red or pink. Often fades somewhat on exposure to light.

4. *Smoky Quartz; Cairngorm Stone.* Frequently in crystals of a smoky yellow to brown and almost black color. Named cairngorm from the locality of Cairngorm in Scotland.

5. *Citrine.* Light yellow in color.

6. *Milky Quartz.* Milky white in color owing to minute liquid inclusions. In some cases with greasy luster.

7. *Cat's-eye.* A stone which, when cut in a round shape (*en cabochon*), exhibits an opalescent or chatoyant effect, as it is termed, is called a cat's eye. Quartz, among other minerals, gives at times this effect, which is due either to fibrous inclusions or to the fibrous nature of the quartz itself. The latter is seen in *tiger's-eye,* a yellow fibrous quartz from South Africa, which is pseudomorphic after the fibrous mineral crocidolite.



Rutilated Quartz, Brazil.

PLATE XIII

8. *With Inclusions.* Many other minerals occur as inclusions in quartz and thus give rise to variety names. *Rutilated quartz* has fine needles of rutile penetrating it (see Plate XIII). Tourmaline and other minerals are found in quartz in the same way. *Aventurine* is quartz including brilliant scales of hematite or mica. Liquids and gases may

occur as inclusions; both liquid and gaseous carbon dioxide exist in some quartz.

Cryptocrystalline Varieties

The cryptocrystalline varieties of quartz may be divided into two general classes; namely, *fibrous* and *granular*, which, in most cases, are impossible to tell apart without microscopic aid.

A. FIBROUS VARIETIES.

Chalcedony is the general name applied to fibrous varieties. It is more specifically thought of as a brown, translucent variety, with a waxy luster, often mammillary and in other imitative shapes. Chalcedony has been deposited from aqueous solutions and is frequently found lining or filling cavities in rocks. Color and banding give rise to the following varieties:

1. *Carnelian.* A red chalcedony.
2. *Chrysoprase.* An apple-green chalcedony.
3. *Heliotrope* or *bloodstone.* A green chalcedony with small red spots in it.
4. *Agate.* A variegated variety with alternating layers of chalcedony and opal, or granular cryptocrystalline quartz. The different colors are usually in delicate, fine parallel bands which are commonly curved, in some specimens concentric (Plate XIV). Most agate used for commercial purposes is colored by artificial means. Some agates have the different colors not arranged in bands but irregularly distributed. *Moss agate* is a variety in which the variation in color is due to visible impurities, often manganese oxide in moss-like patterns.

Wood that has been petrified by replacement by clouded agate is known as *silicified* or *agatized wood.*

5. *Onyx.* Like agate, is a layered chalcedony and opal, with layers arranged in parallel planes.

B. GRANULAR VARIETIES.

1. *Flint.* Something like chalcedony in appearance, but dull, often dark, in color. It usually occurs in nodules in chalk and breaks with a prominent conchoidal fracture, giving sharp edges. Used for various implements by early man.
2. *Chert.* A compact massive rock similar in most properties to flint, but usually light in color.
3. *Jasper.* A granular cryptocrystalline quartz, usually colored red from hematite inclusions.
4. *Prase.* Dull green in color; otherwise similar to jasper, and occurs with it.

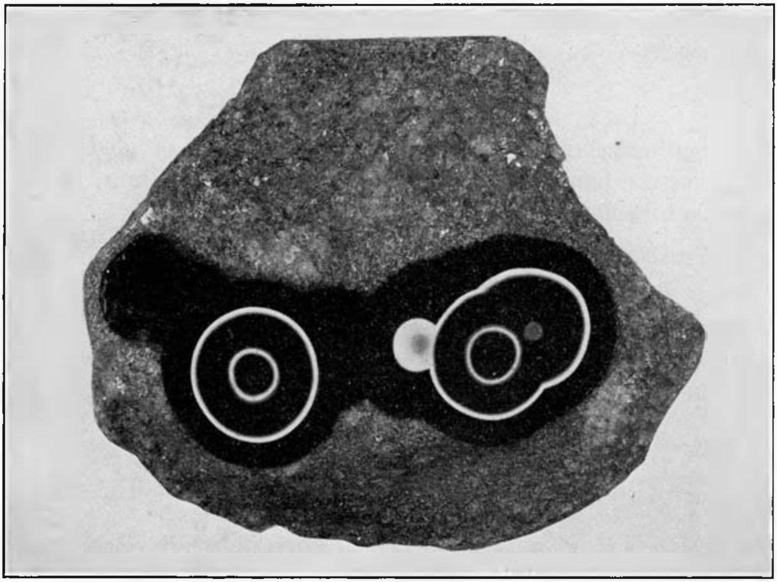


FIG. 1.

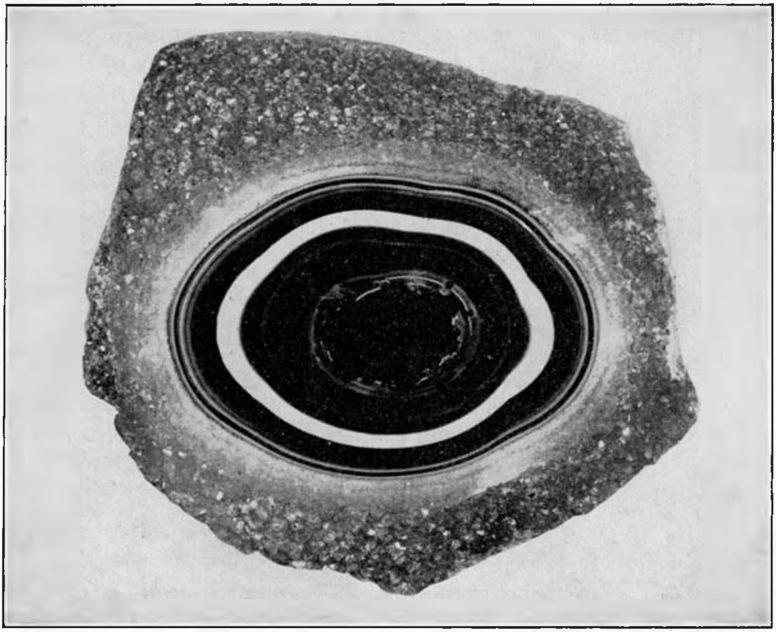


FIG. 2.

PLATE XIV. Agate Cut and Polished, Brazil.

Occurrence. Quartz occurs as an important constituent of those igneous rocks which have an excess of silica, such as granite, rhyolite, pegmatite. It is extremely resistant to both mechanical and chemical attack, and thus the breakdown of igneous rocks containing it yields quartz grains which may accumulate and form the sedimentary rock sandstone. Also occurs in metamorphic rocks, as gneisses and schists, while it forms practically the only mineral of quartzites. Deposited often from solution and is the most common vein and gangue mineral. Forms as flint deposited with chalk on the sea floor in nodular masses. Solutions carrying silica may replace beds of limestone with a granular cryptocrystalline quartz known as *chert,* or discontinuous beds of chert may form contemporaneously with the limestone. In rocks it is associated chiefly with feldspar and muscovite; in veins with practically the entire range of vein minerals. Often carries gold and becomes an important ore of that metal. Occurs in large amount as sand in stream beds and upon the seashore and as a constituent of soils.

Rock crystal is found widely distributed, some of the more notable localities being: the Alps; Minas Geraes, Brazil; the island of Madagascar; Japan. The best quartz crystals from the United States are found at Hot Springs, Arkansas, and Little Falls and Ellenville, New York. Important occurrences of amethyst are in the Ural Mountains; Czechoslovakia; Tyrol; Brazil. Found at Thunder Bay on the north shore of Lake Superior. In the United States found in Delaware and Chester Counties, Pennsylvania; Black Hills, South Dakota; Wyoming. Smoky quartz is found in large and fine crystals in Switzerland; and in the United States at Pikes Peak, Colorado; Alexander County, North Carolina; Auburn, Maine.

The chief source of agates at present is a district in southern Brazil and northern Uruguay. Most of these agates are cut at Oberstein, Germany, itself a famous agate locality. In the United States agate is found in numerous places, notably in Oregon and Wyoming. The chalk cliffs of Dover, England, are famous for the flint nodules that weather from them. Similar nodules are found on the French coast of the English Channel and on islands off the coast of Denmark. Massive quartz, occurring in veins or with feldspar in pegmatite dikes, is mined in Connecticut, New York, Maryland, and Wisconsin for its various commercial uses.

Use. Widely used in its various colored forms as ornamental material, as amethyst, rose quartz, cairngorm, cat's-eye, tiger's-eye, aventurine, carnelian, agate, onyx. As rock crystal in various optical and electrical equipment. As sand used in mortar, in cement, as a flux, as an abrasive, and in the manufacture of glass and silica brick. In powdered form is used in porcelain, paints, sandpaper, and scouring soaps, and as a wood filler. As quartzite, sandstone, and in its various other rock forms as a building stone and for paving purposes. Large amounts of quartz sand are used as an acid flux in certain smelting operations.

Name. The name quartz is a German word of ancient derivation.

Similar Species. *Lechatelierite,* SiO_2, is fused silica or silica glass. Found in fulgurites, tubes of fused sand formed by lightning, and in cavities in some lavas.

Tridymite — SiO_2

Crystallography. Orthorhombic but pseudohexagonal, paramorphic after high-temperature hexagonal tridymite. Crystals are small and commonly twinned.

Physical Properties. **H.** = 7. **G.** = 2.26. Luster vitreous. Colorless to white. Transparent to translucent.

Composition. SiO_2, like quartz.

Tests. Infusible. Soluble in boiling sodium carbonate. More soluble in hydrofluoric acid than quartz.

Diagnostic Features. It is impossible to identify tridymite by macroscopic means, but under the microscope its crystalline outline and refractive index distinguish it from the other silica minerals.

Occurrence. Tridymite is present on a large scale in certain siliceous volcanic rocks and for this reason may be considered an abundant mineral. Usually associated with cristobalite. It is found in large amounts in the lavas of the San Juan District of Colorado.

Name. From the Greek meaning *threefold,* in allusion to its common occurrence in trillings.

Cristobalite — SiO_2

Crystallography. Tetragonal (?); pseudo-isometric. High-temperature cristobalite is isometric and frequently forms in small octahedral crystals. The outward appearance is retained when inversion to the low-temperature form takes place.

Physical Properties. **H.** = 7. **G.** = 2.30. Luster vitreous. Colorless. Translucent.

Composition. SiO_2, like quartz.

Tests. Infusible, but when heated to 200° C. inverts to the high-temperature isometric form and becomes nearly transparent; on cooling, again inverts and assumes its initial white, translucent appearance.

Diagnostic Features. The occurrence in small lava cavities in spherical aggregates, and its behavior when heated, are characteristic, but like tridymite it cannot be determined with certainty without optical determinations made with the microscope.

Occurrence. Cristobalite is present in many siliceous volcanic rocks, both as the lining of cavities and as an important constituent in the fine-grained ground mass. It is, therefore, an abundant mineral. Associated with tridymite in the lavas of the San Juan District, Colorado.

Name. From the Cerro San Cristobal near Pachuca, Mexico.

OPAL — $SiO_2 \cdot nH_2O$

Crystallography. Amorphous. Massive; often botryoidal, stalactitic.

Physical Properties. Conchoidal fracture. **H.** = 5–6. **G.** = 1.9–2.2. Luster vitreous; often somewhat resinous. Colorless, white, pale shades of yellow, red, brown, green, gray, and blue. With darker colors, which are due to various impurities. Often has a milky or " opalescent " effect and may show a fine play of colors. Transparent to translucent.

Composition. Silicon dioxide, like quartz, with a varying amount of water, $SiO_2 \cdot nH_2O$. A mineral gel.

Tests. Infusible. Insoluble. Reacts like quartz. Gives water upon intense ignition in the closed tube.

Diagnostic Features. Distinguished from cryptocrystalline varieties of quartz by lesser hardness and specific gravity and by the presence of water.

Varieties. *Precious Opal.* White, milky blue, yellow. In some specimens dark, as in so-called *black opal.* Translucent, with an internal play of colors. This phenomenon is said to be due to thin curved laminae which refract the light differently from the mass of the material, and so serve to break it up into the various prismatic colors. *Fire opal* is a variety with intense orange to red reflections.

Common Opal. Milk-white, yellow, green, red, etc., without internal reflections.

Hyalite. Clear and colorless opal with a globular or botryoidal surface.

Geyserite or *Siliceous Sinter.* Opal deposited by hot springs and geysers. Found about the geysers in Yellowstone National Park.

Wood Opal. Fossil wood with opal as the petrifying material.

Diatomaceous Earth. Fine-grained deposits, resembling chalk in appearance. Formed by sinking from near the surface and the accumulation on the sea floor of the siliceous tests of diatoms. Also known as *diatomite* or *infusorial earth.*

Occurrence. Opal is found lining and filling cavities in igneous and sedimentary rocks, where it has evidently been deposited through the agency of hot waters. It may also replace wood buried by volcanic tuff. Deposited from hot springs and occurs in sedimentary beds as the result of the accumulation of siliceous skeletons of minute sea animals. In its ordinary variety it is of widespread occurrence.

Precious opals are found at Caernowitza, Hungary; in Queretara and other states in Mexico; in Honduras; and various localities in Australia, the chief district being White Cliffs, New South Wales. Black opal has been found in the United States in Nevada and Idaho. Diatomaceous earth is mined in several western states, chiefly in California.

Use. As a gem. The stones are usually cut in round shapes, *en cabochon.* Stones of large size and exceptional quality are very highly prized. Diatomaceous earth is used extensively as an abrasive, filler, filtration powder, and in insulation products.

Name. The name opal originated in the Sanskrit, *upala,* meaning stone or precious stone.

FELDSPAR GROUP

The feldspars form one of the most important of mineral groups. They are silicates of aluminum with potassium, sodium, and calcium, and rarely barium. They may belong to either the monoclinic or the triclinic systems, but the crystals of the different systems resemble each other closely in angles and crystal habit. They all show good cleavages in two directions which make an angle of 90°, or close to 90°, with each other. Hardness is about 6, and specific gravity ranges from 2.55 to 2.75.

ORTHOCLASE — $KAlSi_3O_8$

Crystallography. Monoclinic; prismatic. Crystals are usually prismatic in habit and elongated parallel to the *a* axis, or elongated parallel to the *c* axis and flattened parallel to the clinopinacoid, and have, as prominent forms, clinopinacoid {010}, base {001}, prism {110}, often with smaller orthodomes and pyramids (Figs. 375, 376, 377). Frequently twinned according to the following laws: *Carlsbad* with orthopinacoid {100} as twin plane or *c* axis as twin axis, and clinopinacoid {010} as composition plane (Fig. 379); *Baveno* with the clinodome {021} as twin and composition plane (Fig. 381); *Manebach* with base {001} as twin and composition plane (Fig. 380). Commonly in crystals or in coarsely cleavable to granular masses; more rarely fine-grained, massive, and cryptocrystalline. Most abundantly in rocks as formless grains.

Physical Properties. Two prominent cleavages making an angle of 90° with each other; one parallel to base {001}, perfect; the other parallel to clinopinacoid {010}, good. Prismatic cleavage {110} frequently observed. **H.** = 6. **G.** = 2.57. Luster vitreous. Colorless, white, gray, flesh-red. Streak white. *Adularia* is a colorless and translucent to transparent variety. It is usually in pseudo-orthorhombic crystals.

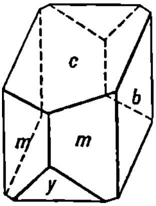


FIG. 375.

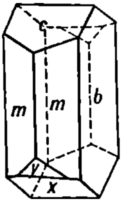


FIG. 376.

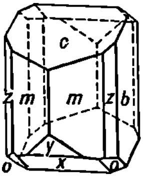


FIG. 377.

Orthoclase.

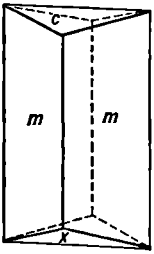


FIG. 378. Adularia.

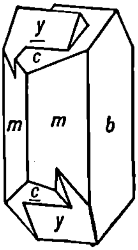


FIG. 379. Carlsbad Twin

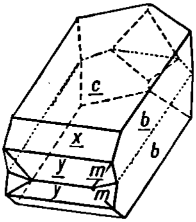


FIG. 380. Manebach Twin.

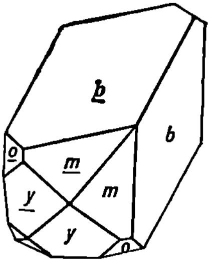


FIG. 381. Baveno Twin

Some adularia shows an opalescent play of colors and is called *moonstone*. *Sanidine* is a glassy, often transparent, variety found as phenocrysts in some igneous rocks.

Composition. Potassium aluminum silicate, $KAlSi_3O_8$. $K_2O = 16.9$ per cent, $Al_2O_3 = 18.4$ per cent, $SiO_2 = 64.7$ per cent. Orthoclase and microcline (page 285) are together known as *potash feldspar*. Sodium may replace potassium, and in the variety *sanidine* as much as 50 per cent of the potassium is replaced. In the variety *hyalophane*, $(K,Ba)(Al,Si)_2Si_2O_8$, barium replaces part of the potassium.

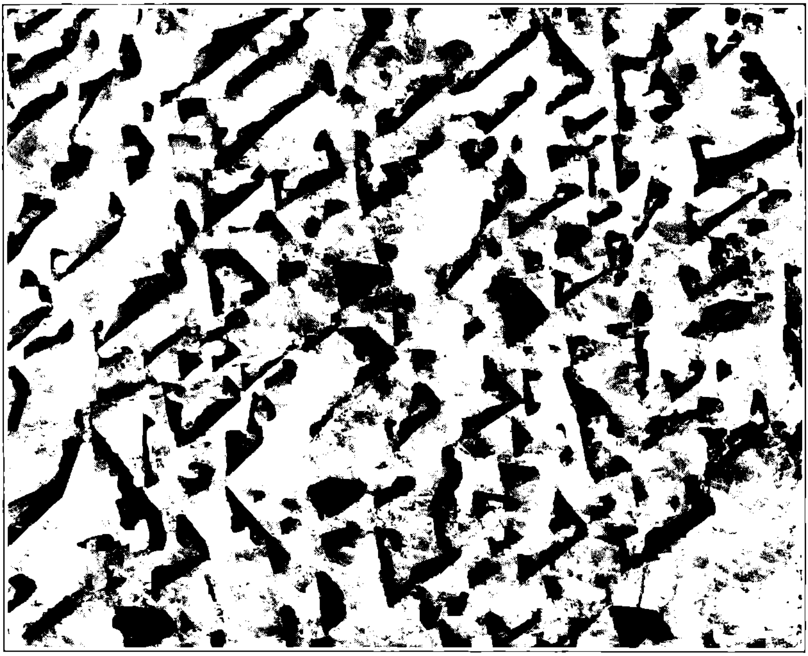


Fig. 1. Graphic Granite, Hybla, Ontario. Quartz Dark, Feldspar Light.

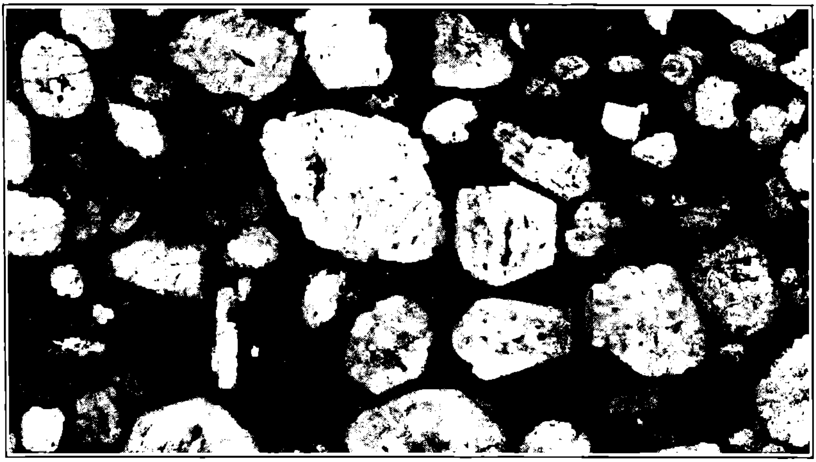


Fig. 2. Phenocrysts of Orthoclase in Lava.

Plate XV

Tests. Difficultly fusible (5). Insoluble in acids. When mixed with powdered gypsum and heated on platinum wire gives the violet flame of potassium.

Diagnostic Features. Is usually recognized by its color, hardness, and cleavage. Distinguished from the other feldspars by its right-angle cleavage and the lack of twin striations on the best cleavage surface.

Alteration. When acted upon by waters carrying carbon dioxide in solution, orthoclase alters forming a soluble carbonate of potassium and leaving as a residue a mixture either of kaolin and silica or of muscovite and silica. Kaolin forms the chief constituent of clays and has been derived in this manner.

Occurrence. Orthoclase is one of the most common of minerals. It is formed during the crystallization of igenous rocks (Plate XV, Fig. 2), and by hydrothermal agencies in pegmatite dikes and in druses in rocks. More rarely by crystallization from aqueous solutions at low temperatures in veins. Widely distributed as a prominent rock constituent, occurring in many types of igneous rocks, especially in granites, syenites, nepheline syenites; in sedimentary rocks is present in arkose and in certain sandstones and conglomerates; in metamorphic rocks in gneisses. Also in large crystals and cleavable masses in pegmatite dikes, associated chiefly with quartz, muscovite, and albite. In pegmatites may be intimately intergrown with quartz, forming *graphic granite* (Plate XV, Fig. 1). Large pegmatite dikes of this character from which feldspar is quarried in considerable amounts occur in the New England and Middle Atlantic states, chiefly in Maine, Connecticut, New York, Pennsylvania, Maryland, and North Carolina.

Use. Orthoclase is used chiefly in the manufacture of porcelain. It is ground very fine and mixed with kaolin or clay, and quartz. When heated to high temperature the feldspar fuses and acts as a cement to bind the material together. Fused feldspar also furnishes the major part of the glaze on porcelain ware. A small amount of feldspar is used in the manufacture of glass to contribute alumina to the batch.

Name. The name *orthoclase* refers to the right-angle cleavage possessed by the mineral. *Feldspar* is derived from the German word *feld*, field.

Similar Species. *Celsian*, $BaAl_2Si_2O_8$, is a rare feldspar in which barium has completely taken the place of potassium.

MICROCLINE — $KAlSi_3O_8$

Crystallography. Triclinic; pinacoidal. Axial lengths and angles only slightly different from those of orthoclase. Microcline crystals may be twinned according to the same laws as orthoclase; Carlsbad twins are common, but Baveno and Manebach twins are rare. It is also twinned according to the *albite law* with the brachypinacoid the twin plane, and the *pericline law* with the *b* crystallographic axis the twin axis. These two types of twinning are characteristic of the triclinic feldspars. A thin section of microcline under the microscope in polarized light usually shows a characteristic grating structure, caused by the crossing at nearly right angles of the twin lamellae formed according to the albite and pericline laws. Orthoclase, being monoclinic, could not show such twinning. Microcline is found in cleavable masses, in crystals, and as a rock constituent in irregular grains. Microcline probably forms the largest known crystals. In Karelia, U.S.S.R., masses weighing over 2,000 tons showed the continuity of a single crystal.

Microcline frequently has irregular and discontinuous bands crossing the basal and brachypinacoids. These bands are composed of albite, and the intergrowth as a whole is called *perthite,* or if very fine, *microperthite.*

Physical Properties. Cleavage parallel to base {001} and brachypinacoid {010}, with angle of 89° 30′ (orthoclase has a 90° angle). Poor cleavage parallel to the prism {110}. **H.** = 6. **G.** = 2.54–2.57. Luster vitreous. Color white to pale yellow, more rarely red. Green microcline is known as *Amazon stone.* Translucent to transparent.

Composition. Like orthoclase, $KAlSi_3O_8$. Sodium may replace potassium, giving rise to *soda-microcline,* and if sodium exceeds potassium the mineral is known as *anorthoclase.*

Tests. Same as for orthoclase.

Diagnostic Features. Distinguished from orthoclase only by determining the presence of triclinic twinning, which can rarely be determined without the aid of the microscope. If a feldspar is a deep green it is microcline.

Occurrence. Same as for orthoclase, and often associated with it. Much that passes as orthoclase in reality is microcline. *Amazon stone,* microcline with a green color, is found in the Ural Mountains and in various places in Norway and Madagascar. In the United States it is found at Pikes Peak, Colorado, and Amelia Court House, Virginia.

Use. Same as for orthoclase. Amazon stone is polished and used as an ornamental material.

Name. *Microcline* is derived from two Greek words meaning *little* and *inclined,* referring to the slight variation of the cleavage angle from 90°.

Plagioclase Feldspar Series

The triclinic, so-called soda-lime, feldspars form an isomorphous series varying in composition from pure albite, $NaAlSi_3O_8$, to pure anorthite, $CaAl_2Si_2O_8$. These two end members can replace each other in all proportions, and, as a consequence, a complete series is formed. The series is divided into the following six wholly arbitrary divisions, according to the relative amounts of albite and anorthite:

	Per Cent Albite	Per Cent Anorthite
Albite $NaAlSi_3O_8$	100–90	0–10
Oligoclase	90–70	10–30
Andesine	70–50	30–50
Labradorite	50–30	50–70
Bytownite	30–10	70–90
Anorthite $CaAl_2Si_2O_8$	10–0	90–100

Although species names are given to the above arbitrary divisions, most of the properties vary in a uniform manner with the change in chemical composition. For this reason the series can be more easily understood if one comprehensive description is given, rather than six individual descriptions, and the dissimilarities between members indicated.

ALBITE — ANORTHITE

Crystallography. Triclinic; pinacoidal. Crystals commonly tabular parallel to the brachypinacoid {010} (Fig. 382); occasionally elongated parallel to the *b* crystal axis (Fig. 383). In anorthite crystals may be prismatic, elongated parallel to the *c* crystal axis.

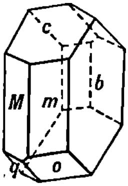


Fig. 382.

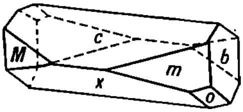


Fig. 383.

Albite.

Crystals are frequently twinned according to the various laws governing the twins of orthoclase, i.e., Carlsbad, Baveno, and Manebach. In addition, they are nearly always twinned according to one or both of two laws known as the *albite* and *pericline laws*. The twinning plane in the albite law is the brachypinacoid {010}. The angle between the basal plane and this twinning plane is about 94°. (See page 65.) Albite twinning is commonly polysynthetic and gives rise to thin lamellae, each one in twin position in respect to those on either side (see Fig. 384). Consequently a basal plane or basal cleavage of such a twinned crystal will be crossed by a number of parallel groovings or striations (Fig. 385). Often these striations are so fine as not to be visible to the unaided eye, but on some specimens they are coarse and easily seen. The presence of these striation lines upon the basal cleavage (the better cleavage surface of a feldspar) is one of the best proofs that it belongs to the plagioclase series. In the pericline law the twinning axis is the *b* crystallographic axis, and when this results in polysynthetic twins the consequent striations are to be seen on the brachypinacoid.

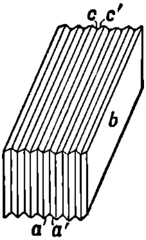


FIG. 384.

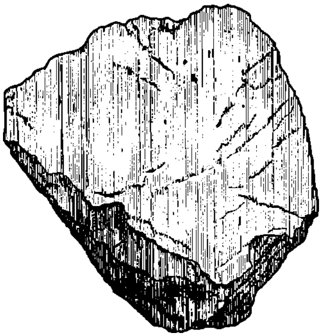


FIG. 385.

Albite Twinning.

Distinct crystals are rare. Usually in twinned, cleavable masses; as irregular grains in igneous rocks.

Physical Properties. Cleavage perfect parallel to the base {001}, and good parallel to the brachypinacoid {010}. Cleavage poor parallel to the prism {110}. The angle between the {001} and {010} cleavages varies from 93° 34′ in albite to 94° 12′ in anorthite. **H.** = 6. **G.** = 2.62 in albite to 2.76 in anorthite (Fig. 386). Colorless, white, gray; less frequently greenish, yellowish, flesh-red. Certain of the species have characteristic colors. Luster vitreous to pearly. Transparent to translucent. A beautiful play of colors is frequently seen, especially in labradorite and andesine.

Composition. Sodium and calcium aluminum silicates. Isomorphous mixtures of albite, $NaAlSi_3O_8$, and anorthite, $CaAl_2Si_2O_8$. Considerable potassium may be present toward the albite end of the series.

Tests. Fusible at 4–4½ to a colorless glass. Albite is insoluble in acids, but anorthite is decomposed by hydrochloric acid with the separation of gelatinous silica. Between these extremes the intermediate members show a greater solubility the greater the amount of anorthite present. A strong sodium flame is given by members rich in soda.

Diagnostic Features. The plagioclase feldspars can be distinguished from other feldspars by detecting the presence on the basal cleavage of striations caused by albite twinning. They may be placed accurately in their proper places in the series only by optical tests or quantitative chemical analyses, but they can be roughly distinguished from one another by specific gravity.

Occurrence. The plagioclase feldspars, as rock-forming minerals, are even more widely distributed and more abundant than the potash feldspars. They are found in igneous, metamorphic, and, more rarely, sedimentary rocks. Albite is included with orthoclase and microcline in what are known as the *alkali feldspars*, all of which have a similar occurrence. They are usually found together in granites, syenites, rhyolites, trachytes.

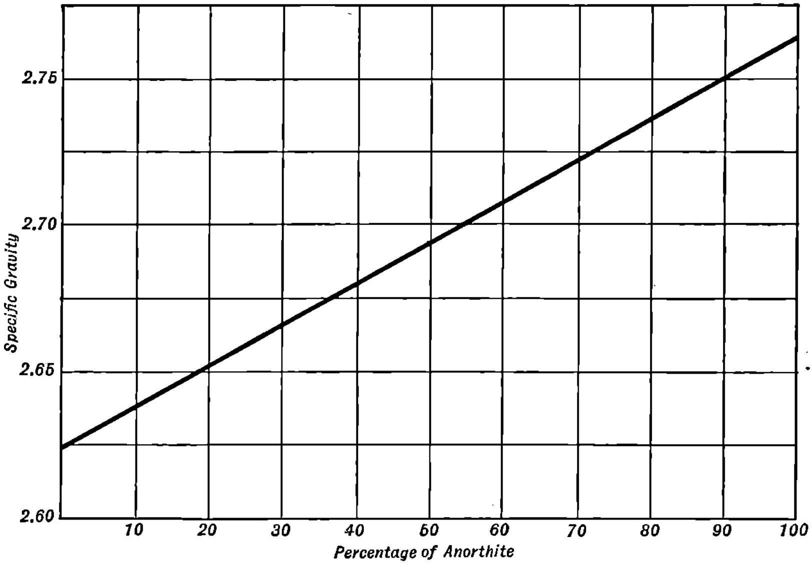


FIG. 386. Specific Gravity of the Plagioclase Feldspars.

The classification of igneous rocks is based largely on the kind and amount of feldspar present (see page 358). As a rule, the greater the percentage of silica in a rock the fewer the dark minerals and the more sodic the feldspar; and conversely, the lower the percentage of silica the greater the percentage of dark minerals and the more calcic the feldspar. If plagioclase feldspar with the composition of oligoclase-andesine is found in an igneous rock, the rock is a granodiorite, monzonite, tonalite, diorite, or the lava equivalent of one of them. If the plagioclase is labradorite-anorthite, the rock is a gabbro, anorthosite, or basalt.

Albite. In addition to its occurrence as a constituent of igneous rocks, albite is present in pegmatite dikes and may be found in crystals and replacing earlier orthoclase. *Cleavelandite* is a platy variety of albite found in some pegmatites. Notable localities for crystals of albite are in Switzerland and the Tyrol. In the United States at Paris, Maine; Chesterfield, Massachusetts; Haddam and Branchville, Connecticut; Amelia Court House, Virginia. Some albite shows an opalescent play of colors and is known as *moonstone.* The name albite is derived from the Latin *albus,* meaning *white,* in allusion to the color.

Oligoclase. Found in various localities in Norway, notably at Tvedestrand, where it contains inclusions of hematite, which give the mineral a golden shimmer and sparkle. Such feldspar is called *aventurine* oligoclase, or *sunstone.* The name is derived from two Greek words meaning *little* and *fracture,* since it was believed to have had less perfect cleavage than albite.

Andesine. Rarely found except as grains in igneous rocks. Named from the Andes Mountains where it is the chief feldspar in the andesite lavas.

Labradorite. Widespread as a rock mineral, and in large masses of rocks known as anorthosite is the only important constituent. Found on the coast of Labrador in large cleavable masses which show a fine iridescent play of colors. The name is derived from this locality.

Bytownite. Rarely found except as grains in igneous rocks. Named from the Canadian locality, Bytown.

Anorthite. Rarer than the more sodic plagioclase. Found in rocks rich in dark minerals and in druses of ejected volcanic blocks and in granular limestones of contact metamorphic deposits. Name derived from the Greek word meaning *oblique,* because its crystals are triclinic.

Use. Plagioclase feldspars are less widely used than potash feldspars. Albite, or *soda spar,* as it is called commercially, is used in ceramics in a manner similar to orthoclase. Labradorite that shows a play of colors is polished and used as an ornamental stone. Those varieties which show opalescence are cut and sold under the name of *moonstone* or *sunstone.*

Name. The name plagioclase is derived from the Greek meaning *oblique,* in allusion to the oblique angle between the cleavages. See under *Occurrence* for names of specific species.

FELDSPATHOID GROUP

The feldspathoids are those minerals that form in place of the feldspars in certain rocks rich in alkalis and deficient in silica. Leucite, nepheline, sodalite, and lazurite are the feldspathoids of greatest importance.

LEUCITE — $KAlSi_2O_6$

Crystallography. Pseudo-isometric. Trapezohedral habit (Fig. 387). Other forms rare. Strictly isometric only at temperatures of 500°C or above. On cooling below this temperature it undergoes an internal molecular rearrangement to that of some other crystal system, probably orthorhombic, but the external form does not change. It is formed in lavas at high temperatures and is then isometric in internal structure as well as outward form. Usually in distinct crystals, also in disseminated grains. (See Plate XVI, Fig. 2.)

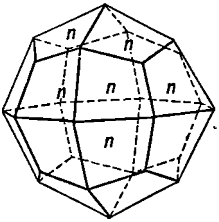


FIG. 387. Leucite.

Physical Properties. **H.** = $5\frac{1}{2}$–6. **G.** = 2.45–2.50. Luster vitreous to dull. Color white to gray. Translucent.

Composition. Potassium aluminum silicate, $KAlSi_2O_6$. K_2O = 21.5 per cent, Al_2O_3 = 23.5 per cent, SiO_2 = 55.0 per cent.

Tests. Infusible. Decomposed by hydrochloric acid with the separation of silica but without the formation of a jelly. Addition of ammonia to the solution gives precipitate of aluminum hydroxide. When mixed with powdered gypsum and fused gives violet potassium flame (best observed through a blue glass).

Diagnostic Features. Characterized by its trapezohedral form and infusibility. It is softer than garnet and harder than analcime; analcime, moreover, is fusible and yields water.

Occurrence. Leucite is a rather rare mineral, occurring only in igneous rocks, usually in the recent lavas; rarely observed in deep-seated rocks. Found in rocks in which the amount of silica in the magma was insufficient to combine with the potassium to form feldspar. Is not observed, therefore, in rocks that contain quartz. Chiefly found in the rocks of central Italy; notably as phenocrysts in the lavas of Vesuvius. In the United States found in rocks of the Leucite Hills, Wyoming, and in certain of the rocks in the Highwood Mountains and Bear Paw Mountains, Montana. Pseudomorphs of a mixture of nepheline, orthoclase, and analcime after leucite, *pseudoleucite*, are found in syenites of Arkansas, Montana, and Brazil.

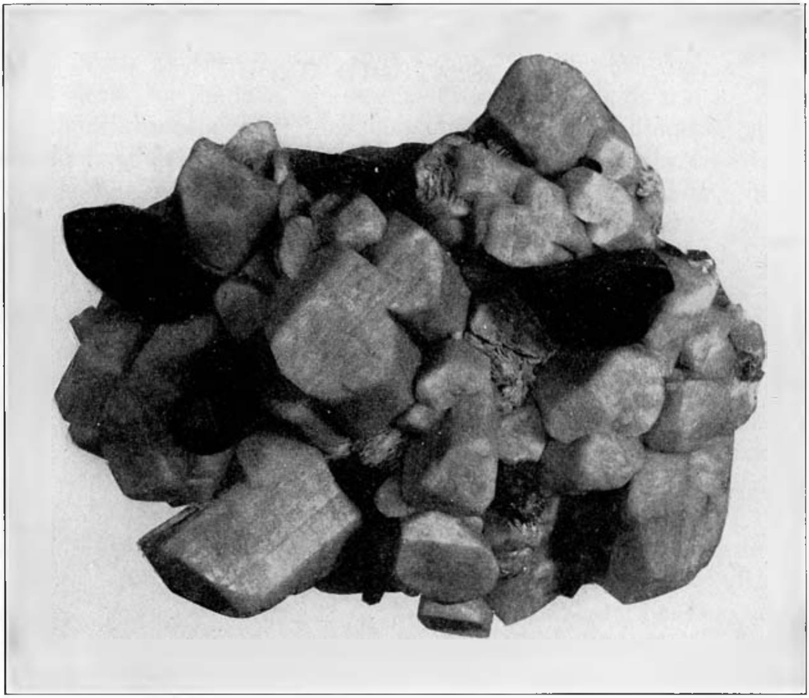


FIG. 1: Microcline and Smoky Quartz, Crystal Peak, Colorado.

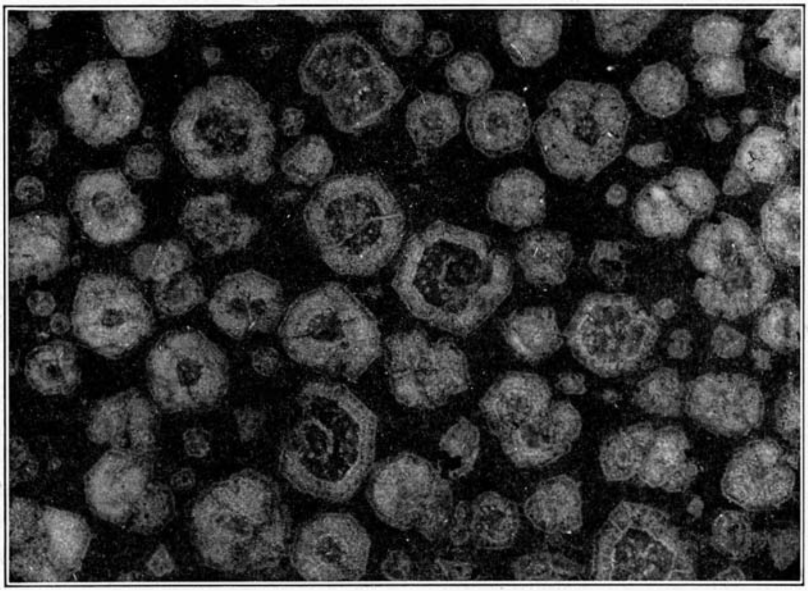


FIG. 2. Leucite Phenocrysts in Lava.

PLATE XVI

Name. From a Greek word meaning *white*.

Similar Species. *Pollucite*, $Cs_4Al_4Si_9O_{26}\cdot H_2O$, is a rare isometric mineral usually occurring in pegmatites.

NEPHELINE — $(Na,K)(Al,Si)_2O_4$

Crystallography. Hexagonal; pyramidal. Rarely in small prismatic crystals with basal plane; in some cases shows pyramidal planes. Almost invariably massive, compact, and in imbedded grains. Massive variety often called *eleolite* because of its greasy luster.

Physical Properties. Distinct cleavage parallel to prism $\{10\bar{1}0\}$. **H.** = $5\frac{1}{2}$–6. **G.** = 2.55–2.65. Luster vitreous in the clear crystals to greasy in the massive variety. Colorless, white, or yellowish. In the massive variety gray, greenish, and reddish. Transparent to translucent.

Composition. Sodium-potassium aluminum silicate, $(Na,K)(Al,Si)_2O_4$. The amount of potassium present is usually low. The percentages of oxides in the artificial compound $NaAlSiO_4$ are: Na_2O = 21.8, Al_2O_3 = 35.9, SiO_2 = 42.3.

Tests. Fusible at 4 to a colorless glass giving a strong yellow flame of sodium. Readily soluble in hydrochloric acid and on evaporation yields a silica jelly.

Diagnostic Features. Characterized in massive varieties by its greasy luster. Distinguished from quartz by inferior hardness and from feldspar by gelatinizing in acid.

Alteration. Easily alters to various other minerals, such as zeolites, sodalite, muscovite, kaolin.

Occurrence. Nepheline is rarely found except in igneous rocks. It occurs in some recent lavas as glassy crystals, such as are found in the lavas of Vesuvius. The massive or coarsely crystalline variety is found in the older rocks and is called *eleolite*. Phonolite, nepheline syenite, and nepheline basalt are important rocks in which nepheline is an essential constituent. It is found only in rocks whose magmas contained insufficient silica to combine with soda to form feldspar. Only in exceptional circumstances, therefore, is it found in rocks that contain quartz. The largest known mass of nepheline rocks is found on the Kola Peninsula, U.S.S.R. Locally in these rocks nepheline is associated with apatite. Extensive masses of nepheline rocks are found in Norway and South Africa. In crystals in the lavas of Vesuvius. In the United States nepheline, both massive and in crystals, is found at Litchfield, Maine, associated with cancrinite. Found near Magnet Cove, Arkansas, and Beemerville, New Jersey. Common in the syenites of the

Bancroft region of Ontario, Canada, where there are pegmatites with rather large masses of nearly pure nepheline.

Use. Recently iron-free nepheline, because of its high alumina content, has been used in place of feldspar in the glass industry. Most of the commercial nepheline comes from Ontario. The Russians report that nepheline, produced as a by-product of apatite mining on the Kola Peninsula, is used in fifteen different industries including ceramics, leather, textile, wood, rubber, and oil.

Name. *Nepheline* is derived from a Greek word meaning a *cloud,* because when immersed in acid the mineral becomes cloudy. *Eleolite* is derived from the Greek word for *oil,* in allusion to its greasy luster.

Similar Species. *Cancrinite,* a hydrous silicate of sodium calcium and aluminum, is a rare mineral similar to nepheline in occurrence and associations.

SODALITE — $Na_4Al_3Si_3O_{12}Cl$

Crystallography. Isometric; hextetrahedral. Crystals rare, usually dodecahedrons. Commonly massive, in imbedded grains.

Physical Properties. Dodecahedral {110} cleavage. **H.** = 5½–6. **G.** = 2.15–2.3. Luster vitreous. Color usually blue, also white, gray, green. Transparent to translucent.

Composition. Sodium aluminum silicate with chlorine, $Na_4Al_3Si_3O_{12}Cl$. Na_2O = 25.6 per cent, Al_2O_3 = 31.6 per cent, SiO_2 = 37.2 per cent, Cl = 7.3 per cent.

Tests. Fusible at 3½–4, to a colorless glass, giving a strong yellow flame (sodium). Soluble in hydrochloric acid and gives gelatinous silica upon evaporation. Nitric acid solution with silver nitrate gives white precipitate of silver chloride. In a salt of phosphorus bead with copper oxide gives azure-blue copper chloride flame.

Diagnostic Features. Distinguished in most instances by its blue color, and told from lazurite by the absence of associated pyrite. If color is not blue, a positive test for chlorine is the only way to distinguish it from analcime, leucite, and hauynite.

Occurrence. Sodalite is a comparatively rare rock-forming mineral associated with nepheline, cancrinite, and other feldspathoids in nepheline syenites, trachytes, phonolites, etc. Found in transparent crystals in the lavas of Vesuvius. The massive blue variety is found at Litchfield, Maine; in Ontario and Quebec; near Kicking Horse Pass, British Columbia.

Name. Named in allusion to its sodium content.

Similar Species. Other feldspathoids, but rare in their occurrence, are *hauynite,* $(Na,Ca)_{6-8}Al_6Si_6O_{24}\cdot(SO_4)_{1-2}$, and *noselite,* $Na_4Al_3Si_3O_{12}\cdot SO_4$.

LAZURITE — $Na_{4-5}Al_3Si_3O_{12}S$

Lapis Lazuli

Crystallography. Isometric. Crystals rare, usually dodecahedral. Commonly massive, compact.

Physical Properties. Imperfect dodecahedral {110} cleavage. **H.** = 5–5½. **G.** = 2.4–2.45. Luster vitreous. Color deep azure-blue, greenish blue. Translucent.

Composition. $Na_{4-5}Al_3Si_3O_{12}S$, with small amounts of the sodalite and hauynite molecules in isomorphous replacement.

Tests. Fusible at 3½, giving strong yellow flame (sodium). Soluble in hydrochloric acid with slight evolution of hydrogen sulfide gas, and gives gelatinous silica upon evaporation.

Diagnostic Features. Characterized by its blue color and the presence of associated pyrite.

Occurrence. Lazurite is a rare mineral, occurring usually in crystalline limestones as a product of contact metamorphism. *Lapis lazuli* is usually a mixture of lazurite with small amounts of calcite, pyroxene, and other silicates, and commonly contains small disseminated particles of pyrite. The best quality of lapis lazuli comes from northeastern Afghanistan. Also found at Lake Baikal, Siberia; and in Chile.

Use. Lapis lazuli is highly prized as an ornamental stone, for carvings, etc. As a powder it was formerly used as the paint pigment *ultra marine.* Now ultramarine is produced artificially.

Name. Lazurite is an obsolete synonym for azurite, and hence the mineral is named because of its color resemblance to azurite.

SCAPOLITE

Wernerite

Crystallography. Tetragonal; dipyramidal. Crystals usually prismatic. Prominent forms are prisms of the first and second orders, and dipyramid of first order (Fig. 388). Rarely shows the faces of the pyramid of the third order (Fig. 389). Crystals are usually coarse, or with faint fibrous appearance.

Physical Properties. Imperfect prismatic cleavage, both {100} and {110}. **H.** = 5–6. **G.** = 2.65–2.74. Luster vitreous when fresh and unaltered. Color white, gray, pale green; more rarely bluish or reddish. Transparent to translucent.

Composition. Scapolite is of varied composition since the name is used to designate all intermediate members of an isomorphous series the end members of which are: *marialite,* $(Na,Ca)_4Al_3(Al,Si)_3Si_6O_{24}(Cl,CO_3,SO_4)$; and *meionite,* $(Ca,Na)_4Al_3(Al,Si)_3Si_6O_{24}(Cl,CO_3,SO_4)$.

Tests. Fusible at 3 with intumescence to a white blebby glass and colors the flame yellow. Imperfectly decomposed by hydrochloric acid, yielding separated silica but without the formation of a jelly.

Diagnostic Features. Characterized by its crystals with square cross section and four cleavage directions at 45°. When massive resembles feldspar but has a characteristic fibrous appearance on the cleavage surfaces. It is also more readily fusible. Its fusibility with intumescence distinguishes it from pyroxene.

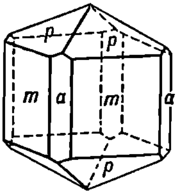


Fig. 388.

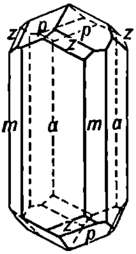


Fig. 389.

Scapolite

Alteration. Easily altered to various other minerals such as mica, epidote, talc, kaolin.

Occurrence. Scapolite occurs in the crystalline schists, gneisses, and amphibolites, and in many cases has probably been derived by alteration from plagioclase feldspars. It also characteristically occurs in crystalline limestones formed through the contact metamorphic action of an intruded igneous rock. Associated with diopside, amphibole, garnet, apatite, sphene, zircon.

Crystals of gem quality with a yellow color occur in Madagascar. In the United States found in various places in Massachusetts, notably at Bolton; Orange, Lewis, and St. Lawrence Counties, New York. Also found at various points in Ontario, Canada.

Name. From the Greek meaning *a shaft,* in allusion to the prismatic habit of the crystals.

ZEOLITE FAMILY

The zeolites form a large family of hydrous silicates which show close similarities in composition and in their associations and mode of occurrence. They are silicates of aluminum with sodium and calcium as the important bases. They average from $3\frac{1}{2}$ to $5\frac{1}{2}$ in hardness and from 2.0 to 2.4 in specific gravity. Many of them fuse readily with marked intumescence, hence the name *zeolite,* from two Greek words meaning *to boil* and *stone.* They are secondary minerals found characteristically in cavities and veins in basic igneous rocks.

HEULANDITE — $(Ca,Na,K)_6Al_{10}(Al,Si)Si_{29}O_{80}\cdot 25H_2O$

Crystallography. Monoclinic; prismatic, but crystals often simulate orthorhombic symmetry (Fig. 390). Clinopinacoid prominent, often having a diamond shape.

Physical Properties. Perfect cleavage parallel to clinopinacoid {010}. **H.** = $3\frac{1}{2}$–4. **G.** = 2.18–2.2. Luster vitreous, pearly on clinopinacoid. Colorless, white, yellow, red. Transparent to translucent.

Composition. Essentially a hydrous calcium aluminum silicate, $(Ca,Na,K)_6Al_{10}(Al,Si)Si_{29}O_{80}\cdot 25H_2O$. The calcium is usually replaced by small amounts of sodium and potassium.

Tests. Fusible at 3 with intumescence to a white glass. Decomposed by hydrochloric acid with separation of silica. Water in the closed tube.

Diagnostic Features. Characterized by its crystal form and one direction of perfect cleavage with pearly luster.

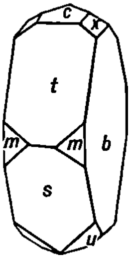


FIG. 390. Heulandite.

Occurrence. Heulandite is a mineral of secondary origin found usually in cavities of basic igneous rocks associated with other zeolites and calcite. Found in notable quality in Iceland; the Faeroe Islands; Andreasberg, Harz Mountains; Tyrol, Austria; British India, near Bombay. In the United States found at West Paterson, New Jersey. Also found in Nova Scotia.

Name. In honor of the English mineral collector, H. Heuland.

STILBITE — $(Ca,Na,K)_3Al_5(Al,Si)Si_{14}O_{40}\cdot 15H_2O$

Crystallography. Monoclinic; prismatic. Uniformly in cruciform (pseudo-orthorhombic) twins. Commonly tabular parallel to clinopinacoid. Crystals usually in distinct individuals or in sheaflike aggregates (Fig. 391).

Physical Properties. Perfect cleavage parallel to clinopinacoid {010}. **H.** = $3\frac{1}{2}$–4. **G.** = 2.1–2.2. Luster vitreous; pearly on clinopinacoid. Color white, more rarely yellow, brown, red. Translucent.

Composition. Essentially a hydrous calcium-sodium aluminum silicate, $(Ca,Na,K)_3Al_5(Al,Si)Si_{14}O_{40}\cdot 15H_2O$. Potassium is usually present in small amounts.

Tests. Fuses with intumescence at 3 to a white enamel. Decomposed by hydrochloric acid with separation of silica but without the formation of a jelly. Water in the closed tube.

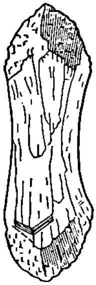


FIG. 391. Stilbite.

Diagnostic Features. Characterized chiefly by its cleavage, pearly luster on the cleavage face, and common sheaflike groups of crystals.

Occurrence. Stilbite is a mineral of secondary origin found in amygdaloidal cavities in basalts and related rocks. Associated with other zeolites and calcite. Notable localities for its occurrence are Poonah, India; Isle of Skye; Faeroe Islands; Kilpatrick, Scotland; Iceland. In the United States found in northeastern New Jersey. Also found in Nova Scotia.

Name. Derived from a Greek word meaning *luster*, in allusion to the pearly luster.

Similar Species. *Phillipsite* and *harmotome* are monoclinic zeolites in the stilbite group with complex and variable composition.

CHABAZITE — $(Ca,Na,K)_7Al_{12}(Al,Si)_2Si_{26}O_{80}\cdot 40H_2O$

Crystallography. Rhombohedral; scalenohedral. Usually in crystals. The common form is the simple rhombohedron $\{10\bar{1}1\}$, having nearly cubic angles. May show several different rhombohedrons (Fig. 392). Often in penetration twins.

Physical Properties. Poor rhombohedral $\{10\bar{1}1\}$ cleavage. **H.** = 4–5. **G.** = 2.05–2.15. Luster vitreous. Color white, yellow, pink, red. Transparent to translucent.

Composition. Essentially a hydrous calcium-sodium aluminum silicate, $(Ca,Na,K)_7Al_{12}(Al,Si)_2Si_{26}O_{80}\cdot 40H_2O$. Potassium is usually present.

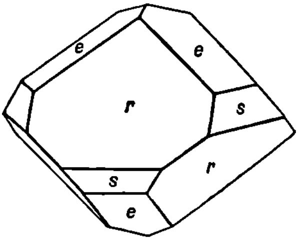


FIG. 392. Chabazite.

Tests. Fuses with swelling at 3 to a blebby glass. Decomposed by hydrochloric acid with the separation of silica but without the formation of a jelly. Solution after filtering off silica gives precipitate of aluminum hydroxide with ammonia, and in filtrate ammonium carbonate gives white precipitate of calcium carbonate. Gives much water in the closed tube.

Diagnostic Features. Recognized usually by its rhombohedral crystals, and distinguished from calcite by its poorer cleavage and lack of effervescence in hydrochloric acid.

Occurrence. Chabazite is a mineral of secondary origin found usually with other zeolites, lining amygdaloidal cavities in basalt. Notable localities for its occurrence are the Faeroe Islands; the Giant's Causeway, Ireland; Aussig, Bohemia; Seiser Alpe, Trentino, Italy; Oberstein, Germany. In the United States found at West Paterson, New Jersey, and Goble Station, Oregon. Also found in Nova Scotia and there known as *acadialite.*

Name. Chabazite is derived from a Greek word which was an ancient name for *a stone.*

Similar Species. *Gmelinite,* $(Na,Ca)_6Al_6(Al,Si)Si_{13}O_{40}{\cdot}20H_2O$, is closely related to chabazite but rarer in occurrence.

NATROLITE — $Na_2Al_2Si_3O_{10}{\cdot}2H_2O$

Crystallography. Monoclinic; sphenoidal. Pseudo-orthorhombic, prismatic, often acicular. Prism zone vertically striated. Some specimens terminated by low pyramid. In some cases in cruciform twins. Usually in radiating crystal groups; also fibrous, massive, granular, or compact.

Physical Properties. Perfect prismatic {110} cleavage. **H.** = 5–5½. **G.** = 2.25. Luster vitreous. Colorless or white. In some cases tinted yellow to red. Transparent to translucent.

Composition. A hydrous sodium aluminum silicate, $Na_2Al_2Si_3O_{10}{\cdot}2H_2O$. The percentages of oxides are: $Na_2O = 16.3$, $Al_2O_3 = 26.8$, $SiO_2 = 47.4$, $H_2O = 9.5$. Potassium may replace sodium with the ratio Na : K = 15 : 1.

Tests. Fusible at 2½ to a clear, transparent glass, giving a yellow (sodium) flame. Water in the closed tube. Soluble in hydrochloric acid and gelatinizes upon evaporation.

Diagnostic Features. Recognized chiefly by its radiating crystals. Distinguished from aragonite by its easy fusibility and water in the closed tube.

Occurrence. Natrolite is a mineral of secondary origin, found lining amygdaloidal cavities in basalt. Associated with other zeolites and calcite. Notable localities for its occurrence are Aussig and Salesel, Bohemia; Puy-de-Dôme, France; Val di Fassa, Trentino, Italy. In the United States found at Bergen Hill, New Jersey. Also found in various places in Nova Scotia.

Name. From the Latin *natrium,* meaning *sodium,* in allusion to its composition.

Similar Species. *Scolecite* (monoclinic), $CaAl_2Si_3O_{10}\cdot 3H_2O$, is a zeolite similar to natrolite.

ANALCIME — $NaAlSi_2O_6\cdot H_2O$

Analcite

Crystallography. Isometric; hexoctahedral. Usually in trapezohedrons (Fig. 393). Cubes with trapezohedral truncations also known (Fig. 394). Usually in crystals, also massive granular.

Physical Properties. **H.** = 5–5½. **G.** = 2.27. Luster vitreous. Colorless or white. Transparent to translucent.

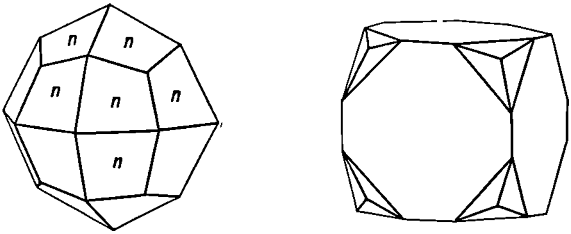


FIG. 393. FIG. 394.

Analcime.

Composition. Hydrous sodium aluminum silicate, $NaAlSi_2O_6\cdot H_2O$. The percentages of oxides are: $Na_2O = 14.1$, $Al_2O_3 = 23.2$, $SiO_2 = 54.5$, $H_2O = 8.2$.

Tests. Fusible at 3½, becoming first a milky white and then a clear glass. Colors the flame yellow (sodium). Decomposed by hydrochloric acid with the separation of silica without the formation of a jelly. Gives water in the closed tube.

Diagnostic Features. Usually recognized by its free-growing crystals and its vitreous luster. Crystals resemble garnet and leucite in form. Distinguished from garnet by inferior hardness and by giving water in the closed tube; from leucite by ease of fusibility, presence of water, and occurrence. (Leucite is always imbedded in rock matrix.)

Occurrence. Analcime is commonly a secondary mineral, formed by the action of hot circulating waters, and is thus found deposited in the cavities of igneous and especially volcanic rocks. Associated with calcite, and various zeolites and related minerals. Also as an original constituent of igneous rocks, as in the analcime basalts. Fine crystals are found in the Cyclopean Islands near Sicily; in the Val di Fassa and on the Seiser Alpe, Trentino, Italy; in Victoria, Australia; Kerguelen Island in the Indian Ocean. In the United States found at Bergen Hill, New Jersey; in the Lake Superior copper district; at Table Mountain, near Golden, Colorado. Also found at Cape Blomidon, Nova Scotia.

Name. Derived from a Greek word meaning *weak,* in allusion to its weak electric property when heated or rubbed.

Similar Species. *Laumontite* is a monoclinic, and *thomsonite* an orthorhombic zeolite associated with other zeolites but much rarer in occurrence.

Cordierite — $Mg_2Al_4Si_5O_{18}$

Iolite. Dichroite

Crystallography. Orthorhombic; dipyramidal. Crystals usually short prismatic pseudohexagonal twins. Also as imbedded grains and massive.

Physical Properties. Pinacoidal cleavage {010} poor. **H.** = 7–7½. **G.** = 2.60–2.66. Luster vitreous. Color different shades of blue. Transparent to translucent. Shows pleochroism.

Composition. A complex silicate of magnesium, and aluminum, $Mg_2Al_4Si_5O_{18}$. Ferrous iron and manganese may replace part of the magnesium, and ferric iron part of the aluminum. Water may also be present.

Tests. Fusible at 5–5½. Only partially attacked by acids.

Diagnostic Features. Cordierite resembles quartz and is distinguished from it with difficulty. Unlike quartz, it is fusible on thin edges. Distinguished from corundum by lower hardness. Pleochroism is characteristic if observed.

Alteration. Most commonly altered to some form of mica, chlorite, or talc and is then various shades of grayish green.

Occurrence. Cordierite is found as an accessory mineral in granite, gneiss (cordierite gneiss), schists, and in contact metamorphic zones. Notable localities for its occurrence are Bavaria, Finland, Greenland, and Madagascar. Gem material has come from Ceylon. In the United States is found chiefly in Connecticut.

Use. Transparent cordierite of good color has been used as a gem known by jewelers as *saphir d'eau.*

Name. After the French geologist P. L. A. Cordier (1777–1861).

Pyrophyllite — $Al_2Si_4O_{10}(OH)_2$

Crystallography. Monoclinic; prismatic. Not observed in distinct crystals. Foliated, in some cases in radiating lamellar aggregates. Also granular to compact. Identical with talc in structure and appearance.

Physical Properties. Perfect basal {001} cleavage. Folia somewhat flexible but not elastic. **H.** = 1–2 (will make a mark on cloth). **G.** = 2.8–2.9. Luster pearly to greasy. Color white, apple-green, gray, brown. Translucent, will transmit light on thin edges.

Composition. Hydrous aluminum silicate, $Al_2Si_4O_{10}(OH)_2$. Al_2O_3 = 28.3 per cent, SiO_2 = 66.7 per cent, H_2O = 5.0 per cent.

Tests. Infusible, but on heating, radiated varieties exfoliate in a fanlike manner. Partly decomposed by sulfuric acid. At high temperature yields water in the closed tube.

Diagnostic Features. Characterized chiefly by its micaceous habit and cleavage, its softness and greasy feel. Distinguished from talc by moistening a small fragment with cobalt nitrate and igniting, when it assumes a blue color (aluminum). Talc under the same conditions becomes pale violet.

Occurrence. Pyrophyllite is a comparatively rare mineral. Found in metamorphic rocks; frequently with kyanite. Occurs in considerable amount in Guilford and Orange Counties, North Carolina.

Use. Quarried in North Carolina and used for the same purposes as talc. It does not command as high a price as the best grades of talc, however. A considerable part of the so-called *agalmatolite,* from which the Chinese carve small images, is this species.

Name. From the Greek meaning *fire* and *a leaf,* since it exfoliates on heating.

KAOLINITE — $Al_2Si_2O_5(OH)_4$

Crystallography. Monoclinic; prismatic. In very minute, thin, rhombic or hexagonal-shaped plates. Usually in claylike masses, either compact or friable.

Physical Properties. Perfect basal {001} cleavage. **H.** = 2–2½. **G.** = 2.6–2.63. Luster usually dull earthy; crystal plates pearly. Color white. Often variously colored by impurities. Usually unctuous and plastic.

Composition. A hydrous aluminum silicate, $Al_2Si_2O_5(OH)_4$. Al_2O_3 = 39.5 per cent, SiO_2 = 46.5 per cent, H_2O = 14.0 per cent.

Tests. Infusible. Insoluble. Assumes a blue color when moistened with cobalt nitrate and ignited (aluminum). Water in the closed tube.

Diagnostic Features. Recognized usually by its claylike character, but without optical tests is impossible to distinguish from the other minerals of similar composition which collectively make up *kaolin.*

Occurrence. Kaolinite is of widespread occurrence. The chief constituent of kaolin or clay. Always a mineral of secondary origin, being derived by the alteration of aluminum silicates, particularly feldspar. It is found mixed with feldspar in rocks that are undergoing alteration; in places it forms entire deposits where such alteration has been carried to completion. As one of the common products of the decomposition of rocks it is found in soils and being transported by water is deposited, mixed with quartz and other materials, in lakes, etc., in the form of beds of clay.

Use. Used in the form of kaolin in making all kinds of pottery, stoneware, and bricks. The finer, purer grades of kaolin are used in the manufacture of porcelain and china.

Name. Kaolinite is derived from *kaolin,* which is a corruption of the Chinese *Kauling,* meaning *high ridge,* the name of a hill near Jauchu Fa, where the material is obtained.

Similar Species. *Dickite, nacrite, halloysite, beidellite,* and *montmorillonite* are clay minerals similar in chemical composition and in physical properties to kaolinite.

TALC — $Mg_3Si_4O_{10}(OH)_2$

Steatite. Soapstone

Crystallography. Monoclinic; prismatic. Crystals rare. Usually tabular with rhombic or hexagonal outline. Foliated massive; in some cases in radiating foliated groups. Also compact.

Physical Properties. Perfect basal {001} cleavage. Thin folia somewhat flexible but not elastic. Sectile. **H.** = 1 (will make a mark on cloth). **G.** = 2.7–2.8. Luster pearly to greasy. Color apple-green, gray, white, or silver-white; in soapstone often dark gray or green. Translucent. Greasy feel.

Composition. A hydrous magnesium silicate, $Mg_3Si_4O_{10}(OH)_2$. $MgO = 31.7$ per cent, $SiO_2 = 63.5$ per cent, $H_2O = 4.8$ per cent. Small amounts of nickel may be present.

Tests. Difficultly fusible (5). Unattacked by acids. Yields water in the closed tube when heated intensely. Moistened with cobalt nitrate and ignited assumes a pale violet color.

Diagnostic Features. Characterized by its micaceous habit and cleavage, by its softness and greasy feel. To be distinguished from pyrophyllite by moistening a fragment with cobalt nitrate and heating intensely; talc will assume a pale violet color, pyrophyllite a blue color.

Occurrence. Talc is a mineral of secondary origin formed by the alteration of magnesium silicates, such as olivine, pyroxenes, and amphiboles, and may be found as pseudomorphs after these minerals. Found in the igneous rocks, because of the alteration of such silicates, especially in peridotites and pyroxenites. Most characteristically found, however, in the metamorphic rocks, where, in the granular to cryptocrystalline form known as *soapstone*, it may make up nearly the entire rock mass. It may also occur as a prominent constituent in the schistose rocks, as in talc-schist.

In the United States, talc or soapstone quarries are located chiefly along the line of the Appalachian Mountains, the mineral being produced in Vermont, Massachusetts, Rhode Island, New York, New Jersey, Pennsylvania, Maryland, Virginia, North Carolina, and Georgia. Important deposits are located in St. Lawrence County, New York, where the talc occurs in the form of beds of schist interstratified with limestones. It is associated here with tremolite and enstatite, from masses of which it has evidently been derived. Large deposits of soapstone occur in Virginia in a narrow belt running from Nelson County northeast into Albermarle County. It occurs here in sheets 100 or more feet in thickness. In Vermont, a long series of talc and soapstone deposits is located along the east side of the Green Mountains. Talc has been mined in considerable quantity in Swain County, North Carolina; also in California.

Use. Large amounts of talc in the powdered form are used in the paint, ceramic, roofing, paper, and rubber industries. Used also as talcum powder, tailor's chalk, and slate pencils. A small percentage of the talc produced is sawed and used as table tops, wash tubs, sinks, etc. (See page 384.)

Name. The name talc is of ancient and doubtful origin, probably derived from the Arabic, *talk*.

Sepiolite — $Mg_2Si_3O_8 \cdot 2H_2O$

Meerschaum

Crystallography. Crystal system uncertain, probably monoclinic. Microscopically is seen to be a mixture of fine fibrous material and an amorphous substance of apparently the same composition. Fine textured and compact.

Physical Properties. **H.** = 2–2½. **G.** = 2.0. Conchoidal fracture. When dry floats on water because of porosity. Luster earthy. Color grayish white, white, or with yellowish or reddish tinge. Smooth feel. Translucent.

Composition. Hydrous magnesium silicate, $Mg_2Si_3O_8 \cdot 2H_2O$. $MgO = 27.1$ per cent, $SiO_2 = 60.8$ per cent, $H_2O = 12.1$ per cent.

Tests. Fusible at 5–5½. Yields much water in the closed tube at high temperature and gives a burnt odor. Decomposed with hydrochloric acid with separation of silica.

Diagnostic Features. Characterized by its smooth feel, compact nature, and low specific gravity.

Occurrence. Sepiolite is found as a secondary mineral in nodular masses associated with serpentine; also with magnesite and opal. Occurs in Asia Minor in stratified earthy or alluvial deposits near Eski-Shehr. Also found in Greece, Czechoslovakia, Spain, and Morocco. In the United States has been found in Pennsylvania, Utah, New Mexico, and California.

Use. Chief use is in the manufacture of meerschaum pipes.

Name. From the Greek word meaning *cuttlefish,* the bone of which is light and porous.

SERPENTINE — $Mg_3Si_2O_5(OH)_4$

Crystallography. Monoclinic; prismatic. Crystals, except as pseudomorphs, unknown. Serpentine occurs in two distinct habits: a platy variety, known as *antigorite,* and a fibrous variety, known as *chrysotile* (Plate XVII). The two are apparently different structurally and may be dimorphic forms.

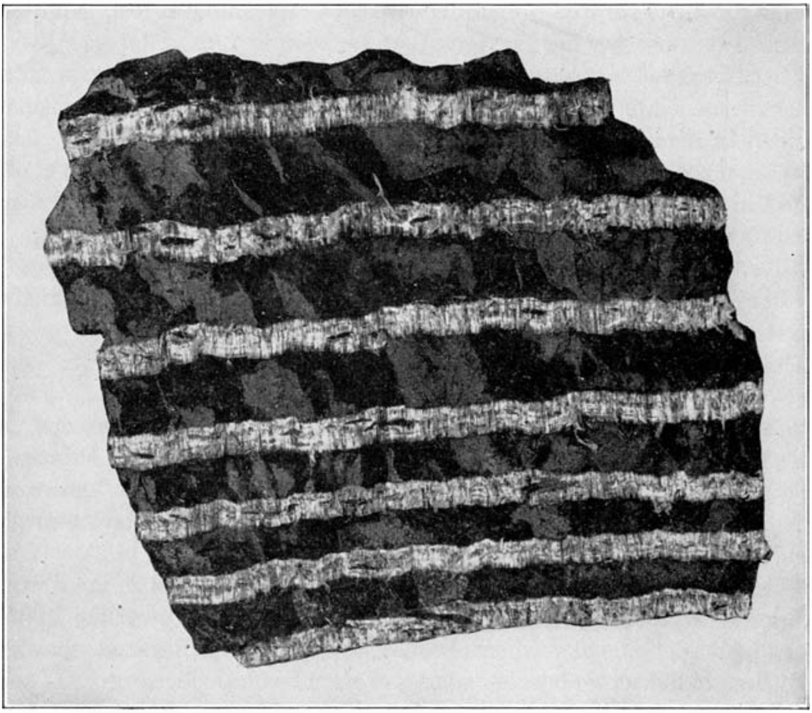
Physical Properties. **H.** = 2–5, usually 4. **G.** = 2.2 in fibrous varieties to 2.65 in massive varieties. Luster greasy, waxlike in the massive varieties, silky when fibrous. Color often variegated, showing mottling in lighter and darker shades of green. Translucent.

Composition. A hydrous magnesium silicate, $Mg_3Si_2O_5(OH)_4$. $MgO = 43.0$ per cent, $SiO_2 = 44.1$ per cent, $H_2O = 12.9$ per cent. Ferrous iron and nickel may be present in small amount.

Tests. Infusible. Decomposed by hydrochloric acid with the separation of silica but without the formation of a jelly. Filtered solution, after having any iron precipitated by ammonium hydroxide, gives a precipitate of ammonium-magnesium phosphate with sodium phosphate. Water in the closed tube.

Diagnostic Features. Recognized by its variegated green color and its greasy luster or by its fibrous nature. Distinguished from fibrous amphibole by the presence of water.

Occurrence. Serpentine is a common mineral and widely distributed; always as an alteration product of some magnesium silicate, especially olivine, pyroxene, amphibole. Frequently associated with magnesite, chromite. Found in both igneous and metamorphic rocks, frequently in disseminated particles, in places in such quantity as to make up practically the entire rock-mass. Serpentine, as a rock name, is applied to such rock-masses made up mostly of the variety antigorite. Large deposits of the fibrous variety, chrysotile, are located in the Province of Quebec, Canada; in the Ural Mountains, U.S.S.R.; and in South Africa. In the United States chrysotile is found in Vermont; New York; New Jersey; in Arizona near Globe from the Sierra Ancha, and in the Grand Canyon.



Veins of Chrysotile Asbestos in Serpentine, Thetford, Quebec.

PLATE XVII

Use. The variety *chrysotile* is the chief source of asbestos. Fibrous amphibole is also used for the same purposes. The uses of asbestos depend upon its fibrous, flexible nature, which allows it to be made into felt and woven into cloth and other fabrics; and upon its incombustibility and slow conductivity of heat. Asbestos products, therefore, are used for fireproofing and as an insulation material against heat and electricity. The massive mineral, which is translucent and of a light to dark green color, is often used as an ornamental stone and may be valuable as building material. Mixed with white marble and showing beautiful variegated coloring, is called *verd antique* marble.

Name. The name refers to the green serpent-like cloudings of the massive variety.

GARNIERITE — $(Ni,Mg)SiO_3 \cdot nH_2O$

Crystallography. Apparently amorphous. Found as incrustations and earthy masses.

Physical Properties. **H.** = 2–3. **G.** = 2.2–2.8. Luster earthy and dull. Color apple-green to white.

Composition. A hydrous nickel-magnesium silicate, $(Ni,Mg)SiO_3 \cdot nH_2O$.

Tests. Infusible, but becomes magnetic on heating. Difficultly decomposed by hydrochloric acid, giving separated silica. In the oxidizing flame colors the borax bead brown. In the closed tube blackens and gives water.

Diagnostic Features. Characterized by its apple-green color, earthy luster, and lack of crystal structure.

Occurrence. Garnierite is a mineral of secondary origin associated with serpentine, and probably an alteration product of nickel-bearing peridotites. Found in considerable amount, associated with serpentine and chromite, near Noumea, New Caledonia. Also in the Transvaal, South Africa, and Madagascar. In the United States found at Riddle, Oregon, and Webster, North Carolina.

Use. An ore of nickel.

Name. In honor of Jules Garnier, discoverer of the mineral.

APOPHYLLITE — $Ca_4K(Si_4O_{10})_2F \cdot 8H_2O$

Crystallography. Tetragonal; ditetragonal-dipyramidal. Usually in crystals showing a combination of prism of second order {010}, dipyramid of first order {111}, and basal plane {001} (Figs. 395 and 396). Small faces of a ditetragonal prism are occasionally observed (Fig. 397). Crystals may resemble an isometric combination of cube and octahedron, but are shown to be tetragonal by difference in luster between faces of prism and base.

Physical Properties. Perfect basal {001} cleavage. **H.** = $4\frac{1}{2}$–5. **G.** = 2.3–2.4. Luster of base pearly, other faces vitreous. Usually colorless, white, or grayish; may show pale shades of green, yellow, rose. Transparent to translucent.

Composition. A hydrous calcium potassium fluosilicate, $Ca_4K(Si_4O_{10})_2F \cdot 8H_2O$.

Tests. Fusible at 2, with swelling, forms a white vesicular enamel. Colors the flame pale violet (potassium). Yields much water in the closed tube. Decomposed by hydrochloric acid with separation of silica but without the formation of a jelly. Solution gives little or no precipitate with ammonia but gives an abundant white precipitate with ammonium oxalate or ammonium carbonate (calcium).

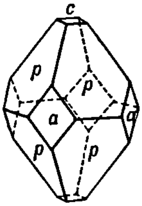


Fig. 395.

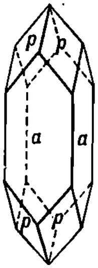


Fig. 396.

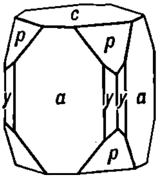


Fig. 397.

Apophyllite.

Diagnostic Features. Recognized usually by its crystals, color, luster, and basal cleavage.

Occurrence. Apophyllite occurs commonly as a secondary mineral lining cavities in basalt and related rocks. Associated with various zeolites, calcite, datolite, pectolite.

It is found in fine crystals at Andreasberg, Harz Mountains; Aussig, Bohemia; on the Seiser Alpe in Trentino, Italy; near Bombay, India; Faeroe Islands; Iceland; Greenland; Guanajuato, Mexico. In the United States at Bergen Hill and Paterson, New Jersey; Lake Superior copper district. Found in fine crystals in Nova Scotia.

Name. Apophyllite is named from two Greek words meaning *from* and *a leaf*, because of its tendency to exfoliate when ignited.

CHLORITE GROUP

A number of minerals are included in the chlorite group all of which have similar chemical, crystallographic, and physical properties. Without quantitative chemical analyses or careful study of the optical properties, it is extremely difficult to distinguish between the members. The following is a composite description of the principal members of the group: *clinochlore*, *penninite*, and *prochlorite*.

CHLORITE — $(Mg,Fe)_5(Al,Fe''')_2Si_3O_{10}(OH)_8$*

Crystallography. Monoclinic; prismatic. In pseudohexagonal tabular crystals, with prominent basal planes. Similar in habit to the crystals of the mica group, but distinct crystals rare. Usually foliated massive or in aggregates of minute scales; also in finely disseminated particles.

Physical Properties. Perfect basal {001} cleavage. Folia flexible but not elastic. **H.** = 2–2½. **G.** = 2.6–2.9. Luster vitreous to pearly. Color green of various shades. Rarely pale green, yellow, white, rose-red. Transparent to translucent.

Composition. Hydrous iron-magnesium aluminum silicate. $Mg_5Al_2Si_3O_{10}(OH)_8$ is the formula for clinochlore. Ferrous iron may be present. Penninite is essentially the same; prochlorite has less silicon and usually contains iron.

Tests. Difficultly fusible (5–5½). Unattacked by hydrochloric acid. Decomposed by boiling concentrated sulfuric acid, giving a milky solution. Water in the closed tube at high temperature.

Diagnostic Features. Characterized by its green color, micaceous habit and cleavage, and by the fact that the folia are not elastic.

Occurrence. Chlorite is a common and widespread mineral, usually of secondary origin. It results from the alteration of silicates containing aluminum, ferrous iron, and magnesium, such as pyroxenes, amphiboles, biotite, garnet, idocrase. To be found where rocks containing such minerals have undergone metamorphic change. Some schists are composed almost entirely of chlorite. The green color of many igneous rocks is due to the chlorite into which the ferromagnesian silicates have altered. The green color of many schists and slates is due to finely disseminated particles of the mineral.

Name. Chlorite is derived from a Greek word meaning *green,* in allusion to the common color of the mineral.

Margarite — $CaAl_4Si_2O_{10}(OH)_2$

Crystallography. Monoclinic; prismatic. Seldom in distinct crystals. Usually in foliated aggregates with micaceous habit.

Physical Properties. Perfect basal {001} cleavage. **H.** = 3½–5 (harder than the true micas). **G.** = 3.0–3.1. Luster vitreous to pearly. Color pink, white, and gray. Translucent. Folia somewhat brittle. Because of this brittleness margarite is known as a *brittle mica.*

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* The more general formula may be written: $(Mg,Fe)_{6-p}(Al,Fe''')_{2p}Si_{4-p}O_{10}(OH)_8$.

Composition. Essentially a hydrous calcium aluminum silicate, $CaAl_4Si_2O_{10}(OH)_2$. Percentages of oxides are: $CaO = 14.0$, $Al_2O_3 = 51.3$, $SiO_2 = 30.2$, $H_2O = 4.5$.

Tests. Fuses at 4–4½, turning white. Slowly and incompletely decomposed by boiling hydrochloric acid.

Diagnostic Features. Characterized by its micaceous cleavage, brittleness, and association with corundum.

Occurrence. Margarite occurs usually with corundum and apparently as one of its alteration products. It is found in this way with the emery deposits of Asia Minor; on the islands Naxos and Nicaria, of the Grecian Archipelago. In the United States associated with emery at Chester, Massachusetts; Chester County, Pennsylvania; with corundum deposits in North Carolina.

Name. From the Greek meaning *pearl.*

Similar Species. Several minerals similar to margarite in physical and chemical properties are included under the general heading of *brittle micas.* Aside from margarite, *ottrelite* and *chloritoid* are the most important members of the group.

PREHNITE — $Ca_2Al_2Si_3O_{10}(OH)_2$

Crystallography. Orthorhombic. Distinct crystals rare, commonly tabular parallel to the base {001}. Usually reniform, stalactitic, and in rounded groups of tabular crystals.

Physical Properties. **H.** = 6–6½. **G.** = 2.8–2.95. Luster vitreous. Color usually light green, passing into white. Translucent.

Composition. Hydrous calcium aluminum silicate, $Ca_2Al_2Si_3O_{10}(OH)_2$. Percentages of oxides: $CaO = 27.1$, $Al_2O_3 = 24.8$, $SiO_2 = 43.7$, $H_2O = 4.4$. Some iron may replace aluminum.

Tests. Fuses at 2½ with intumescence to a white enamel. Yields water in the closed tube. Slowly acted upon by hydrochloric acid but gelatinizes after simple fusion.

Diagnostic Features. Characterized by its green color and crystalline aggregates forming reniform surfaces. Resembles hemimorphite but is of lower specific gravity and fuses easily. Ease of fusion also distinguishes it from quartz and beryl.

Occurrence. Prehnite occurs as a mineral of secondary origin lining amygdaloidal cavities in basalt and related rocks. Associated with zeolites, datolite, pectolite, calcite. In the United States occurs at Farmington, Connecticut; Paterson and Bergen Hill, New Jersey; Somerville, Massachusetts; Lake Superior copper district. Found in good crystals at Coopersburg, Pennsylvania.

Name. In honor of Colonel Prehn, who brought the mineral from the Cape of Good Hope.

MICA GROUP

The micas form a series of complex aluminum silicates with potassium and hydroxyl, often also magnesium, ferrous iron, and in some varieties, sodium, lithium, ferric iron. More rarely manganese, chromium, barium, fluorine, and titanium are present in small amounts. The composition of many of the micas is not definitely understood, and the formulas assigned to them are only approximate.

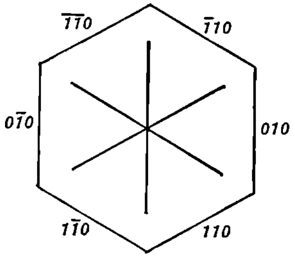

Fig. 398. Percussion Figure in Mica.

They crystallize in the monoclinic system but with inclination of the *a* axis practically 90°, so that their monoclinic symmetry is not clearly seen. The crystals are usually tabular with prominent basal planes, and have either a diamond-shaped or hexagonal outline with angles of approximately 60° and 120°. The crystals, as a rule, therefore, appear to be either orthorhombic or hexagonal in their symmetry. They are all characterized by a very perfect basal {001} cleavage. A blow with a somewhat dull-pointed instrument on a cleavage plate of mica develops in all the species a six-rayed *percussion figure* (Fig. 398), two lines of which are nearly parallel to the prismatic edges; the third, which is the most strongly developed, is parallel to the clinopinacoid or plane of symmetry.

The micas form incomplete isomorphous series, with various gradations between the different members. Two members of the group frequently crystallize together in parallel position in the same crystal plate. Biotite occurs crystallizing in this way with muscovite, and muscovite with lepidolite, etc.

MUSCOVITE — $KAl_3Si_3O_{10}(OH)_2$

White Mica. Common Mica. Potash Mica

Crystallography. Monoclinic; prismatic. The β angle is nearly 90°. Distinct crystals comparatively rare. Occurs in tabular crystals with prominent base. The presence of prism faces {110} having angles of nearly 60° with each other gives some plates a diamond-shaped outline, making them simulate orthorhombic symmetry. If the clinopinacoid faces are also present, the crystals have hexagonal outline with apparently hexagonal symmetry. The prism faces are roughened by horizontal striations and frequently taper. Foliated in large to small sheets; in scales which are in some cases aggregated into plumose or globular forms. Also cryptocrystalline and compact massive.

Physical Properties. Extremely perfect cleavage parallel to base {001}, allowing the mineral to be split into excessively thin sheets. Folia very flexible and elastic. **H.** = 2–2½. **G.** = 2.76–3.1. Luster vitreous to silky or pearly. Transparent and colorless in thin sheets. In thicker blocks translucent, with light shades of yellow, brown, green, red. Some crystals allow more light to pass in a direction perpendicular to the prism zone than in a direction perpendicular to the base.

Composition. Essentially $KAl_3Si_3O_{10}(OH)_2$. Frequently contains small amounts of ferrous and ferric iron, magnesium, calcium, sodium, lithium, fluorine, titanium.

Tests. Fusible at 5. Not decomposed by acids. Water in the closed tube.

Diagnostic Features. Characterized by its highly perfect cleavage and light color. Distinguished from phlogopite by not being decomposed in sulfuric acid and from lepidolite by not giving a crimson flame.

Occurrence. Muscovite is a widespread and very common rock-forming mineral. Characteristic of deep-seated siliceous igneous rocks as granite and syenite. Especially characteristic of pegmatite dikes, and found lining cavities in granites, where it has evidently been formed by the action of mineralizing vapors during the last stages of the formation of the rock. Also very common in metamorphic rocks, as gneiss and schist, forming the chief constituent in certain mica-schists. In some schistose rocks it occurs in the form of fibrous aggregates of minute scales which have a silky luster, but which do not show plainly the true nature of the mineral. This variety, known as *sericite*, is usually the product of alteration of feldspar. Muscovite also originates as the alteration product of several other minerals, as topaz, kyanite, spodumene, andalusite, scapolite. *Pinite* is a name given to the micaceous alteration product of various minerals, which corresponds in composition more or less closely to muscovite.

In the pegmatite dikes, muscovite occurs associated with quartz and feldspar, with tourmaline, beryl, garnet, apatite, and fluorite. It is found often in these veins in large crystals, called books, which in some localities are several feet across.

Several notable localities for muscovite are found in the Alps; also Mourne Mountains, Ireland; Cornwall, England; Norway; Sweden. Large and important deposits occur in India. Muscovite is found in the United States in commercial deposits chiefly in the Appalachian and

Rocky Mountain regions. The most productive pegmatite dikes occur in New Hampshire, in North Carolina, and in the Black Hills of South Dakota. Of less importance are the deposits in Colorado, Alabama, and Virginia. Muscovite has been mined in Maine and Connecticut.

Use. Used chiefly as an insulating material in the manufacture of electrical apparatus. Many of the small parts used for electrical insulation are built up of thin sheets of mica cemented together. They may thus be pressed into shape before the cement hardens. Most of the mica used for this purpose in the United States is imported from India. Used as a transparent material, *isinglass,* for stove doors, lanterns, etc. Scrap mica, or the waste material in the manufacture of sheet mica, is used in many ways, as in the manufacture of wall papers to give them a shiny luster; as a lubricant when mixed with oils; as a nonconductor of heat; and as a fireproofing material.

Name. *Muscovite* was so called from the popular name of the mineral, *Muscovy-glass,* because of its use as a substitute for glass in old Russia (Muscovy). *Mica* was probably derived from the Latin *micare,* meaning *to shine.*

BIOTITE — $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$

Crystallography. Monoclinic; prismatic. In tabular or short prismatic crystals with prominent basal planes. Crystals rare, frequently pseudorhombohedral. Usually in irregular foliated masses; often in disseminated scales or in scaly aggregates.

Physical Properties. Perfect basal {001} cleavage. Folia flexible and elastic. **H.** = $2\frac{1}{2}$–3. **G.** = 2.8–3.2. Luster splendent. Color usually dark green, brown to black. More rarely light yellow. Thin sheets usually have a smoky color (differing from the almost colorless muscovite).

Composition. A potassium magnesium-iron-aluminum silicate, essentially $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$.

Tests. Difficultly fusible at 5. Unattacked by hydrochloric acid. Decomposed by boiling concentrated sulfuric acid, giving a milky solution. Gives water in the closed tube.

Diagnostic Features. Characterized by its micaceous cleavage and dark color.

Occurrence. Biotite is an important and widely distributed rock-forming mineral. Occurs in igneous rocks, especially those in which feldspar is prominent, such as granite and syenite, but occurs in a greater variety of rocks than muscovite. In some cases found in pegmatite veins in large sheets. Found also in many felsite lavas and porphyries. Less common in the ferromagnesian rocks. Is also present in some gneisses and schists often associated with muscovite. Occurs in fine crystals in blocks included in the lavas of Vesuvius.

Name. In honor of the French physicist, J. B. Biot.

Similar Species. *Glauconite,* commonly found in green pellets in sedimentary deposits, is similar in composition to biotite.

Phlogopite — $KMg_2Al_2Si_3O_{10}(OH)_2$

Crystallography. Monoclinic; prismatic. Usually in six-sided plates or in tapering prismatic crystals. Crystals frequently large and coarse. Found also in foliated masses.

Physical Properties. Perfect basal {001} cleavage. Folia flexible and elastic. **H.** = 2½–3. **G.** = 2.86. Luster vitreous to pearly. Color yellowish brown, green, white, often with copper-like reflections from the cleavage surface. Transparent in thin sheets. When viewed in transmitted light, most phlogopite shows a starlike effect known as asterism.

Composition. A hydrous potassium magnesium aluminum silicate, $KMg_2Al_2Si_3O_{10}(OH)_2$. Usually contains about 3 per cent of fluorine and some iron.

Tests. Fusible at 4½–5. Insoluble in hydrochloric acid. Decomposed by boiling concentrated sulfuric acid, giving a milky solution. Yields water in the closed tube.

Diagnostic Features. Characterized by its micaceous cleavage and yellowish brown color. Distinguished from muscovite by its decomposition in sulfuric acid and from biotite by its lighter color. But it is impossible to draw a sharp distinction between biotite and phlogopite.

Occurrence. Phlogopite occurs as a product of metamorphism in crystalline magnesium limestones or dolomitic marbles and is also found in serpentine. Rarely found in igneous rocks. Notable localities are in Finland; Sweden; Campolungo, Switzerland; Ceylon; Madagascar. In the United States found chiefly in Jefferson and St. Lawrence Counties, New York. Found abundantly in Canada in Ontario at North and South Burgess, and in various other localities in Ontario and Quebec.

Use. Same as for muscovite; chiefly as electrical insulator.

Name. Named from a Greek word meaning *firelike,* in allusion to its color.

LEPIDOLITE — $K_2Li_3Al_4Si_7O_{21}(OH,F)_3$

Lithia Mica

Crystallography. Monoclinic; prismatic. Crystals usually in small plates or prisms with hexagonal outline. Commonly in coarse- to fine-grained scaly aggregates.

Physical Properties. Perfect basal {001} cleavage. **H.** = $2\frac{1}{2}$–4. **G.** = 2.8–3.0. Luster pearly. Color pink and lilac to grayish white. Translucent.

Composition. A fluosilicate of potassium, lithium, aluminum, $K_2Li_3Al_4Si_7O_{21}(OH,F)_3$. Magnesium may be present.

Tests. Fusible at 2, giving a crimson flame (lithium). Insoluble in acids. Gives acid water in the closed tube.

Diagnostic Features. Characterized chiefly by its micaceous cleavage and usually by its lilac to pink color. Muscovite may be pink, or lepidolite white, and therefore a flame test should be made to distinguish the two.

Occurrence. Lepidolite is a comparatively rare mineral, found in pegmatite dikes, usually associated with other lithium-bearing minerals such as pink and green tourmaline, amblygonite, spodumene. Often intergrown with muscovite in parallel position. Notable foreign localities for its occurrence are the Ural Mountains, U.S.S.R.; Isle of Elba; Rožna, Moravia; Madagascar. In the United States is found in western Maine at Hebron, Auburn, Norway, Paris, Rumford; near Middletown, Connecticut; Pala, San Diego County, California.

Use. A source of lithium compounds.

Name. Derived from a Greek word meaning *scale*.

AMPHIBOLE GROUP

The minerals of the amphibole group crystallize in the orthorhombic, monoclinic, and triclinic systems, but the crystals of the different species are closely similar in many respects. Chemically they form a group parallel to the pyroxene group (page 319), being silicates with calcium, magnesium, and ferrous iron as important bases, and also with manganese and the alkalis. The amphiboles, however, contain hydroxyl. Certain molecules that are present in some varieties contain aluminum and ferric iron. The amphiboles and pyroxenes closely resemble one another and are distinguished by cleavage. The prismatic cleavage angle of amphiboles is about 56° and 124° (Fig. 399), while the pyroxene cleavage angle is about 87° and 93° (Fig. 402).

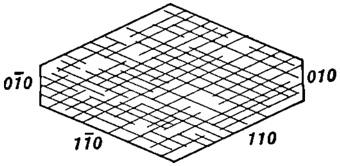

Fig. 399. Amphibole Cleavage.

Anthophyllite — $(Mg,Fe)_7Si_8O_{22}(OH)_2$

Crystallography. Orthorhombic, corresponding to the orthorhombic pyroxene group, enstatite-hypersthene. Rarely in distinct crystals. Commonly lamellar or fibrous.

Physical Properties. Perfect prismatic {110} cleavage. **H.** = 5½–6. **G.** = 2.85–3.2. Color gray to various shades of green and brown. Luster vitreous. Translucent.

Composition. Magnesium-iron silicate, $(Mg,Fe)_7Si_8O_{22}(OH)_2$. *Gedrite* is a variety in which aluminum is present in considerable amount.

Tests. Fusible at 5 to a black magnetic enamel. Insoluble in acids. Yields water in the closed tube.

Diagnostic Features. Characterized by its clove-brown color but unless in crystals cannot be distinguished from other amphiboles without optical tests.

Occurrence. Anthophyllite is a comparatively rare mineral, occurring in the crystalline schists and thought to have been derived from the metamorphism of olivine. Occurs at Kongsberg, Norway; in many localities in southern Greenland. In the United States is found at several localities in Pennsylvania and at Franklin, North Carolina.

Name. From the Latin *anthophyllum,* meaning *clove,* in allusion to the clove-brown color.

Similar Species. *Cummingtonite,* a monoclinic amphibole, has the same composition as anthophyllite but is usually relatively higher in iron.

TREMOLITE — $Ca_2Mg_5Si_8O_{22}(OH)_2$

Crystallography. Monoclinic; prismatic. Crystals prismatic in habit; the prism faces make angles of 56° and 124° with each other. The termination of the crystals is almost always formed by the two faces of a low clinodome (Figs. 400 and 401). Tremolite is often bladed and frequently in radiating columnar aggregates. In some cases in silky fibers. Coarse to fine granular. Compact.

Physical Properties. Perfect prismatic {110} cleavage at an angle of 56°, often yielding a splintery surface. **H.** = 5–6. **G.** = 3.0–3.3. Luster vitreous. Often with silky sheen in the prism zone. Color varying from white to light green in actinolite (see under Composition). Color deepens with increase in the amount of iron present. Transparent to translucent. A tough compact variety which supplies much of the material known as *jade* is called *nephrite* (see also under *Jadeite*).

Composition. Tremolite, $Ca_2Mg_5Si_8O_{22}(OH)_2$, is an end member of an isomorphous series. Iron may replace magnesium in part, and when present in amounts greater than 2 per cent, the mineral is called *actinolite.*

Tests. Fusible at 3–4. After decomposition with sodium carbonate, will give tests for calcium and magnesium. Yields water in the closed tube.

Diagnostic Features. Characterized by slender prisms and good prismatic cleavage. Distinguished from pyroxenes by the cleavage angle and from hornblende by lighter color.

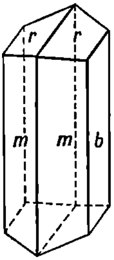

FIG. 400.

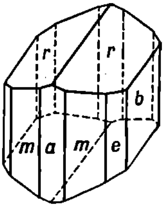

FIG. 401.

Tremolite.

Occurrence. Tremolite is most frequently found in impure, crystalline, dolomitic limestones where it has formed on the recrystallization of the rock during metamorphism. It is also found in talc schists. Actinolite commonly occurs in the crystalline schists, being often the chief constituent of green-colored schists and greenstones. Frequently the actinolite of such rocks has had its origin in the pyroxene contained in the igneous rock from which the metamorphic type has been derived.

Notable localities for crystals of tremolite are: Ticino, Switzerland; in the Tyrol; in Piedmont, Italy. In the United States from Russell, Gouverneur, Amity, Pierrepont, DeKalb, and Edwards, New York. Crystals of actinolite are found at Greiner, Zillerthal, Tyrol. Actinolite frequently is fibrous, and is the material to which the name *asbestos* was originally given. The asbestos form of actinolite has been found in the metamorphic rocks in various states along the Appalachian Mountains. A famous locality for nephrite is in the Kuen Lun Mountains, on the southern border of Turkestan.

Use. The fibrous variety is used to some extent as asbestos material. The fibrous variety of serpentine furnishes more and usually a better grade of asbestos. The compact variety nephrite is used largely for ornamental material by oriental peoples.

Names. Tremolite is derived from the Tremola Valley near St. Gothard, Switzerland. Actinolite comes from two Greek words meaning *a ray* and *stone,* in allusion to its frequently somewhat radiated habit.

HORNBLENDE

Crystallography. Monoclinic; prismatic. Crystals prismatic, usually terminated by the clinodome {011}. The prism zone shows, in addition to the prism faces, usually those of the clinopinacoid {010}, and more rarely those of the orthopinacoid {100}. May be columnar or fibrous; coarse to fine-grained.

Physical Properties. Perfect prismatic {110} cleavage, at angles of 56° and 124°. **H.** = 5–6. **G.** = 3.2. Luster vitreous; fibrous varieties often silky. Color various shades of dark green to black. Translucent; will transmit light on thin edges.

Composition. What passes under the name of hornblende is in reality a complex isomorphous series that varies with respect to the ratios of Ca : Na, Mg : Fe″, Al : Fe‴, Al : Si, and OH : F. A generalized formula for common hornblende is: $Ca_2Na(Mg,Fe'')_4(Al,Fe''',Ti)_3Si_6O_{22}(O,OH)_2$. The presence of aluminum in hornblende is the principal chemical difference between it and tremolite.

Tests. Fusible at 4. Yields water in the closed tube.

Diagnostic Features. Crystal form and cleavage angle serve to distinguish hornblende from dark pyroxenes. Usually distinguished from other amphiboles by its dark color.

Occurrence. Hornblende is an important and widely distributed rock-forming mineral, occurring in both igneous and metamorphic rocks; it is particularly characteristic of the latter. It characteristically alters from pyroxene both during the late magmatic stages of crystallization of igneous rocks and during metamorphism. The latter type is frequently called *uralitic hornblende* or *uralite.* Hornblende is the chief constituent of the rock, *amphibolite.*

Name. From an old German word for any dark prismatic mineral occurring in ores but containing no metal.

Similar Species. Because of the variation in the hornblende series, many names have been proposed for members on the basis of chemical composition and physical and optical properties. The most common names on the basis of chemical composition are: *edenite, pargasite, hastingsite, kaersutite.*

Arfvedsonite — $Na_3Mg_4AlSi_8O_{22}(OH,F)_2$

Crystallography. Monoclinic; prismatic. Crystals long prismatic, often tabular parallel to the clinopinacoid {010}. Found in prismatic aggregates as well as in isolated crystals.

Physical Properties. Perfect prismatic {110} cleavage at angles of 56° and 124°. **H.** = 6. **G.** = 3.45. Luster vitreous. Color deep green to black. Translucent, will transmit light only on thin edges.

Composition. A sodium-rich member of the hornblende series, $Na_3Mg_4AlSi_8O_{22}(OH,F)_2$. Iron and calcium may also be present.

Tests. Fusible at 2 with intumescence to a black magnetic globule. Colors flame yellow (sodium). Insoluble in acid.

Diagnostic Features. Characterized by its dark green to black color and its presence in igneous rocks poor in silica. More easily fusible than hornblende and actinolite.

Occurrence. Arfvedsonite and other sodium-rich amphiboles are rock-forming minerals of igneous rocks poor in silica, such as nepheline syenites. Large crystals are found in pegmatite dikes associated with such rocks as in the Julianehaab district of southern Greenland. Also occurs in the nepheline syenites and related rocks near Oslo, Norway, and on the Kola Peninsula, U.S.S.R.

Name. In honor of the Swedish chemist, Prof. J. A. Arfvedson.

Similar Species. *Holmquistite*, *glaucophane*, and *riebeckite* are other sodium-rich members of the hornblende series.

PYROXENE GROUP

The pyroxene group includes a number of species which crystallize in the orthorhombic and monoclinic systems and yet are closely related in crystal form. They all have prismatic cleavage that makes angles of about 87° and 93° (Fig. 402). (Compare with amphibole, Fig. 399, page 315.) The pyroxenes form a series in which members are closely analogous chemically to the members of the amphibole group. The following species are here described as members of the pyroxene group:

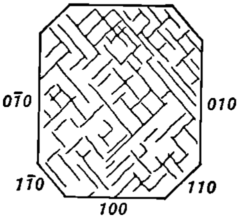

Fig. 402. Pyroxene Cleavage.

- Enstatite
- Diopside
- Augite
- Jadeite
- Aegirite
- Spodumene

ENSTATITE — $MgSiO_3$

Crystallography. Orthorhombic; dipyramidal. Prismatic habit, crystals rare. Usually massive, fibrous, or lamellar.

Physical Properties. Good prismatic {110} cleavage at angles of 87° and 93°. H. = $5\frac{1}{2}$. G. = 3.2–3.5. Luster vitreous to pearly on cleavage surfaces; a variety with a submetallic, bronzelike luster is known as *bronzite*. Color grayish, yellowish, or greenish white to olive-green and brown. Translucent.

Composition. Magnesium silicate, $MgSiO_3$. $MgO = 40.0$ per cent, $SiO_2 = 60.0$ per cent. Rarely pure, usually contains some iron. Iron may replace magnesium in all proportions until the ratio of Mg : Fe = 1 : 1, and thus there exists an isomorphous series. When the amount of FeO exceeds 15 per cent the mineral is called *hypersthene;* the variety *bronzite* is an iron-bearing enstatite. Aluminum may also be present in amounts up to 10 per cent.

Tests. Almost infusible; thin edges will become slightly rounded. Fuses more easily with increasing amounts of iron. Insoluble in acid when pure. Hypersthene decomposed by hydrochloric acid.

Diagnostic Features. Usually recognized by its color and unusual luster. Varieties high in iron are black and difficult to distinguish from augite without optical tests.

Occurrence. Enstatite is common in pyroxenites, peridotites, gabbros, norites, and basalts, and is thus a widespread mineral. A common mineral in both metallic and stony meteorites.

Enstatite is found in the United States at the Tilly Foster Mine, Brewster, New York, and at Edwards, St. Lawrence County, New York. At Texas, Pennsylvania; Bare Hills, near Baltimore, Maryland; Webster, North Carolina. Hypersthene occurs in New York in the norites of the Cortland region on the Hudson River and in the Adirondack region.

Name. Enstatite is named from the Greek word meaning *opponent* because of its refractory nature. Hypersthene is named from two Greek words meaning *very* and *strong* because its hardness is greater than that of hornblende.

Similar Species. *Clinoenstatite* is a monoclinic, dimorphic form of $MgSiO_3$.

DIOPSIDE — $CaMgSi_2O_6$

Crystallography. Monoclinic; prismatic. In prismatic crystals showing square or eight-sided cross section. Also granular massive, columnar, and lamellar. Frequently twinned polysynthetically with the basal pinacoid {001} the twin plane. Less commonly twinned on the orthopinacoid {100}.

Physical Properties. Imperfect prismatic {110} cleavage. Frequently parting parallel to the basal pinacoid {001}, and less commonly parallel to the orthopinacoid {100}. This latter type is characteristic of the variety *diallage*. **H.** = 5–6. **G.** = 3.2–3.3. Color white to light green; deepens with increase of iron. Luster vitreous. Transparent to translucent.

Composition. Calcium-magnesium silicate, $CaMgSi_2O_6$. CaO = 25.9 per cent, MgO = 18.5 per cent, SiO_2 = 55.6 per cent. Iron may replace magnesium in all proportions, and an isomorphous series exists between diopside and *hedenbergite*, $CaFeSi_2O_6$.

Tests. Fusible at 4 to a green glass. Insoluble in acids. With fluxes gives tests for calcium and magnesium.

Diagnostic Features. Characterized by its crystal form, light color, and imperfect prismatic cleavage at 87° and 93°.

Occurrence. Diopside is characteristically found as a contact metamorphic mineral in crystalline limestones. In such deposits it is associated with tremolite, scapolite, idocrase, garnet, sphene. It is also found in regionally metamorphosed rocks. The variety diallage is frequently found in gabbros, peridotites, and serpentines.

Fine crystals have been found in the Ural Mountains, U.S.S.R.; Austrian Tyrol; Binnenthal, Switzerland; Piedmont, Italy. At Nordmark, Sweden, fine crystals range from diopside to hedenbergite. In the United States found at Canaan, Litchfield County, Connecticut; DeKalb Junction and Gouverneur, St. Lawrence County, New York.

Use. Transparent varieties of diopside have been cut and used as gem stones.

Name. From two Greek words meaning *double* and *appearance,* since the prism zone can apparently be oriented in two ways.

AUGITE — $Ca(Mg,Fe,Al)(Al,Si)_2O_6$

Crystallography. Monoclinic; prismatic. Crystals prismatic in habit; prism faces make angles of 87° and 93° with each other. The prism zone commonly shows the prism faces truncated by the faces of both vertical pinacoids, so that the crystals, when viewed parallel to the vertical axis, show a rectangular cross section with truncated corners. The interfacial angles in the prism zone are either exactly or very close to 90° and 45°. The terminations vary, being made up frequently of a combination of the basal plane with positive and negative pyramids (Figs. 403–405). Often lamellar and coarse to fine granular.

Twinning on the base {001} and orthopinacoid {100} common.

Physical Properties. Prismatic {110} cleavage may be good, often interrupted. Frequently basal parting observed, often shown by twinning lamellae. **H.** = 5–6. **G.** = 3.2–3.4. Luster vitreous. Color dark green to black. Translucent, transmits light only on thin edges.

Composition. $Ca(Mg,Fe,Al)(Al,Si)_2O_6$. Augite can be considered an intermediate member in the diopside-hedenbergite series in which aluminum has taken the place of some of the silicon and magnesium.

Tests. Fusible from 4 to 4½. Insoluble in hydrochloric acid. After fusion with sodium carbonate gives tests for aluminum, iron, calcium, and magnesium.

Diagnostic Features. Recognized usually by its characteristic crystals with four- or eight-sided cross section. Distinguished from diopside by its darker color and from hornblende by its cleavage angle of 87° and 93°.

Occurrence. Augite is the most common pyroxene and an important rock-forming mineral. It is found chiefly in the dark-colored igneous rocks, especially those whose magmas were rich in iron, calcium, and magnesium. Seldom found in rocks that contain much quartz. Augite is found in basaltic lavas, and in the dark-colored intrusions known generally as trap, in gabbros and peridotites. Found in some syenites and similar rocks and in some gneisses. In igneous rocks augite is associated with orthoclase, the plagioclase feldspars, nepheline, olivine, leucite, hornblende, magnetite.

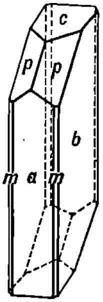

Fig. 403.

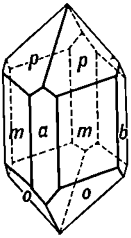

Fig. 404.

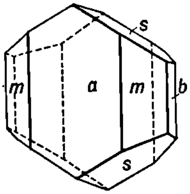

Fig. 405.

Augite.

Some of the notable localities, particularly for fine crystals, are the following: in the lavas of Vesuvius; at Val di Fassa, Trentino, Italy; Bilin, Bohemia.

Name. Augite comes from a Greek word meaning *luster.* The name pyroxene, *stranger to fire,* is a misnomer, and was given to the mineral because it was thought that it did not occur in igneous rocks.

Aegirite — $NaFe'''Si_2O_6$

Crystallography. Monoclinic; prismatic. Slender prismatic crystals with steep terminations. Often in fibrous aggregates. Faces often imperfect.

Physical Properties. Imperfect prismatic {110} cleavage at angles of 87° and 93°. **H.** = 6–6½. **G.** = 3.40–3.55. Luster vitreous. Color brown or green. Translucent.

Composition. Essentially a sodium-ferric iron silicate, $NaFe'''Si_2O_6$. Na_2O = 13.4 per cent, Fe_2O_3 = 34.6 per cent, SiO_2 = 52.0 per cent. A mineral with this exact composition is known as *acmite* and is rarely found. Usually some calcium replaces sodium and some magnesium and aluminum replace iron. Some vanadium may be present.

Tests. Fusible at 3, giving yellow sodium flame. Fused globule slightly magnetic. With fluxes gives tests for iron and in many cases magnesium and aluminum.

Diagnostic Features. The slender prismatic crystals, brown to green color, and associations are characteristic. However, it is not easily distinguished without optical tests.

Occurrence. Aegirite is a comparatively rare rock-forming mineral found chiefly in rocks rich in soda and poor in silica, such as nepheline syenite and phonolite. Associated with orthoclase, feldspathoids, augite, and soda-rich amphiboles. It occurs in the nepheline syenites and related rocks of Norway; southern Greenland; Kola Peninsula, U.S.S.R. In the United States is found in fine crystals at Magnet Cove, Arkansas. Found in Montana at Libby and in the Highwood and Bear Paw Mountains.

Name. From *Aegir*, the Icelandic god of the sea.

Jadeite — $NaAlSi_2O_6$

Crystallography. Monoclinic; prismatic. Rarely in isolated crystals. Usually fibrous in compact massive aggregates.

Physical Properties. Prismatic {110} cleavage at angles of 87° and 93°. Extremely tough and difficult to break. **H.** = 6½–7. **G.** = 3.3–3.5. Color apple-green to emerald-green, white. May be white with spots of green. Luster vitreous, pearly on cleavage surfaces.

Composition. Sodium aluminum silicate, $NaAlSi_2O_6$. Na_2O = 15.4 per cent, Al_2O_3 = 25.2 per cent, SiO_2 = 59.4 per cent. Contains some iron, calcium, magnesium.

Tests. Fuses at 2½ to a transparent blebby glass. Insoluble in acids.

Diagnostic Features. Characterized by its green color and tough aggregates of compact fibers. Distinguished from nephrite by its ease of fusion.

Occurrence. Jadeite occurs in large masses in serpentine apparently formed by the metamorphism of a nepheline-albite rock. It is found chiefly in eastern Asia in Upper Burma. It is also found in Tibet and southern China.

Use. Jadeite has long been highly prized in the Orient, especially China, where it is worked into ornaments and utensils of great variety and beauty. It was also used by early man for various weapons and implements.

Name. Jadeite is so named because it was found to make up many jade specimens. Under the term *jade* are included both the amphibole, nephrite, and the pyroxene, jadeite.

SPODUMENE — $LiAlSi_2O_6$

Crystallography. Monoclinic; prismatic. Prismatic crystals, flattened frequently parallel to the orthopinacoid {100}. Deeply striated vertically. Crystals usually coarse and with roughened faces; some very large. Occurs also in cleavable masses. Twinning on the orthopinacoid {100} common.

Physical Properties. Perfect prismatic {110} cleavage at angles of 87° and 93°. Usually a well-developed parting parallel to {100}. **H.** = 6½–7. **G.** = 3.15–3.20. Luster vitreous. Color white, gray, pink, yellow, green. Transparent to translucent.

The clear lilac-colored variety is called *kunzite*, and the clear emerald-green variety *hiddenite*.

Composition. Lithium aluminum silicate, $LiAlSi_2O_6$. Li_2O = 8.0 per cent, Al_2O_3 = 27.4 per cent, SiO_2 = 64.6 per cent. Usually has a small amount of sodium replacing the lithium.

Tests. Fusible at 3½, throwing out fine branches at first, and then fusing to a clear glass. Gives crimson flame (lithium). Insoluble in acids.

Diagnostic Features. Characterized by its prismatic cleavage and orthopinacoid parting. The angle formed by one cleavage direction and the {100} parting resembles the cleavage angle of tremolite. A careful angular measurement or a lithium flame is necessary to distinguish them.

Alteration. Spodumene very easily alters to other species, becoming dull. The alteration products include albite, eucryptite [$Li(Al,Si)_2O_4$], muscovite, microcline.

Occurrence. Spodumene is a comparatively rare species, but found occasionally in very large crystals in pegmatite dikes. Occurs in Goshen, Chesterfield, Huntington, and Sterling, Massachusetts; Branchville, Connecticut; Etta Mine, Black Hills, South Dakota, in crystals measuring as much as 40 feet in length and weighing many tons. Hiddenite occurs with emerald beryl at Stony Point, Alexander County, North Carolina. Kunzite is found with pink beryl at Pala, San Diego County, California, and at various localities in Madagascar.

Use. As a source of lithium. The varieties hiddenite and kunzite furnish very beautiful gem stones but are limited in their occurrence.

Names. *Spodumene* comes from a Greek word meaning *ash colored.* *Hiddenite* is named for Mr. W. E. Hidden; *kunzite* for Dr. G. F. Kunz.

RHODONITE — $MnSiO_3$

Crystallography. Triclinic; pinacoidal. Crystallographically closely related to the pyroxenes. Crystals commonly tabular parallel to base {001} (Fig. 406). Crystals often rough with rounded edges. Commonly massive, cleavable to compact; in imbedded grains.

Physical Properties. Prismatic {110} and $\{1\bar{1}0\}$ cleavages at about 88° and 92°. **H.** = $5\frac{1}{2}$–6. **G.** = 3.4–3.7. Luster vitreous. Color rose-red, pink, brown; frequently with black exterior of manganese oxide. Transparent to translucent.

Composition. Manganese silicate, $MnSiO_3$. MnO = 54.1 per cent, SiO_2 = 45.9 per cent. Calcium is usually present replacing manganese.

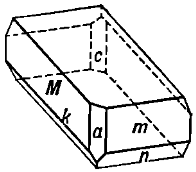

FIG. 406. Rhodonite.

Tests. Fusible at 3 to a nearly black glass. Insoluble in hydrochloric acid. In the oxidizing flame gives clear reddish violet color to borax bead and a blue-green color to the sodium carbonate bead.

Diagnostic Features. Characterized by its pink color and prismatic cleavage. Distinguished from rhodochrosite by its greater hardness and insolubility, and from feldspar by its higher specific gravity.

Occurrence. Rhodonite is found at Långban, Sweden, with other manganese minerals and iron ore; found in large masses near Sverdlovsk in the Ural Mountains, U.S.S.R.; from Broken Hill, New South Wales. In the United States a zinciferous variety, known as *fowlerite,* occurs in good-sized crystals in limestone with franklinite, willemite, zincite, etc., at Franklin, New Jersey.

Use. Some rhodonite is polished for use as an ornamental stone. This material is obtained chiefly from the Ural Mountains.

Name. Derived from the Greek word for a *rose,* in allusion to the color.

Similar Species. *Tephroite,* Mn_2SiO_4, is a red to gray mineral associated with rhodonite.

WOLLASTONITE — $CaSiO_3$

Crystallography. Triclinic; pinacoidal. Usually in tabular crystals, with either base {001} or macropinacoid {100} prominent. Commonly massive, cleavable to fibrous; also compact.

Pseudowollastonite, $CaSiO_3$, is formed above 1,200° C.; it is pseudohexagonal with different properties from wollastonite.

Physical Properties. Perfect cleavage parallel to the basal {001} and macro- {100} pinacoids, giving cleavage fragments an elongation parallel to the *b* crystallographic axis. **H.** = 5-5½. **G.** = 2.8-2.9. Luster vitreous, pearly on cleavage surfaces. May be silky when fibrous. Colorless, white, or gray. Translucent.

Composition. Calcium silicate, $CaSiO_3$. CaO = 48.3 per cent, SiO_2 = 51.7 per cent.

Tests. Fusible at 4 to a white, almost glassy globule. Decomposed by hydrochloric acid, with the separation of silica but without the formation of a jelly. Filtered solution with ammonium hydroxide and ammonium oxalate gives white precipitate of calcium oxalate.

Diagnostic Features. Characterized by its two perfect cleavages at about 84° and 96°. It resembles tremolite but is distinguished from it by the cleavage angle and solubility in acid.

Occurrence. Wollastonite occurs chiefly as a contact mineral in crystalline limestones. It is associated with calcite, diopside, lime garnet, tremolite, lime feldspars, idocrase, epidote.

In places may be so plentiful as to constitute the chief mineral of the rock mass. Such wollastonite rocks are found in the Black Forest, in Brittany, and in California. Crystals of the mineral are found at Csiklova in Rumania; Harz Mountains, Germany; Chiapas, Mexico. In the United States found in New York at Diana, Lewis County, and also in Orange and St. Lawrence Counties. In California at Crestmore, Riverside County.

Name. In honor of the English chemist, W. H. Wollaston (1766-1828).

Similar Species. The common wollastonite is triclinic as described above. The name *parawollastonite* is given to the less common monoclinic modification of $CaSiO_3$. All the properties of the two species are closely related.

Pectolite — $Ca_2NaSi_3O_8(OH)$

Crystallography. Triclinic; pinacoidal. Crystals usually elongated parallel to the macro-axis. Usually in aggregates of acicular crystals. Frequently radiating, with fibrous appearance. In compact masses.

Physical Properties. Perfect cleavage parallel to the basal {001} and macro- {100} pinacoids. **H.** = 5. **G.** = 2.7–2.8. Luster vitreous to silky. Colorless, white, or gray.

Composition. Hydrous calcium-sodium silicate, $Ca_2NaSi_3O_8(OH)$. Percentage of oxides: $CaO = 33.8$, $Na_2O = 9.3$, $SiO_2 = 54.2$, $H_2O = 2.7$.

Tests. Fuses quietly at 2½–3 to a glass; colors flame yellow (sodium). Decomposed by hydrochloric acid, with the separation of silica but without the formation of a jelly. Solution gives tests for calcium. Water in the closed tube.

Diagnostic Features. Characterized by two directions of perfect cleavage yielding sharp acicular fragments. Resembles wollastonite but gives test for water and sodium. Distinguished from similar-appearing zeolites by absence of aluminum.

Occurrence. Pectolite is a mineral of secondary origin similar in its occurrence to the zeolites. Found lining amygdaloidal cavities in basalt, associated with various zeolites, prehnite, calcite, etc. Found at Bergen Hill and West Paterson, New Jersey.

Name. From the Greek word meaning *compact*, in allusion to its habit.

CHRYSOCOLLA — $CuSiO_3 \cdot 2H_2O$

Crystallography. Cryptocrystalline. Has been observed in small, acicular crystals but commonly cryptocrystalline or amorphous. Massive compact. In some cases earthy.

Physical Properties. Fracture conchoidal. **H.** = 2–4. **G.** = 2.0–2.4. Luster vitreous to earthy. Color green to greenish blue; brown to black when impure.

Composition. Hydrous copper silicate, whose formula is near $CuSiO_3 \cdot 2H_2O$. $CuO = 45.2$ per cent, $SiO_2 = 34.3$ per cent, $H_2O = 20.5$ per cent. Varies considerably in composition and often impure.

Tests. Infusible. Decomposed by hydrochloric acid with the separation of silica but without the formation of a jelly. Gives a copper globule when fused with sodium carbonate on charcoal. In the closed tube darkens and gives water.

Diagnostic Features. Characterized by its green or blue color and conchoidal fracture. Distinguished from turquois by inferior hardness.

Occurrence. Chrysocolla is a mineral of secondary origin, occurring in the oxidized zones of copper veins. Associated with malachite, azurite, cuprite, native copper, etc. Found in the copper districts of Arizona and New Mexico. In microscopic crystals in Mackay, Idaho.

Use. A minor ore of copper.

Name. Chrysocolla, derived from two Greek words meaning *gold* and *glue,* which was the name of a similar-appearing material used to solder gold.

Similar Species. *Dioptase* is a rhombohedral hydrous copper silicate occurring in well-defined green crystals.

TOURMALINE

Crystallography. Rhombohedral; ditrigonal-pyramidal. Crystals usually prismatic, vertically striated. A triangular prism, with three faces, prominent, which with the tendency of the prism faces to be vertically striated and to round into each other gives the crystals a cross section like a spherical triangle (Fig. 407). Crystals are commonly terminated by base and low positive and negative rhombohedrons; scalenohedrons may be present. When doubly terminated, crystals usually show different forms at the opposite ends of the vertical axis (Figs. 408 and 409). Usually in crystals. Some massive compact; also coarse to fine columnar, either radiating or parallel.

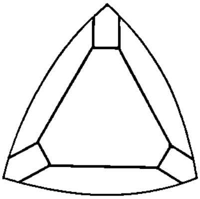

Fig. 407.

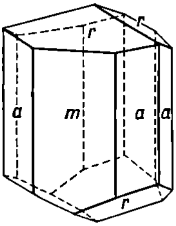

Fig. 408

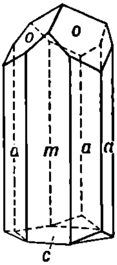

Fig. 409.

Tourmaline.

Physical Properties. H. = 7–7$\frac{1}{2}$. G. = 3.0–3.25. Luster vitreous to resinous. Color varied, depending upon the composition. Common tourmaline with much iron (*schorlite*) is black, some is brown. More rarely light colored in fine shades of red, pink, green, blue, yellow. Rarely white or colorless. A single crystal may show several different colors either arranged in concentric bands about the center of the crystal or in transverse layers along its length. Strongly pyroelectric; i.e., when cooling from being heated to about 100° C. it develops positive electricity at one end of the crystal and negative at the other, which enables the crystal to attract and hold bits of paper, etc. Strongly dichroic; i.e., light traversing the crystal in one direction may be of quite a different color or shade of color from that traversing the crystal in a direction at right angles.

Composition. A complex silicate of boron and aluminum, whose composition can be expressed by the general formula $WX_3B_3Al_3(AlSi_2O_9)_3$-$(O,OH,F)_4$, where W = Na,Ca. X = Al,Fe''',Li,Mg.

Tests. Fusibility varies with composition: magnesium varieties fusible at 3; iron varieties fusible with difficulty; lithium varieties infusible. Fused with boron flux gives momentary green flame of boron. Insoluble in acids.

Diagnostic Features. Recognized usually by the characteristic rounded triangular cross section of the crystals and coal-like fracture of black variety. Distinguished from hornblende by absence of prismatic cleavage.

Occurrence. Tourmaline is one of the most common and characteristic minerals formed by pneumatolytic action. That is, it is a mineral that has been formed at high temperatures and pressures through the agency of vapors carrying boron and fluorine. It is found, therefore, commonly as an accessory mineral in pegmatite dikes, occurring with granite intrusions. It may be deposited in rocks surrounding pegmatites. Associated with the ordinary minerals of granite pegmatite, orthoclase, albite, quartz, and muscovite; also with lepidolite, beryl, apatite, fluorite, and rarer minerals. (See Plate XVIII, Figs. 1 and 2.) Found also as an accessory mineral in metamorphic rocks, such as gneisses, schists, and crystalline limestones. The black tourmaline is of widespread occurrence as an accessory mineral in metamorphic rocks. The light-colored gem varieties are found in the pegmatite dikes.

Famous localities for the occurrence of the gem tourmalines are the Island of Elba; the state of Minas Geraes, Brazil; Ural Mountains near Sverdlovsk; Madagascar. In the United States found at Paris and Auburn, Maine; Chesterfield, Massachusetts; Haddam Neck, Connecticut; Mesa Grande, Pala, Rincon, and Ramona in San Diego County, California. Brown crystals are found near Gouverneur, New York, and fine black crystals at Pierrepont, New York.

Use. Tourmaline forms one of the most beautiful of the semi-precious gem stones. The color of the stones varies, the principal shades being olive-green, pink to red, and blue. Sometimes a stone is so cut as to show different colors in different parts. The green-colored stones are usually known by the mineral name, tourmaline, or as *Brazilian emeralds*. The red or pink stones are known as *rubellite*, while the rarer dark blue stones are called *indicolite*.

Name. The name *tourmaline* comes from *turamali*, a name given to the early gems from Ceylon.

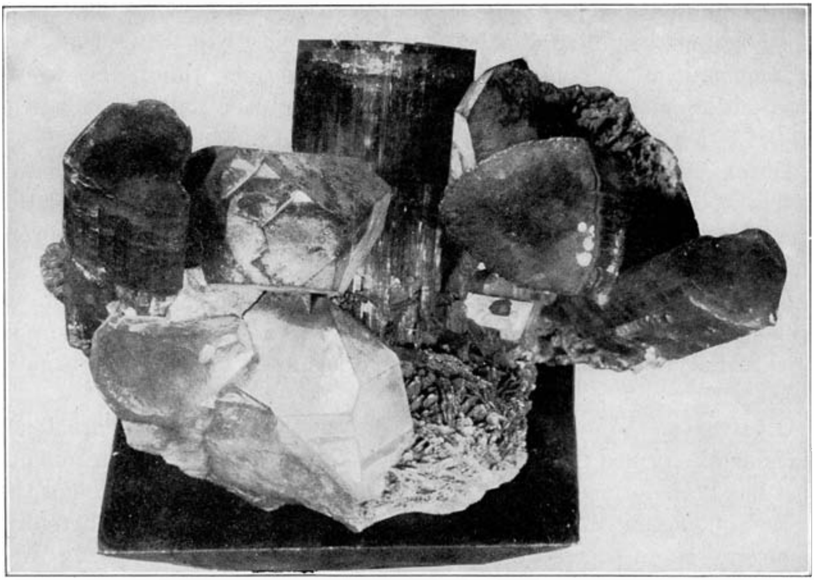

FIG. 1. Tourmaline Crystals with Quartz and Clevelandite, Pala, California.

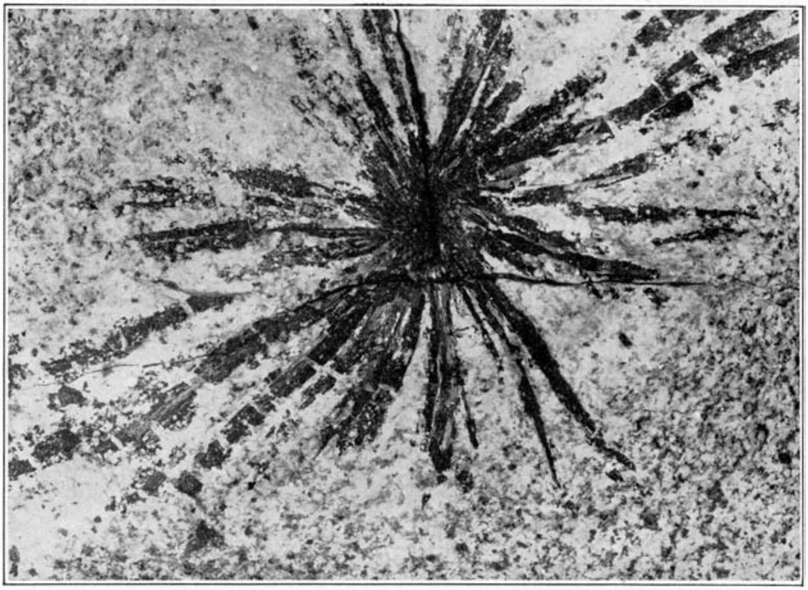

FIG. 2. Sunburst of Tourmaline in Granite, Fitchburg, Massachusetts.

PLATE XVIII

BERYL — $Be_3Al_2Si_6O_{18}$

Crystallography. Hexagonal; dihexagonal-dipyramidal. Strong prismatic habit. Frequently vertically striated and grooved. Forms usually present consist only of prism of first order $\{10\bar{1}0\}$ and base $\{0001\}$ (Fig. 410). Dihexagonal forms are rare. Crystals frequently of considerable size with rough faces. Also found massive, with indistinct columnar aggregates or granular.

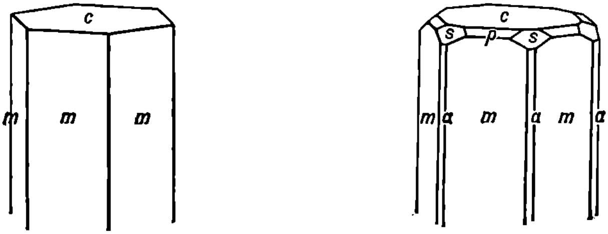

FIG. 410. FIG. 411.

Beryl.

Physical Properties. H. = $7\frac{1}{2}$–8. G. = 2.75–2.8. Luster vitreous. Color commonly bluish green or light yellow; may be deep emerald-green, golden-yellow, pink, white, or colorless. Transparent to translucent. Frequently the larger, coarser crystals show a mottled appearance due to the alternation of clear transparent spots with cloudy portions.

Color serves as the basis for several variety names of beryl. *Aquamarine* is the pale greenish blue transparent variety. *Morganite,* or *rose beryl,* is pale pink to deep rose. *Emerald* is the deep green transparent beryl. *Golden beryl* is a clear golden-yellow variety.

Composition. Beryllium aluminum silicate, $Be_3Al_2Si_6O_{18}$. BeO = 14.0 per cent, Al_2O_3 = 19.0 per cent, SiO_2 = 67.0 per cent. Small amounts of the alkali oxides, often in part consisting of cesium oxide, frequently replace the beryllium oxide.

Tests. Before the blowpipe, whitens and fuses with difficulty at 5–$5\frac{1}{2}$ to an enamel. Yields a little water on intense ignition. Insoluble in acids.

Diagnostic Features. Recognized usually by its hexagonal crystal form and color. Distinguished from apatite by greater hardness.

Occurrence. Beryl, although containing the rare element beryllium, is rather common and widely distributed. It occurs usually in granitic rocks, either in druses or in pegmatite dikes. It is also found in mica schists and associated with tin ores. Emeralds of gem quality occur in a dark bituminous limestone at Muso, 65 miles northwest of Bogotá, Colombia. This locality has been worked almost continually since the middle of the sixteenth century, and has furnished the greater part of the emeralds of the world. Another famous locality for emeralds is in Siberia on the river Takowaja, 45 miles east of Sverdlovsk. There they occur in a mica schist associated with phenacite, chrysoberyl, rutile. Rather pale emeralds have been found in small amount in Alexander County, North Carolina, associated with the green variety of spodumene, hiddenite. Beryl of the lighter aquamarine color is much more common, and is found in gem quality in Brazil and Siberia. Also in Madagascar. In the United States gem beryls, chiefly aquamarine, have been found in various places in Maine, New Hampshire, Massachusetts, Connecticut, North Carolina, Colorado. Golden beryl has been found in Maine, Connecticut, North Carolina, and Pennsylvania; also in Siberia and Ceylon. Rose-colored beryl has been found in San Diego County, California, associated with pink tourmaline and the pink spodumene, kunzite. A similar occurrence in Madagascar has furnished magnificent rose-colored stones.

Use. Used as a gem stone of various colors. The emerald ranks as the most valuable of stones, and may have a much greater value than the diamond. Beryl is also used as a source of beryllium.

Name. The name beryl is of ancient origin, derived from the Greek word which was applied to green gem stones.

Similar Species. *Euclase*, $Be_2Al_2(SiO_4)_2(OH)_2$, and *gadolinite*, $Ye,Fe'' Be_2(SiO_4)_2O_2$, are rare beryllium silicates.

HEMIMORPHITE — $Zn_4Si_2O_7(OH)_2 \cdot H_2O$

Calamine

Crystallography. Orthorhombic; pyramidal. Crystals usually tabular parallel to the brachypinacoid. They show prism faces and are terminated above usually by a combination of macrodomes and brachydomes and base, and below by a pyramid (Fig. 412). Usually in crystal groups with the individuals attached at their lower (pyramidal) ends and lying with their brachypinacoid faces in common. Crystals often divergent, giving rounded groups with slight re-entrant notches between the individual crystals, forming knuckle or coxcomb masses. Also mammillary, stalactitic, massive, and granular.

Physical Properties. Prismatic {110} cleavage. **H.** = $4\frac{1}{2}$–5. **G.** = 3.4–3.5. Luster vitreous. Color white, in some cases with faint bluish or greenish shade; also yellow to brown. Transparent to translucent. Strongly pyroelectric.

Composition. Hydrous silicate of zinc, $Zn_4Si_2O_7(OH)_2 \cdot H_2O$. ZnO = 67.5 per cent, SiO_2 = 25.0 per cent, H_2O = 7.5 per cent. Small amounts of aluminum and iron may be present.

Tests. Fusible with difficulty at 5. Soluble in hydrochloric acid and yields gelatinous silica on evaporation. Fused on charcoal with sodium carbonate gives a nonvolatile coating of zinc oxide (yellow when hot, white when cold). Fused with cobalt nitrate on charcoal turns blue. Water in the closed tube.

Diagnostic Features. Characterized by the grouping of crystals. Resembles prehnite but higher specific gravity. Distinguished from smithsonite by its crystal aggregates.

Occurrence. Hemimorphite is a mineral of secondary origin, found in the oxidized portion of zinc deposits, associated with smithsonite, sphalerite, cerussite, anglesite, galena.

Notable localities for its occurrence are at Moresnet, Belgium; Aix-la-Chapelle, Germany; Carinthia; Rumania; Sardinia; Cumberland and Derbyshire, England; Algeria; Chihuahua, Mexico. In the United States is found at Sterling Hill, Ogdensburg, New Jersey; Friedensville, Pennsylvania; Wythe County, Virginia; with the zinc deposits of southwestern Missouri; Leadville, Colorado; Organ Mountains, New Mexico; Elkhorn Mountains, Montana.

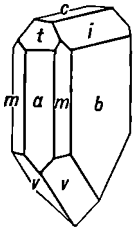

Fig. 412. Hemimorphite.

Use. An ore of zinc.

Name. From the hemimorphic character of the crystals.

Danburite — $CaB_2Si_2O_8$

Crystallography. Orthorhombic; dipyramidal. Prismatic crystals, closely related to those of topaz in habit. Commonly in crystals.

Physical Properties. **H.** = 7. **G.** = 2.97–3.02. Luster vitreous. Colorless or pale yellow. Transparent to translucent.

Composition. Calcium borosilicate, $CaB_2Si_2O_8$. $CaO = 22.8$ per cent, $B_2O_3 = 28.4$ per cent, $SiO_2 = 48.8$ per cent.

Tests. Fusible at $3\frac{1}{2}$–4 to a colorless glass, giving a green flame. Insoluble in acids, but when previously ignited gelatinizes in hydrochloric acid.

Diagnostic Features. Characterized by its crystal form and high hardness. Distinguished from topaz by the test for boron.

Occurrence. Found in crystals in eastern Switzerland; Madagascar; Japan. In the United States at Danbury, Connecticut; Russell, New York. Recently found in a salt dome in Louisiana.

Name. From the locality, Danbury, Connecticut.

OLIVINE — $(Mg,Fe)_2SiO_4$

Chrysolite. Peridot

Crystallography. Orthorhombic; dipyramidal. Crystals usually a combination of prism, macro- and brachypinacoids and domes, pyramid and base. Often flattened parallel to either the macro- or brachypinacoid. Usually in imbedded grains or in granular masses.

Physical Properties. Fracture conchoidal. **H.** = $6\frac{1}{2}$–7. **G.** = 3.27–3.37, increasing with increase in iron content. Luster vitreous. Olive to grayish green, brown. Transparent to translucent.

Composition. Silicate of magnesium and ferrous iron, $(Mg,Fe)_2SiO_4$. A complete isomorphous series exists, grading from *forsterite*, Mg_2SiO_4, to *fayalite*, Fe_2SiO_4. The more common olivines are richer in magnesium than in iron.

Tests. Infusible. Rather slowly soluble in hydrochloric acid and yields gelatinous silica upon evaporation. Solution gives tests for iron and magnesium.

Diagnostic Features. Distinguished usually by its glassy luster, conchoidal fracture, green color, and granular nature.

Occurrence. Olivine is a rather common rock-forming mineral, varying in amount from that of an accessory to that of a main constituent of the rock. It is found principally in the dark-colored ferromagnesian igneous rocks such as gabbro, peridotite, and basalt. A rock known as *dunite* is made up almost wholly of olivine. Found also as glassy grains in meteorites. Occasionally in crystalline dolomitic limestones. Associated often with pyroxene, calcic plagioclase feldspar, magnetite, corundum, chromite, serpentine.

The transparent green variety is known as *peridot*. It was used as a gem in ancient times in the East, but the exact locality for the stones is not known. At present peridot is found on St. John's Island in the Red Sea, and in rounded grains associated with pyrope garnet in the surface gravels of Arizona and New Mexico. Crystals of olivine are found in the lavas of Vesuvius. Larger crystals, altered to serpentine, come from Sharum, Norway. Olivine occurs in granular masses in volcanic bombs in the Eifel District, Germany, and in Arizona. Dunite rocks are found at Dun Mountain, New Zealand, and with the corundum deposits of North Carolina.

Alteration. Very readily altered to serpentine and less commonly to *iddingsite*. Magnesite and iron oxides may form at the same time as a result of the alteration.

Use. As the clear green variety, peridot, it has some use as a gem.

Name. Olivine derives its name from the usual olive-green color of the mineral, and is the term usually given to the species when speaking of it as a rock-forming mineral. Peridot is an old name for the species.

Similar Species. Other members of the olivine group which are rarer in occurrence are *monticellite*, $CaMgSiO_4$; *tephroite*, Mn_2SiO_4; *larsenite*, $PbZnSiO_4$.

Phenacite — Be_2SiO_4

Crystallography. Rhombohedral; rhombohedral class. Crystals usually rhombohedral in form. Short prisms may be present. Often with complex development and frequently showing the faces of the third-order rhombohedron.

Physical Properties. Imperfect prismatic $\{11\bar{2}0\}$ cleavage. **H.** = $7\frac{1}{2}$–8. **G.** = 2.97–3.00. Luster vitreous. Colorless, white. Transparent to translucent.

Composition. Beryllium silicate, Be_2SiO_4. BeO = 45.6 per cent, SiO_2 = 54.4 per cent.

Tests. Infusible and insoluble. Fused with sodium carbonate yields a white enamel.

Diagnostic Features. Characterized by its crystal form and great hardness.

Occurrence. Phenacite is a rare mineral, found in pegmatite dikes as a pneumatolytic mineral, associated with topaz, chrysoberyl, beryl, apatite. Fine crystals are found at the emerald mines in the Ural Mountains, U.S.S.R., and in Minas Geraes, Brazil. In the United States found at Mount Antero, Colorado.

Use. Occasionally cut as a gem stone.

Name. From the Greek meaning *a deceiver*, in allusion to its having been mistaken for quartz.

WILLEMITE — Zn_2SiO_4

Crystallography. Rhombohedral; rhombohedral class. In hexagonal prisms with rhombohedral terminations. Faces of third-order rhombohedrons rare. Usually massive to granular. Rarely in crystals.

Physical Properties. Basal $\{0001\}$ cleavage. **H.** = $5\frac{1}{2}$. **G.** = 3.9–4.2. Luster vitreous to resinous. Color yellow-green, flesh-red, and brown; white when pure. Transparent to translucent. Most willemite from Franklin, New Jersey, fluoresces. (See frontispiece.)

Composition. Zinc silicate, Zn_2SiO_4. ZnO = 73.0 per cent, SiO_2 = 27.0 per cent. Manganese often replaces a considerable part of the zinc (manganiferous variety called *troostite*); iron may also be present in small amount.

Tests. Pure willemite infusible, troostite difficultly fusible (4½–5). Soluble in hydrochloric acid and yields gelatinous silica on evaporation. Gives a coating of zinc oxide (yellow when hot, white when cold) when heated with sodium carbonate on charcoal; coating moistened with cobalt nitrate and heated turns green. When heated on charcoal with cobalt nitrate assay turns blue. Troostite will give reddish violet color to the borax bead in the oxidizing flame (manganese).

Diagnostic Features. Willemite from Franklin, New Jersey, can usually be recognized by its association with franklinite and zincite. Other specimens must be identified by the above tests. Distinguished from hemimorphite by absence of water.

Occurrence. Willemite is found in crystalline limestone and may be the result of metamorphism of earlier hemimorphite or smithsonite. It is also found sparingly as a secondary mineral in the oxidized zone of zinc deposits.

Found at Altenberg, near Moresnet, Belgium; Algeria; French Congo; Northern Rhodesia; Southwest Africa; Greenland. The most important locality is in the United States at Franklin, New Jersey, where willemite occurs associated with franklinite and zincite and as grains imbedded in calcite. It has also been found at the Merritt Mine, New Mexico.

Use. A valuable zinc ore.

Name. In honor of the King of the Netherlands, William I.

Chondrodite — $Mg_5(SiO_4)_2(F,OH)_2$

Crystallography. Monoclinic; prismatic. Crystals are frequently complex with many forms. Usually in isolated grains. Also massive.

Physical Properties. **H.** = 6–6½. **G.** = 3.1–3.2. Luster vitreous to resinous. Color light yellow to red. Translucent.

Composition. A magnesium fluosilicate, $Mg_5(SiO_4)_2(F,OH)_2$. Hydroxyl replaces part of the fluorine, and iron often takes the place of magnesium. Chondrodite is the most common member of the *humite group.* The species in the group and their compositions are:

Norbergite	$Mg_3(SiO_4)_1(F,OH)_2$
Chondrodite	$Mg_5(SiO_4)_2(F,OH)_2$
Humite	$Mg_7(SiO_4)_3(F,OH)_2$
Clinohumite	$Mg_9(SiO_4)_4(F,OH)_2$

Tests. Infusible. Fused with potassium disulfate in a bulb tube gives test for fluorine. Yields water in the closed tube. Gelatinizes with acids.

Diagnostic Features. Characterized by its light yellow to red color and its mineral associations in crystalline limestone. The members of the *humite group* cannot be distinguished from one another without optical tests.

Occurrence. Chondrodite occurs most commonly in metamorphosed dolomitic limestones of Archean age. The mineral association including phlogopite, spinel, pyrrhotite, graphite is highly characteristic. Noteworthy localities of chondrodite are Mte. Somma; Pargas, Finland; Kafveltorp, Sweden. In the United States is found abundantly at the Tilly Foster magnetite deposit near Brewster, New York.

Name. Chondrodite is from the Greek meaning *a grain* alluding to its occurrence as isolated grains. Humite is named in honor of Sir Abraham Hume.

GARNET GROUP

The garnet group includes a series of subspecies that crystallize in the hexoctahedral class of the isometric system and are similar in crystal habit. They all correspond to the same general formula although the elements present differ widely.

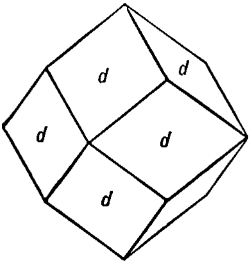

Fig. 413.

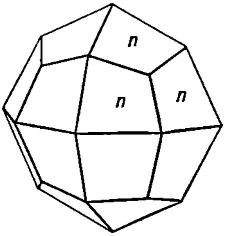

Fig. 414.

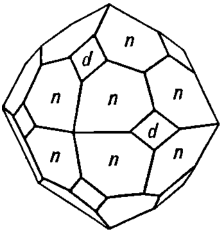

Fig. 415.

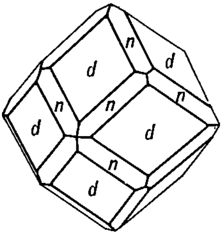

Fig. 416.

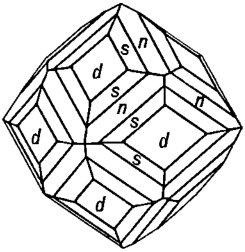

Fig. 417.

Garnet.

Crystallography. Isometric; hexoctahedral. Common forms dodecahedron (Fig. 1, Plate XIX, and Fig. 413) and trapezohedron (Fig. 414), often in combination (Figs. 415 and 416). Hexoctahedron observed occasionally (Fig. 417). Other forms rare. Usually distinctly crystallized; also in rounded grains; massive granular, coarse or fine.

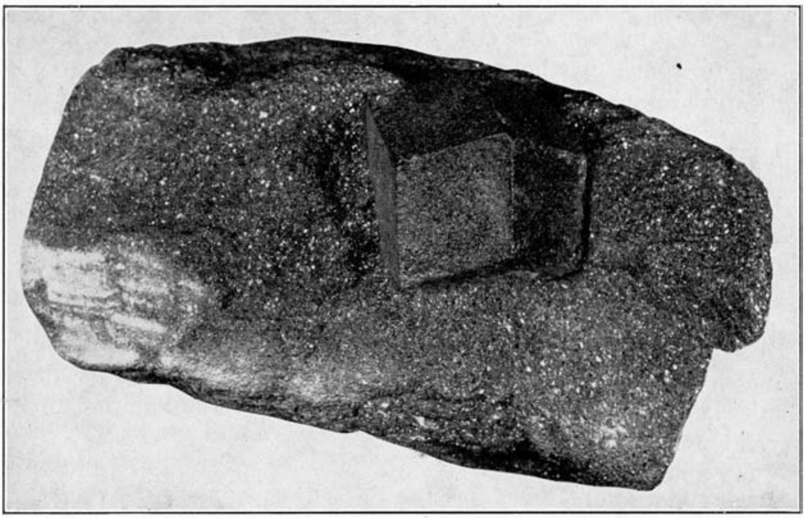

FIG. 1. Garnet in Chlorite Schist, Salida, Colorado.

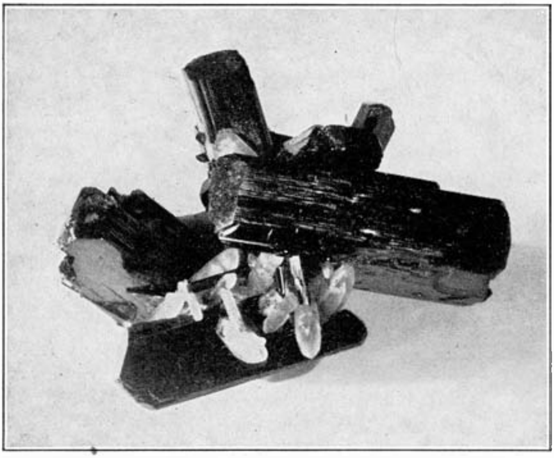

FIG. 2. Epidote with Quartz, Salzburg, Austria.

PLATE XIX

Physical Properties. H. = 6½–7½. G. = 3.5–4.3, varying with the composition (see below). Luster vitreous to resinous. Color varying with composition; most commonly red, also brown, yellow, white, green, black. White streak. Transparent to translucent.

Composition. The garnets are silicates which conform to the general formula $R_3''R_2'''(SiO_4)_3$. R″ may be calcium, magnesium, ferrous iron, and manganese; R‴ may be aluminum, ferric iron, titanium, and chromium. The formulas of the chief subspecies are given below, with the specific gravity for the pure compound; many of them, however, grade more or less into each other.

SUBSPECIES	COMPOSITION	SPECIFIC GRAVITY
Pyrope	$Mg_3Al_2(SiO_4)_3$	3.51
Almandite	$Fe_3Al_2(SiO_4)_3$	4.25
Spessartite	$Mn_3Al_2(SiO_4)_3$	4.18
Grossularite	$Ca_3Al_2(SiO_4)_3$	3.53
Andradite	$Ca_3Fe_2(SiO_4)_3$	3.75
Uvarovite	$Ca_3Cr_2(SiO_4)_3$	3.45

Pyrope. Precious garnet in part. Calcium and iron usually present. Color deep red to nearly black. Often transparent and then used as a gem. Name derived from Greek, meaning *firelike. Rhodolite* is name given to a pale rose-red or purple garnet, corresponding in composition to two parts of pyrope and one of almandite.

Almandite. Precious garnet in part, common garnet in part. Ferric iron may replace aluminum, and magnesium, ferrous iron. Color fine deep red, transparent in precious garnet; brownish red, translucent in common garnet. Name derived from Alabanda, where in ancient times garnets were cut and polished.

Spessartite. Ferrous iron usually replaces some of the manganese and ferric iron some of the aluminum. Color brownish to red.

Grossularite (*essonite, cinnamon stone*). Often contains ferrous iron replacing calcium and ferric iron replacing aluminum. Color white, green, yellow, cinnamon-brown, pale red. Name derived from the botanical name for gooseberry, in allusion to the light green color of the original grossularite.

Andradite. Common garnet in part. Aluminum may replace ferric iron; ferrous iron, manganese, and magnesium may replace calcium. Color various shades of yellow, green, brown to black. *Demantoid* is a green variety with a brilliant luster used as a gem. Named after the Portuguese mineralogist, d'Andrada.

Uvarovite. Calcium-chromium garnet. Color emerald-green. Named after Count Uvarov.

Tests. With the exception of uvarovite, all garnets fuse at 3–3½; uvarovite is almost infusible. The iron garnets, almandite and andradite, fuse to magnetic globules. Spessartite when fused with sodium carbonate gives a bluish green bead (manganese). Uvarovite gives a green color to salt of phosphorus bead (chromium). Andradite is somewhat difficultly soluble in hydrochloric acid and gelatinizes imperfectly on evaporation. All the other garnets are practically insoluble in acids. All of them, with the exception of uvarovite, may be dissolved in hydrochloric acid after simple fusion and the solutions will gelatinize on evaporation.

Diagnostic Features. Garnets are usually recognized by their characteristic isometric crystals, their hardness, and their color. It may require chemical analysis to distinguish positively between the different members of the group, but the specific gravity and refractive index taken together will usually serve to distinguish them.

Occurrence. Garnet is a common and widely distributed mineral, occurring as an accessory constituent of metamorphic and in some igneous rocks. Its most characteristic occurrence is in mica schists (see Fig. 1, Plate XIX), hornblende schists, and gneisses. Found in pegmatite dikes, more rarely in granitic rocks. Grossularite is found chiefly as a product of contact or regional metamorphism in crystalline limestones. Almandite is especially characteristic of the mica schists. Pyrope is often found in peridotite rocks and the serpentines derived from them. Spessartite occurs in the igneous rock, rhyolite. *Melanite*, a black variety of andradite, occurs mostly in certain igneous rocks. Uvarovite is found in serpentine associated with chromite. Garnet frequently occurs as rounded grains in stream- and sea-sands.

Almandite, of gem quality, is found in northern India, Ceylon, Brazil. Fine crystals, although for the most part too opaque for cutting, are found in a mica schist on the Stikine River, Alaska. Pyrope of gem quality is found associated with clear grains of olivine (peridot) in the surface sands near Fort Defiance, close to the Utah-Arizona line. A locality near Meronitz, Bohemia, is famous for pyrope gems. Grossularite is used only a little in jewelry, but essonite or cinnamon stones of good size and color are found in Ceylon.

Alteration. Garnet often alters to other minerals, particularly talc, serpentine, and chlorite.

Use. Chiefly as a rather inexpensive gem stone. A green andradite, known as *demantoid*, comes from the Ural Mountains, U.S.S.R., and yields fine gems known as *Uralian emeralds*. Considerable amounts of garnet are ground and used, on account of its hardness, for abrading purposes, as for sawing and grinding stone, or for making garnet paper.

Name. *Garnet* is derived from the Latin *granatus,* meaning like a grain.

IDOCRASE — $Ca_{10}Al_4(Mg,Fe)_2Si_9O_{34}(OH)_4$

Vesuvianite

Crystallography. Tetragonal; ditetragonal-dipyramidal. Crystals prismatic in habit, often vertically striated. Common forms are prisms of first {110} and second {100} orders, dipyramid of first order {111}, and base {001} (Figs. 418 and 419). Some crystals show a more complex development with other prisms, dipyramids, ditetragonal forms. Frequently found in crystals, but striated columnar aggregates more common. Also granular, massive.

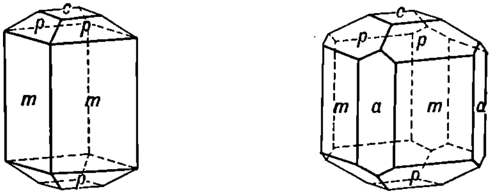

FIG. 418. FIG. 419.

Idocrase.

Physical Properties. **H.** = $6\frac{1}{2}$. **G.** = 3.35–3.45. Luster vitreous to resinous. Color usually green or brown; also yellow, blue, red. Subtransparent to translucent. Streak white.

Composition. Essentially a hydrous calcium aluminum silicate, but with some magnesium and iron, $Ca_{10}Al_4(Mg,Fe)_2Si_9O_{34}(OH)_4$. Boron or fluorine is present in some varieties. Beryllium has been reported in some analyses.

Tests. Fuses at 3 with intumescence to a greenish or brownish glass. Only slightly soluble in acids but gelatinizes in hydrochloric acid after simple fusion. Water in the closed tube.

Diagnostic Features. Brown tetragonal prisms and striated columnar masses are characteristic of idocrase.

Occurrence. Idocrase is usually found in crystalline limestones formed as the result of contact metamorphism. Associated with other contact minerals, such as garnet, wollastonite, diopside, tourmaline. Was originally discovered in the ancient ejections of Vesuvius and in the dolomitic blocks of Monte Somma.

Important localities are Zermatt, Switzerland; Ala, Piedmont; Monzoni, Trentino; Vesuvius; Christiansand, Norway; Achmatovsk, Ural Mountains, and River Vilui, Siberia, U.S.S.R.; Morelos and Chiapas, Mexico. In the United States found at Auburn and Sanford, Maine; near Amity, New York; Franklin, New Jersey. Found at many contact metamorphic deposits in western United States. A compact green variety found in Siskiyou, Fresno, and Tulare Counties, California, is known as *californite.* In Quebec, Canada, found at Litchfield, Pontiac County; at Templeton, Ottawa County.

Use. The variety californite is used to a small extent as a semiprecious stone. An attempt has been made to mine beryllium-bearing idocrase as a source of beryllium.

Name. From two Greek words meaning *form* and *a mixture* because the crystal forms present appear to be a combination of those found on different minerals.

EPIDOTE GROUP

The epidote group is made up of several complex calcium aluminum silicates. They correspond to the general formula $R_2''R_3'''(SiO_4)_3(OH)$, where usually $R'' = Ca, Mn$; and $R''' = Al, Fe, Mn$. With the exception of the comparatively rare *zoisite,* the minerals of the epidote group are monoclinic and have similar crystallographic properties.

EPIDOTE — $Ca_2(Al,Fe)_3(SiO_4)_3(OH)$

Crystallography. Monoclinic; prismatic. Crystals are often much elongated parallel to the ortho-axis with a prominent development of the faces of the orthodome zone, giving them a prismatic aspect (Plate XIX, Fig. 2). Striated parallel to the ortho-axis. Terminated usually only at one end of the ortho-axis and most commonly by the two faces of a pyramid (Fig. 420). Some crystals twinned with {100} the twin plane. Usually coarse to fine granular; also fibrous.

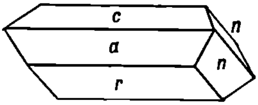

Fig. 420.

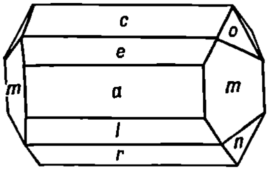

Fig. 421.

Epidote.

Physical Properties. Perfect basal {001} cleavage and imperfect orthopinacoidal {100}. **H.** = 6–7. **G.** = 3.35–3.45. Luster vitreous. Color usually pistachio-green or yellowish to blackish green, in some specimens gray or black. Transparent to translucent. Transparent varieties often show strong dichroism, appearing dark green in one direction and brown in a direction at right angles.

Composition. Hydrous calcium aluminum-iron silicate, $Ca_2(Al,Fe)_3$-$(SiO_4)_3(OH)$. The ratio of aluminum to iron varies from 6 : 1 to 3 : 2.

Tests. Fuses at 3–4 with intumescence to a black slag; once formed, this slag is not again fusible. On intense ignition in the closed tube yields a little water. When previously ignited, gelatinizes with acid.

Diagnostic Features. Characterized by its peculiar green color and one perfect cleavage. The slag formed on fusing which is again infusible is diagnostic.

Occurrence. Epidote occurs commonly in the crystalline metamorphic rocks, as gneiss, amphibolite, and various schists, where it is the product of alteration of such minerals as feldspar, pyroxene, amphibole, biotite. Often associated with chlorite. Is formed frequently also during the metamorphism of an impure limestone, and is especially characteristic of contact metamorphic deposits in limestone.

Epidote is a widespread mineral. Notable localities for its occurrence in fine crystals are Knappenwand, Untersulzbachthal, Salzburg, Austria; Bourg d'Oisans, Isère, France; the Ala Valley and Traversella, Piedmont. In the United States found at Haddam, Connecticut; Riverside, California. In Alaska on Prince of Wales Island.

Name. From the Greek meaning *increase*, since the base of the prism has one side longer than the other.

Clinozoisite — $Ca_2Al_3(SiO_4)_3(OH)$

Crystallography. Monoclinic; prismatic. Crystals have prismatic aspect parallel to the ortho-axis. Striated parallel to the ortho-axis. Columnar, massive granular.

Physical Properties. **H.** = 6–6½. **G.** = 3.25–3.37. **Luster vitreous.** Color grayish white, green, pink. Transparent to translucent.

Composition. A hydrous calcium aluminum silicate, Ca_2Al_3-$(SiO_4)_3(OH)$. Clinozoisite and epidote form an isomorphous series. Manganese is present in the pink variety, *thulite.*

Tests. Fuses at 3–4 with intumescence to a light-colored slag. Yields a little water on intense ignition in the closed tube. Not decomposed by acids but will gelatinize after simple fusion.

Diagnostic Features. Characterized by the columnar habit and intumescence on fusion. Distinguished from epidote by its lighter color.

Occurrence. Clinozoisite is usually found in crystalline schists which have been derived by the metamorphism of a dark igneous rock containing calcic feldspar. Commonly accompanies an amphibole. In igneous rocks it is present as an alteration of plagioclase.

Name. Clinozoisite is so named because it is the monoclinic modification of zoisite. Zoisite is named after the Austrian Baron Zois von Edelstein.

Similar Species. *Zoisite* (orthorhombic) is dimorphous with clinozoisite. It is similar in appearance and occurrence to, but less common than, clinozoisite.

Allanite — $R_2''R_3'''(SiO_4)_3(OH)$

Orthite

Crystallography. Monoclinic; prismatic. Habit of crystals often similar to epidote. Commonly massive and in imbedded grains.

Physical Properties. H. = 5½–6. **G.** = 3.5–4.2. Luster submetallic to pitchy and resinous. Color brown to pitch-black. Often coated with a yellow-brown alteration product. Subtranslucent, will transmit light on thin edges.

Composition. A silicate of variable composition, $R_2''R_3'''(SiO_4)_3(OH)$ where $R'' =$ Ca, Ce, La, Na, and $R''' =$ Al, Fe, Mn, Be, Mg.

Tests. Fuses at 2½ with intumescence to a black magnetic glass. Gelatinizes in acids if not previously ignited.

Diagnostic Features. Characterized by its black color, pitchy luster, and association with granitic rocks.

Occurrence. Allanite occurs as a minor accessory constituent in many igneous rocks, such as granite, syenite, diorite, and pegmatites. Frequently associated with epidote. Has been noted in limestone as a contact mineral. Found in some magnetite bodies.

Notable localities are at Miask, Ural Mountains, U.S.S.R.; Greenland; Falun, Ytterby, and Sheppsholm, Sweden; Madagascar. In the United States allanite is found at Moriah, Monroe, and Edenville, New York; Franklin, New Jersey; Amelia Court House, Virginia; Barringer Hill, Texas.

Name. In honor of Thomas Allan, who first observed the mineral.

Similar Species. *Ilvaite,* $Ca(Fe,Mn)_2Fe'''(SiO_4)_2(OH)$, is a black orthorhombic mineral, somewhat similar in composition to members of the epidote group.

ZIRCON — $ZrSiO_4$

Crystallography. Tetragonal; ditetragonal-dipyramidal. Crystals usually show a simple combination of prism and dipyramid of the first order (Figs. 422 and 423). The prism of the second order and a ditetragonal dipyramid also observed (Fig. 424). Base very rare. Usually in crystals; also in irregular grains.

Physical Properties. H. = $7\frac{1}{2}$. G. = 4.68. Luster adamantine. Color commonly some shade of brown; also colorless, gray, green, red. Streak uncolored. Usually translucent; in some cases transparent.

Composition. Zirconium silicate, $ZrSiO_4$. $ZrO_2 = 67.2$ per cent, $SiO_2 = 32.8$ per cent.

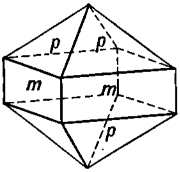

FIG. 422.

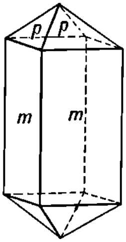

FIG. 423.

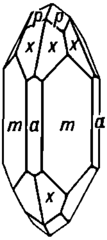

FIG. 424.

Zircon.

Tests. Infusible. A small fragment when intensely ignited glows and gives off a white light. When fused with sodium carbonate and fusion then dissolved in dilute hydrochloric acid, the solution will turn a piece of turmeric paper to an orange color (zirconium).

Diagnostic Features. Recognized usually by its characteristic crystals, color, luster, hardness, and high specific gravity.

Occurrence. Zircon is a common and widely distributed accessory mineral in all types of igneous rocks. It is especially frequent in the more silicic types such as granite, granodiorite, syenite, monzonite. Very common in nepheline syenite. It is usually the first silicate to crystallize out from a cooling magma. Found also commonly in crystalline limestone, in gneiss, schist, etc. Found frequently as rounded grains in stream and beach sands, often with gold.

Gem zircons are found in the stream sands at Matura, Ceylon, and in the gold gravels in the Ural Mountains and Australia. In large crystals from Madagascar. Found in the nepheline syenites of Norway. Found in the United States at Litchfield, Maine, and in Orange and St. Lawrence Counties, New York; in considerable quantity in the sands of Henderson and Buncombe Counties, North Carolina.

Use. When transparent serves as a gem stone. It is colorless in some specimens, but more often of a brownish and red-orange color, called *hyacinth* or *jacinth.* Blue is not a natural color for zircon but is produced by heat treatment. The colorless, yellowish, or smoky stones are called *jargon,* because while resembling the diamond they have little value; and thence the name *zircon.* Serves as the source of zirconium oxide, which was used extensively in the manufacture of the Nernst lamp. Zircon is now used as a refractory.

Similar Species. *Thorite,* $ThSiO_4$, is like zircon in form and structure; usually hydrated and black in color.

DATOLITE — $CaBSiO_4(OH)$

Crystallography. Monoclinic; prismatic. Crystals usually nearly equidimensional in the three axial directions and often complex in development (Fig. 425). Usually in crystals. Also coarse to fine granular. Compact, massive.

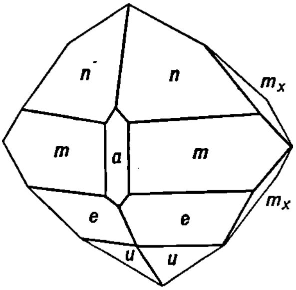

FIG. 425. Datolite.

Physical Properties. **H.** = 5–5½. **G.** = 2.8–3.0. Luster vitreous. Colorless, white, often with faint greenish tinge. Transparent to translucent.

Composition. A basic silicate of calcium and boron, $CaBSiO_4(OH)$. $CaO = 35.0$ per cent, $B_2O_3 = 21.8$ per cent, $SiO_2 = 37.6$ per cent, $H_2O = 5.6$ per cent.

Tests. Fuses at 2–2½ to a clear glass and colors the flame green (boron). Soluble in hydrochloric acid and yields gelatinous silica on evaporation. Gives a little water in the closed tube.

Diagnostic Features. Characterized by its glassy luster, pale green color, and its crystals with many and usually irregularly developed faces. Distinguished from quartz by ease of fusibility and boron flame. Massive datolite is difficult to recognize, and blowpipe and chemical tests are necessary for its identification.

Occurrence. Datolite is a mineral of secondary origin, found usually in cavities in basalt lavas and similar rocks. Associated with zeolites, prehnite, apophyllite, calcite. Notable foreign localities are Andreasberg, Harz Mountains; in Italy near Bologna; from Seiser Alpe and Theiso, Trentino; Arendal, Norway. In the United States occurs associated with the trap rocks of Massachusetts, Connecticut, and New Jersey, particularly at Westfield, Massachusetts, and Bergen Hill, New Jersey. Found associated with the copper deposits of Lake Superior.

Name. Derived from a Greek word meaning *to divide,* in allusion to the granular character of a massive variety.

TOPAZ — $Al_2SiO_4(F,OH)_2$

Crystallography. Orthorhombic; dipyramidal. In prismatic crystals terminated by pyramids, domes, and basal plane (Figs. 426, 427, and 428). Often highly modified (Fig. 429). Prism faces frequently vertically striated. Usually in crystals but also in crystalline masses; granular, coarse or fine.

Physical Properties. Perfect basal {001} cleavage. **H.** = 8 (unusually high). **G.** = 3.4–3.6. Luster vitreous. Colorless, straw-yellow, wine-yellow, pink, bluish, greenish. Transparent to translucent.

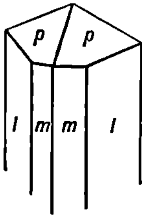

Fig. 426.

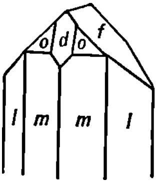

Fig. 427.

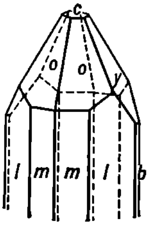

Fig. 428.

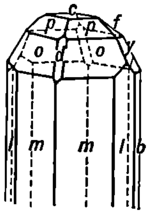

Fig. 429.

Topaz.

Composition. An aluminum fluosilicate, $Al_2SiO_4(F,OH)_2$.

Tests. Infusible. Insoluble. In a bulb tube with potassium disulfate gives a weak test for fluorine. With cobalt nitrate solution the pulverized mineral gives a fine blue on heating (aluminum).

Diagnostic Features. Recognized chiefly by its crystals, its basal cleavage, its hardness (8), and its high specific gravity.

Occurrence. Topaz is a mineral formed through the agency of fluorine-bearing vapors given off during the last stages of the solidification of igneous rocks. Found in cavities in rhyolite lavas and granite; a characteristic mineral in pegmatite dikes, especially in those carrying tin. Associated with other pneumatolytic minerals, as tourmaline, cassiterite, apatite, fluorite; also with beryl, quartz, mica, feldspar. Found in some localities as rolled pebbles in stream sands.

Notable localities for its occurrence are in the U.S.S.R. in the Nerchinsk district in Siberia in large wine-yellow crystals, and in Mursinsk, Ural Mountains, in pale blue crystals; in Saxony from various tin localities; from Minas Geraes, Brazil; Omi and Mino Provinces, Japan; San Luis Potosí, Mexico. In the United States found at Pikes Peak, near Florissant and Nathrop, Colorado; Thomas Range, Utah; Streeter, Texas; San Diego County, California; Stoneham and Topsham, Maine.

Use. As a gem stone. A number of other inferior stones are also frequently called topaz, or *oriental topaz.* The color of the stones varies, being colorless, wine-yellow, golden brown, pale blue, and pink. The pink color is usually artificial, being produced by gently heating the dark yellow stones.

Name. Derived from Topazion, the name of an island in the Red Sea, but originally probably applied to some other species.

Axinite — $H(Ca,Mn,Fe)_3Al_2B(SiO_4)_4$

Crystallography. Triclinic; pedial. Axinite is the only common mineral to crystallize in this class. Crystals usually thin with sharp edges but varied in habit (Fig. 430). Frequently in crystals and crystalline aggregates; also massive, lamellar to granular.

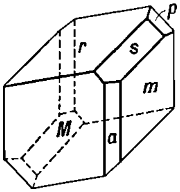

FIG. 430. Axinite.

Physical Properties. **H.** = $6\frac{1}{2}$–7. **G.** = 3.27–3.35. Luster vitreous. Color clove-brown, violet, gray, green, yellow. Transparent to translucent.

Composition. A hydrous aluminum borosilicate with varying amounts of calcum, manganese, and ferrous iron, $H(Ca,Mn,Fe)_3Al_2B(SiO_4)_4$.

Tests. Fusible at $2\frac{1}{2}$–3 with intumescence. When mixed with boron flux and the mixture heated on platinum wire gives a green flame (boron). Gives water in the closed tube. Insoluble, but when previously ignited gelatinizes with hydrochloric acid.

Diagnostic Features. Characterized by the triclinic crystals with very acute angles.

Occurrence. Axinite occurs in cavities in granite, and in the contact zones surrounding granitic intrusions. Notable localities for its occurrence are Bourg d'Oisans, Isère, France; various points in Switzerland; St. Just, Cornwall; Obira, Japan. In the United States at Luning, Nevada, and a yellow manganous variety at Franklin, New Jersey.

Name. Derived from a Greek word meaning *axe,* in allusion to the wedgelike shape of the crystals.

ANDALUSITE — Al_2SiO_5

Crystallography. Orthorhombic; dipyramidal. Usually in coarse, nearly square prisms terminated by the basal pinacoid.

Physical Properties. **H.** = $7\frac{1}{2}$. **G.** = 3.16–3.20. Luster vitreous. Color flesh-red, reddish brown, olive-green. The variety *chiastolite* has dark-colored carbonaceous inclusions arranged in a regular manner forming a cruciform design (Fig. 431). Transparent to translucent. In some cases strongly dichroic, appearing, in transmitted light, green in one direction and red in another.

Composition. Aluminum silicate, Al_2SiO_5. $Al_2O_3 = 63.2$ per cent, $SiO_2 = 36.8$ per cent.

Tests. Infusible. Insoluble. When fine powder is made into a paste with cobalt nitrate and intensely ignited it turns blue (aluminum).

Diagnostic Features. Characterized by the nearly square prism, hardness, and infusibility. Chiastolite is readily recognized by the symmetrically arranged inclusions.

Alteration. Pseudomorphs of fine-grained muscovite (sericite) after andalusite are common.

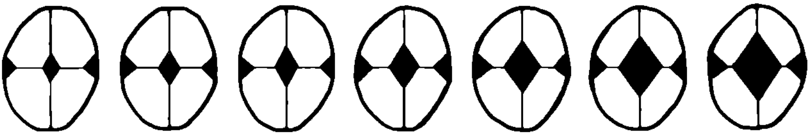

FIG. 431. Successive Cross Sections through a Chiastolite Crystal.

Occurrence. Andalusite is formed usually by the metamorphism of aluminous shales and slate. It may be the result of regional metamorphism or a contact mineral found especially in connection with granitic intrusions.

Notable localities are in Andalusia, Spain; the Austrian Tyrol; in water-worn pebbles from Minas Geraes, Brazil. Crystals of chiastolite are found at Bimbowrie, South Australia. In the United States found in the White Mountains near Laws, California; at Standish, Maine; Delaware County, Pennsylvania. Chiastolite is found at Westford, Lancaster, and Sterling, Massachusetts.

Use. Andalusite is mined in large quantities in California for use in the manufacture of spark plugs and other porcelain of a highly refractory nature. When clear and transparent may serve as a gem stone.

Name. From Andalusia, a province of Spain.

SILLIMANITE — Al_2SiO_5

Fibrolite

Crystallography. Orthorhombic; dipyramidal. Occurs in long slender crystals without distinct terminations; often in parallel groups; frequently fibrous.

Physical Properties. Perfect pinacoidal {010} cleavage. **H.** = 6–7. **G.** = 3.23. Luster vitreous. Color brown, pale green, white. Transparent to translucent.

Composition. An aluminum silicate like andalusite, Al_2SiO_5. Al_2O_3 = 63.2 per cent, SiO_2 = 36.8 per cent.

Tests. Infusible. Insoluble. The finely ground mineral turns blue when heated with cobalt nitrate solution.

Diagnostic Features. Characterized by slender crystals with one direction of cleavage.

Occurrence. Sillimanite is a comparatively rare mineral, found as an accessory constituent of gneiss, mica schist, etc.; rarely a contact mineral. Often occurs with corundum.

Notable localities for its occurrence are Maldau, Bohemia; Fassa, Austrian Tyrol; Bodenmais, Bavaria; Freiburg, Saxony; water-worn masses in diamantiferous sands of Minas Geraes, Brazil. In the United States found at Worcester, Massachusetts; at Norwich and Willimantic, Connecticut.

Name. In honor of Benjamin Silliman (1779–1864), professor of chemistry at Yale University.

KYANITE — Al_2SiO_5

Crystallography. Triclinic; pinacoidal. Usually in long, tabular crystals, rarely terminated. In bladed aggregates.

Physical Properties. Perfect pinacoidal {100} cleavage. **H.** = 5 parallel to length of crystals, 7 at right angles to this direction. **G.** = 3.56–3.66. Luster vitreous to pearly. Color usually blue, often of darker shade toward the center of the crystal. Also, in some cases, white, gray, or green. Color may be in irregular streaks and patches.

Composition. Aluminum silicate, like andalusite and sillimanite, Al_2SiO_5. Al_2O_3 = 63.2 per cent, SiO_2 = 36.8 per cent.

Tests. Infusible. Insoluble. A fragment moistened with cobalt nitrate solution and ignited assumes a blue color.

Diagnostic Features. Characterized by its bladed crystals, good cleavage, blue color, and the fact that it is softer than a knife in the direction parallel to the length of the crystals but harder than a knife in the direction at right angles.

Occurrence. Kyanite is an accessory mineral in gneiss and mica schist, often associated with garnet, staurolite, and corundum. Notable localities for its occurrence are St. Gothard, Switzerland; the Austrian Tyrol; Pontivy, Morbihan, France. In the United States found at Chesterfield, Massachusetts; Litchfield, Connecticut; Gaston, Lincoln, and Yancey Counties, North Carolina; northern Georgia.

Use. Kyanite is mined in North Carolina and Georgia for use in spark plugs and other highly refractory porcelains.

Name. Derived from a Greek word meaning *blue*.

Similar Species. *Mullite*, $Al_6Si_2O_{13}$, is rare as a mineral, but common in artificial melts, and it forms when kyanite, andalusite, and sillimanite are heated to high temperatures.

STAUROLITE — $Fe''Al_5Si_2O_{12}(OH)$

Crystallography. Orthorhombic. Habit prismatic, showing usually a combination of prism {110} with large angle (130°), brachypinacoid {010}, base {001}, and macrodome {101} (Fig. 432). Cruciform twins very common; of two types: (1) with the brachydome {032} the twin plane, in which the two individuals cross at nearly 90° (Fig. 433); (2) with the pyramid {232} the twin plane, in which they cross at nearly 60° (Fig. 434). In some cases both types are combined in one twin group. Usually in crystals; rarely massive.

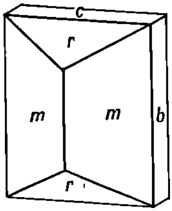

FIG. 432.

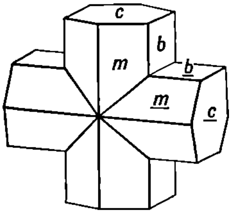

FIG. 433.

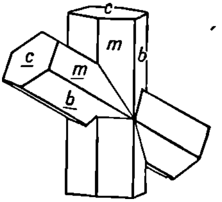

FIG. 434.

Staurolite.

Physical Properties. **H.** = 7–7½. **G.** = 3.65–3.75. Luster resinous to vitreous, for pure and fresh material; often dull to earthy when altered or impure. Color red-brown to brownish black. Translucent.

Composition. A ferrous iron aluminum silicate, $Fe''Al_5Si_2O_{12}(OH)$. Percentages of oxides are: $FeO = 15.8$, $Al_2O_3 = 55.9$, $SiO_2 = 26.3$, $H_2O = 2.0$.

Tests. Infusible. Insoluble. On intense ignition in the closed tube yields a little water. Often very impure.

Diagnostic Features. Recognized by its characteristic crystals and twins. Distinguished from andalusite by its obtuse prism.

Occurrence. Staurolite is an accessory mineral in crystalline schists, slates, and in some cases gneisses. Often associated with garnet, kyanite, sillimanite, tourmaline. May grow on kyanite in parallel orientation. In some localities may include carbonaceous impurities.

Notable localities for its occurrence are Monte Campione, Switzerland; Goldenstein, Moravia; Aschaffenburg, Bavaria; in large twin crystals in Brittany and Scotland. In the United States found at Windham, Maine; Franconia and Lisbon, New Hampshire; Chesterfield, Massachusetts; Macon, Madison, and Clay Counties, North Carolina; Fannin County, Georgia; Ducktown, Tennessee.

Use. Occasionally a transparent stone from Brazil is cut as a gem.

Name. Derived from a Greek word meaning *cross*, in allusion to its cruciform twins.

SPHENE — $CaTiSiO_5$

Titanite

Crystallography. Monoclinic. Crystals varied in habit. Often with prominent basal plane which is steeply inclined and which in combination with short prism and pyramid faces gives a thin wedge-shaped crystal (Figs. 435 and 436). Usually well crystallized or lamellar.

Physical Properties. Prismatic {110} cleavage. Parting parallel to the pyramid {221} may be present. **H.** = 5–5½. **G.** = 3.4–3.55. Luster resinous to adamantine. Color gray, brown, green, yellow, black. Transparent to translucent.

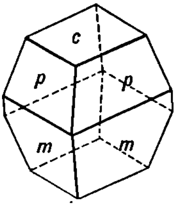

FIG. 435.

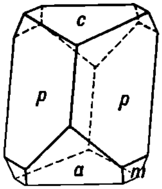

FIG. 436.

Sphene.

Composition. Calcium titanosilicate, $CaTiSiO_5$. $CaO = 28.6$ per cent, $TiO_2 = 40.8$ per cent, $SiO_2 = 30.6$ per cent. Iron is usually present in small amounts.

Tests. Fusible at 4 with slight intumescence to a dark mass. Only slightly attacked by hydrochloric acid. Gives violet bead with salt of phosphorus in reducing flame. Fused with sodium carbonate, fusion dissolved in sulfuric acid, solution turns yellow to amber on addition of hydrogen peroxide (titanium).

Diagnostic Features. Characterized by its wedge-shaped crystals and high luster. Hardness is less than that of staurolite and greater than that of sphalerite. The reaction for titanium is distinctive.

Occurrence. Sphene is a rather common accessory mineral in igneous rocks, being found as small crystals in granites, granodiorites, diorites, syenites, nepheline syenites. Also found in crystals of considerable size imbedded in the metamorphic rocks, gneiss, chlorite schist, and crystalline limestone. Very commonly associated with chlorite. Also found with iron ores, pyroxene, amphibole, scapolite, zircon, apatite, feldspar, quartz.

The most notable locality for its occurrence is on the Kola Peninsula, U.S.S.R., where it is associated with apatite and nepheline in connection with large intrusions of nepheline syenite. It is mined there extensively as a granular aggregate. It is found in crystals at Tavetsch, Binnental, and St. Gothard, Switzerland; Zillertal, Tyrol; Ala, Piedmont; Vesuvius; Arendal, Norway. In the United States in Diana, Rossie, Fine, Pitcairn, Edenville, and Brewster, New York. Also in various places in Ontario and Quebec, Canada.

Use. As a source of titanium for use as a paint pigment.

Name. *Sphene* comes from a Greek word meaning *wedge*, in allusion to a characteristic development of the crystals.

Similar Species. *Benitoite* is a calcium titanium silicate associated with *neptunite* in San Benito, California. *Astrophyllite, aenigmatite, lamprophyllite, ramsayite, fersmannite* are rare titanium-bearing silicates found associated with alkalic rocks.

Dumortierite — $Al_8BSi_3O_{19}(OH)$

Crystallography. Orthorhombic; prismatic. Rarely in distinct crystals. Usually in fibrous to columnar aggregates, frequently radiating.

Physical Properties. Poor pinacoidal {100} cleavage. **H.** = 7. **G.** = 3.26–3.36. Luster vitreous. Color blue, greenish blue, violet, pink. Transparent to translucent.

Composition. An aluminum borosilicate, $Al_8BSi_3O_{19}(OH)$. Percentages of oxides are: $Al_2O_3 = 64.6$, $B_2O_3 = 5.5$, $SiO_2 = 28.5$, $H_2O = 1.4$.

Tests. Infusible; loses color on ignition. Heated with cobalt nitrate solution turns blue (aluminum). Yields a small amount of water in the closed tube.

Diagnostic Features. Characterized by fibrous habit, but difficult to identify positively without optical tests.

Occurrence. Dumortierite is found in schists and gneisses, and, more rarely, in pegmatite dikes. Notable localities are Lyon, France; Wolfschau, Silesia; Madagascar; Rio de Janeiro, Brazil; Nacozari, Mexico. In the United States is found at Dehesa, California; in Nevada at Oreana and over a large area in the Rochester mining district.

Use. Dumortierite is mined in Nevada for use in the manufacture of high-grade porcelain.

Name. In honor of the French paleontologist, Eugene Dumortier.

OCCURRENCE AND ASSOCIATION OF MINERALS

Although minerals have many modes of occurrence, and an almost endless variety of associations, there are, nevertheless, certain ways in which their occurrence is common and characteristic. An understanding of the conditions under which a particular mineral is usually formed, together with a knowledge of the other minerals that are characteristically associated with it, is of the greatest value in the identification of the mineral. On the following pages is given, therefore, a brief discussion of the more important modes of mineral occurrence, and of the more common associations.

ROCKS AND ROCK-FORMING MINERALS

Since minerals occur most commonly and abundantly as rock constituents a short description of the more important rock types and of the common rock-forming minerals will be given first. Only the barest outline of the subject can be presented here; for more detailed information the reader is referred to one of the textbooks which treats more particularly of petrology.

Rocks are divided into the three main divisions:

I. Igneous. II. Sedimentary. III. Metamorphic.

I. Igneous Rocks

Igneous rocks, as the name indicates, are those which have been formed by the cooling and consequent solidification of a once hot and fluid mass of rock material, known as a rock magma. A magma is a solution containing the chemical constituents which, when cooled sufficiently, crystallize to form the various minerals that make up the resulting rock. The elements which form the chief constituents of the magmas of igneous rocks, named in the order of their abundance, are oxygen, silicon, aluminum, iron, calcium, magnesium, sodium, and potassium. When a magma cools each mineral crystallizes out when its point of supersaturation is reached. Some minerals crystallize from the fluid mass earlier than others, and thus, in most igneous rocks, a more or less definite order of crystallization of the various mineral constituents can be determined. In general, the dark minerals and those which contain the smaller amounts of silica crystallize first, and minerals rich in silica last. Among the more common rock-forming minerals the usual order of crystallization is: the accessory minerals such as zircon, rutile, hematite, ilmenite, magnetite; then the ferromagnesian minerals, like pyroxenes and amphiboles; next the plagioclase feldspars; then orthoclase and quartz.

The mineral assemblage found in any igneous rock depends chiefly upon the chemical composition of the original magma. If the magma had a high percentage of silica, the resulting rock would contain the silica-rich minerals and free quartz. It would usually be light in color. If, on the other hand, the magma had a low percentage of silica, the resulting rock would contain minerals poor in silica and no quartz. It would, in general, be dark in color.

In addition to the wide variation in chemical and mineral composition shown by igneous rocks there is also a variation in the size of the crystals that make up the rock. This is determined chiefly by the rate at which the rock cooled. If a rock has been formed from a magma buried at a considerable depth in the crust of the earth it must have cooled very slowly and taken a long period of time for its gradual crystallization and solidification. Under these conditions the mineral particles would have had the opportunity, because of the slowness of crystallization, to grow to considerable size. A rock having such a deep-seated origin has, therefore, a coarse texture, and its constituent minerals can usually be recognized and differentiated by the unaided eye. Such rocks are commonly termed *plutonic.*

On the other hand, if the magma has been extruded upon the surface of the earth, its subsequent cooling and solidification go on rapidly. Under these conditions the mineral particles have little chance to grow and the resulting rock is fine-grained. In some cases the cooling has been too rapid to allow the separation of any minerals and the resulting rock is a glass. Ordinarily the mineral constituents of fine-grained rocks can be definitely recognized only by a microscopic examination of a thin section of the rock. Such igneous rocks are known as *volcanic* or *extrusive* rocks.

Magma intruded as dikes and sills close to the earth's surface forms a group of rocks known as *hypabyssal.* The texture of these rocks is usually finer than that of the plutonic but coarser than that of the volcanic.

Porphyry and Porphyritic Texture

Some igneous rocks show distinct crystals of some minerals which lie imbedded in a much finer-grained matrix. These larger crystals are known as *phenocrysts,* and the finer-grained material as the *groundmass.* Such rocks are known as *porphyries.* The phenocrysts may vary in size from crystals an inch or more across down to very small individuals. The groundmass may also be composed of fairly coarse-grained material or its grains may be microscopic in size. It is the difference in size existing between the phenocrysts and the particles of the groundmass that is the distinguishing feature of a porphyry. The porphyritic texture develops when some of the crystals grow to considerable size before the main mass of the magma consolidates into the finer and uniform-grained material. Any one of the types of igneous rocks described below may have a porphyritic variety, such as *granite-porphyry, diorite-porphyry, rhyolite-porphyry.* Porphyritic varieties occur more frequently in volcanic rocks, especially in the more siliceous types.

An igneous rock, because of the mode of its formation, consists of crystalline particles which may be said to interlock with each other, and each mineral particle is intimately and firmly imbedded in the surrounding particles. This texture will enable one ordinarily to distinguish an igneous from a sedimentary rock, the latter being composed of grains which do not interlock with each other but stand out, more or less, by themselves. A sedimentary rock is not so firm and coherent as an igneous rock. Further, the texture of most igneous rocks is the same in all directions, and it forms a fairly uniform and homogeneous mass. This characteristic will enable one to distinguish an igneous from a metamorphic rock, since the latter commonly shows a layered structure, with a more or less definite parallel arrangement of its minerals.

Because of the almost infinite variation possible in the chemical composition of magmas, and because of the various conditions under which they may form, igneous rocks show a wide variation in character; and there is a complete gradation from one rock type into another, so that the names of igneous rocks, and the boundaries between types, are largely arbitrary.

Classification of the Igneous Rocks

Many schemes have been proposed for the classification of igneous rocks, but the most practical for the elementary student are based on the mineral content. It can be said in general that three criteria are to be considered in classifying a rock. 1. The relative amount of silica present. Quartz indicates an excess of silica; feldspathoids indicate a deficiency of silica. 2. The kinds of feldspar present and the relative amount of each kind. 3. The texture, or size of the grains. Is the rock coarse or fine grained; that is, is it plutonic or volcanic?

It is obvious that the exact determination of the kind of feldspar or a correct estimate of the amount of each kind is impossible in the field or in the hand specimen. It is also impossible in many fine-grained rocks to recognize individual minerals. Such precise work must be left for the laboratory and carried out by the microscopic examination of thin sections of rocks. Nevertheless, it is important that the basis for the general classification be understood in order that a simplified field classification may have more meaning.

Three major divisions may be made on the basis of the silica content.* 1. Quartz present in amounts greater than 5 per cent. 2. Less than 5 per cent quartz or 5 per cent feldspathoids. 3. Feldspathoids in amounts greater than 5 per cent. The above divisions made on the basis of silica content are further divided according to the kind and amount (or the absence) of feldspar. Most of the rocks thus classified have a coarse- and fine-grained variety, which receive different names. The table on page 358 gives the principal rock types according to such a classification. It should be remembered that, although these rock names are the most important, over 600 have been proposed to indicate specific types.

Plutonic Rocks

Brief descriptions of the more important rock types listed in the following table are given below.

Granite–Granodiorite. Granite is a granular rock of light color and even texture consisting chiefly of feldspar and quartz. Usually both potash feldspar and oligoclase are present; the former may be flesh-colored or red, while the latter is commonly white and can be recognized by the presence of albite twinning striations. The quartz can be recognized by its glassy luster and lack of cleavage. Granites usually carry a small amount (about 10 per cent) of mica or hornblende. The mica is commonly biotite, but muscovite may also be present. The minor accessory minerals are zircon, sphene, apatite, magnetite, ilmenite.

A complete series of rocks exists which grades from a granite whose feldspar is almost entirely potash varieties to granodiorite whose feldspar is mostly plagioclase with only slightly more than 5 per cent potash feldspar. The boundary between the two types is arbitrarily set. Granites are those rocks in which potash feldspar exceeds plagioclase; granodiorites are those in which plagioclase exceeds potash feldspar. In most instances it so happens that as the plagioclase increases in amount the percentage of dark minerals also increases, and thus, in general, granodiorites are darker than granites. However, in the field or in a hand specimen, it is usually impossible to distinguish between the two rock types with certainty.

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* Feldspathoids are minerals which take the place of all, or part, of the feldspar in rocks low in silica. A magma may have just the exact amount of silica to combine with the alkalis, calcium, and aluminum and form feldspar on complete crystallization of the rock. If silica is in excess of this amount, quartz will form; if there is a deficiency, feldspathoids will form.

SIMPLIFIED CLASSIFICATION OF THE IGNEOUS ROCKS

Feldspar	Quartz > 5 per cent		No Quartz; No Feldspathoids		Nepheline or Leucite > 5 per cent	
	Coarse	Fine	Coarse	Fine	Coarse	Fine
*Potash feldspar > plagioclase	Granite	Rhyolite	Syenite	Trachyte	Nepheline syenite Leucite syenite	Phonolite Leucite phonolite
Plagioclase > potash feldspar	Granodiorite	Quartz latite	Monzonite	Latite	Nepheline monzonite	
Plagioclase (oligoclase or andesine)	Tonalite	Dacite	Diorite	Andesite	Nepheline diorite	
Plagioclase (labradorite to anorthite)	Quartz gabbro		Gabbro	Basalt	Nepheline gabbro	Tephrite (−olivine) Basanite (+olivine)
No feldspar			Peridotite (olivine dominant) Pyroxenite (pyroxene dominant) Hornblendite (hornblende dominant)		Ijolite	Nephelinite (−olivine) Nepheline basalt (+olivine)

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* Under potash feldspar are included orthoclase, microcline, anorthoclase, microperthite.

Syenite–Monzonite. A syenite is a granular rock of light color and even texture composed essentially of potash feldspar and oligoclase, with lesser amounts of hornblende, biotite, and pyroxene. It thus resembles a granite in appearance, but differs from granite in that it contains less than 5 per cent quartz. Accessory minerals are apatite, sphene, zircon, and magnetite.

A series exists between syenite and monzonite, and if plagioclase feldspar exceeds potash feldspar the rock is called a monzonite. Monzonites are usually darker than syenites, for an increase in dark minerals frequently accompanies an increase in plagioclase. However, without microscopic aid it is rarely possible to distinguish between the two types.

Nepheline is present in some syenites; if the amount exceeds 5 per cent, the rock is called a *nepheline syenite.* The nepheline has a greasy luster and may be mistaken for quartz, but can be distinguished by its hardness (5½–6). Some nepheline syenites may contain sodalite; others, corundum.

Syenites in which leucite is present in amounts greater than 5 per cent are called *leucite syenites.* The leucite can be recognized by its trapezohedral form. Such rocks are extremely rare.

Tonalite. A *tonalite* or *quartz diorite* is composed essentially of plagioclase feldspar and quartz with only minor amounts of potash feldspar (less than 5 per cent). The plagioclase is oligoclase or andesine. Dark minerals, especially biotite and hornblende, are plentiful; pyroxene is more rarely present. Apatite, sphene, magnetite are common accessory minerals. Although not essential to the classification, dark minerals are usually abundant, and thus in general, tonalites are darker in color than granites and granodiorites.

As the plagioclase becomes richer in lime, tonalite grades into the rather uncommon rock *quartz gabbro.* With a lessening of the amount of quartz, it grades into *diorite.*

Diorite–Gabbro. A diorite is a granular rock characterized by plagioclase feldspar (oligoclase to andesine) but lacking quartz and potash feldspar in appreciable amounts. Hornblende is the principal dark mineral, but biotite is usually present. Pyroxenes are rare. Magnetite, ilmenite, apatite, and, less commonly, sphene and zircon are accessory minerals. Normally dark minerals are present in sufficient amount to give the rock a dark appearance.

If the plagioclase is more calcic in composition than andesine (labradorite to anorthite) the rock is called a gabbro. Although the distinction is made on this criterion alone, it so happens that rocks carrying labradorite or more calcic plagioclase usually have pyroxene as the chief dark constituent, while the diorites with more sodic feldspar usually have amphiboles as dark minerals. Olivine is also present in most gabbros.

The name *norite* is given to a gabbro in which the pyroxene is essentially hypersthene; it is usually impossible to make this distinction without microscopic aid. A type of gabbro, known as *anorthosite* is composed almost entirely of feldspar and is, therefore, light in color.

If amounts of nepheline in diorites and gabbros exceed 5 per cent the rocks are called respectively nepheline diorite and nepheline gabbro. These rocks are rare and unimportant.

The term *diabase* is sometimes used to indicate a fine-grained gabbro characterized by a certain texture. This "diabasic" texture is shown microscopically to have augite filling the interstices of tabular plagioclase crystals.

Peridotite. A peridotite is a granular rock composed of dark minerals; feldspar is negligible (less than 5 per cent). The dark minerals are chiefly pyroxene and olivine in varying proportions, but hornblende may be present. .If the rock is composed almost wholly of pyroxene it is called a *pyroxenite;* if it is composed almost wholly of olivine it is called a *dunite.* The name *hornblendite* is given to a rare type of rock composed almost wholly of hornblende. Magnetite, chromite, ilmenite, and garnet are frequently associated with peridotites. Platinum is associated with chromite in some peridotites, usually dunites, while diamond is found in a variety of peridotite known as *kimberlite.*

The olivine in peridotites is usually altered in whole or in part to the mineral serpentine. If the entire rock is thus altered the name *serpentine* is given to it.

Volcanic Rocks

Because of their fine-grained texture it is much more difficult to distinguish between the different types of volcanic rocks than between their plutonic equivalents. In the field only an approximate classification, depending chiefly upon whether the rock is light or dark in color, can be made. The term *felsite* is thus used to include the dense, fine-grained rocks of all colors except dark gray, dark green, or black. Felsite thus embraces the following types described below: rhyolite, trachyte, quartz latite, latite, dacite, and andesite. The experienced petrographer may be able, by the aid of a hand lense, to discern differences in texture or mineral composition which enable him to classify these rocks fairly accurately, but to the untrained observer they all appear much the same.

Fine-grained rocks that are a very dark green or black are called *traps.* This term is applied to dark, fine-grained rocks of indefinite mineral composition irrespective of whether they have been intruded as dikes or extruded as lava. It so happens that rocks thus classified as traps in the field or hand specimen are almost always basalts and satisfy the more rigorous classification based on microscopic examination.

Rhyolite is a dense fine-grained rock, the volcanic equivalent of a granite. It is thus composed essentially of alkali feldspar and quartz, but much of the silica may be present as tridymite or cristobalite. Phenocrysts of quartz, orthoclase (frequently sanidine), and oligoclase are common. Dark minerals are never abundant, but dark brown biotite is most common. Augite and hornblende are found in some rhyolites.

Rhyolites may be very uniform in appearance or may show a flow structure, giving a banded or streaked appearance to the rock. The groundmass may be partly or wholly glassy. Where the rock is completely glassy and of a compact nature it is known as *obsidian* and is usually black. Similar glassy rocks of a brown, pitchy appearance are called *pitchstones*. *Pumice* is rhyolite glass in which expanding gas bubbles have distended the magma to form a highly vesicular material. In pumice, therefore, cavities are so numerous as to make up the bulk of the rock and give it an apparent low specific gravity.

Trachyte is the volcanic equivalent of syenite. It is thus composed chiefly of alkali feldspar with some dark minerals, but lacks quartz. Small amounts of tridymite and cristobalite are often found in gas cavities. Phenocrysts of sanidine are frequently present and characteristically show Carlsbad twinning; phenocrysts of oligoclase, biotite, hornblende, and pyroxene are less common. Olivine may be present.

Banding or streaking, due to flow, is common in the trachytes. Unlike the rhyolites, glass is seldom found in the groundmass and there are thus few glassy or vesicular types. As a result of flow the tabular feldspar frequently shows a subparallel orientation which is so common in trachytes that it is called *trachytic texture*.

Phonolite is the volcanic equivalent of nepheline syenite and is thus poorer in silica than trachyte. This is expressed mineralogically by the presence of feldspathoids. Orthoclase (sanidine) is the common feldspar; albite is rarely present. Nepheline occurs in the groundmass as minute hexagonal crystals and can be observed only by microscopic aid. Sodalite and other feldspathoids may be present, usually altered to zeolites. When leucite is present it is in well-formed crystals which range from microscopic sizes to ½ inch in diameter. When leucite is present the rock is known as a *leucite phonolite*. Aegirite is the common dark mineral and normally occurs as phenocrysts, but biotite may be abundant in the leucite-rich rocks. The phonolites are completely crystalline, and there are thus no glassy varieties.

Latite and **quartz latite** are respectively the volcanic equivalents of monzonite and granodiorite. They, therefore, contain plagioclase in excess of potash feldspar. The dark minerals are chiefly biotite and hornblende. The distinction between them rests on the amount of quartz present; quartz latites would contain more, latites less, than 5 per cent quartz. Both of these rocks are relatively unimportant.

Dacite is the dense volcanic equivalent of tonalite or quartz diorite. It contains plagioclase feldspar and quartz, both of which may occur as phenocrysts. The dark mineral is usually hornblende, but biotite is found in some varieties. Some glass may be present in the groundmass, but glassy equivalents of dacites are rare.

Andesite is the volcanic equivalent of diorite and thus is composed chiefly of oligoclase or andesine feldspar. Orthoclase and quartz are absent or present in amounts of less than 5 per cent. Hornblende, biotite, augite, or hypersthene may be present, frequently as phenocrysts. Andesites are usually named according to the dark mineral present, as *hornblende andesite*, *hypersthene andesite*, etc. In some andesites the groundmass is partly glassy and in rarer types completely so.

Andesites are abundant in certain localities, notably in the Andes Mountains of South America, from which locality the rock receives its name.

Basalt is a dark-colored, fine-grained rock, the volcanic equivalent of gabbro. Labradorite feldspar is the chief constituent of the groundmass, while more calcic plagioclase (bytownite to anorthite) may be present as phenocrysts. Augite and olivine are usually present; the augite is frequently found both as phenocrysts and in the groundmass, while olivine, as a rule, is only in phenocrysts. Brown hornblende and brown biotite are present in some basalts.

The groundmass of some basalts contains small amounts of interstitial glass and in rare instances is wholly glassy. Gas cavities near the top of basalt flows may be abundant enough to make the rock vesicular. If the cavities are drawn out by flow, the rock is known as an *amygdaloidal basalt.*

The presence of nepheline or leucite in basalt gives rise to the rare rock types *tephrite* and *leucite tephrite.*

Basalts are the most abundant of the volcanic rocks and form extensive lava flows in many regions; the most noted are the Columbia River flows in western United States and the Deccan " traps " of western India. Many of the great volcanos, such as form the Hawaiian Islands, are built up of basaltic material. In addition to forming extrusive rock masses basalt is widely found forming many small dikes and other intrusives.

Fragmental Igneous Rocks

During periods of igneous activity volcanos eject much fragmental material which accumulates and forms the *fragmental igneous rocks,* or *pyroclastic rocks.* The ejectamenta vary greatly in size. Rock composed of finer particles of *volcanic ash* and *volcanic dust* is called *tuff;* that composed of coarser *volcanic bombs* is called *agglomerate,* or *volcanic breccia.* Such rocks are frequently water-laid and bedded, and thus form a transition between the igneous and sedimentary rocks.

The Igneous Rock-Forming Minerals

Many minerals are found in the igneous rocks, but those that can be called rock-forming minerals are comparatively few in number. The following list is divided into two parts: (1) the common rock-forming minerals of igneous rocks; (2) the accessory minerals of igneous rocks.

Common Rock-Forming Minerals of Igneous Rocks

1. Quartz.
2. Feldspars.
    - Orthoclase.
    - Microcline.
    - Plagioclase.
3. Nepheline.
4. Sodalite.
5. Leucite.
6. Micas.
    - Muscovite.
    - Biotite.
    - Phlogopite.
7. Pyroxenes.
    - Augite.
    - Aegirite.
    - Hypersthene.
8. Amphiboles.
    - Hornblende.
    - Arfvedsonite.
    - Riebeckite.
9. Olivine.

Common Accessory Minerals of Igneous Rocks

1. Zircon.
2. Sphene.
3. Magnetite.
4. Ilmenite.
5. Hematite.
6. Apatite.
7. Pyrite.
8. Rutile.
9. Corundum.
10. Garnet.

Pegmatites

Pegmatites are extremely coarse-grained igneous bodies closely related genetically and in space to large masses of plutonic rocks. They are commonly found as veins or dikes traversing the granular igneous rock or extending out from it into the surrounding country rock. Granites more frequently than any other rock have pegmatites associated with them; consequently, unless modified by other terms, pegmatite refers to *granite pegmatite.* The minerals in most pegmatites, therefore, are the common minerals found in granite — quartz, feldspar, mica — but of extremely large size. Crystals of these minerals measuring a foot across are common, and in some localities they reach gigantic sizes. Probably the largest crystals ever found were of feldspar in pegmatites in Karelia, U.S.S.R., where material weighing thousands of tons was mined from single crystals. Quartz crystals weighing thousands of pounds and mica crystals over 10 feet across have been found. One of the characteristics of pegmatites is the simultaneous and interpenetrating crystallization of quartz and feldspar (usually microcline) to form *graphic granite.* (See Plate XV, Fig. 1.)

Although most pegmatites are composed entirely of the minerals found abundantly in granite, those of greatest interest contain other, and rarer, minerals. In these pegmatites there has apparently been a definite sequence in deposition. The earliest minerals are microcline and quartz, with smaller amounts of garnet and black tourmaline. These are followed, and partly replaced, by albite, lepidolite, gem tourmaline, beryl, spodumene, amblygonite, topaz, apatite, and fluorite. A host of rarer minerals such as triphylite, columbite, monazite, molybdenite, and uranium minerals may be present. In places some of the above minerals are abundant and form large crystals that are mined for their rare constituent elements. Thus spodumene crystals over 40 feet long have been found in the Black Hills of South Dakota, and beryl crystals from Albany, Maine, have measured as much as 18 feet long and 4 feet in diameter.

The formation of pegmatite dikes is believed to be directly connected with the crystallization of the larger mass of associated plutonic rock. The process of crystallization brings about a concentration of the volatile constituents in the remaining liquid portion of the magma. The presence of these volatiles (water, boron, fluorine, chlorine, and phosphorus) decreases the viscosity and thus facilitates crystallization. Such an end-product of consolidation is also enriched in the rare elements originally disseminated through the magma. When this residual liquid is injected into the already crystallized rock, its fluid nature permits coarse crystallization, and the concentration of rare elements gives rise to the unusual minerals found in pegmatites.

Nepheline syenite pegmatites have been found in a number of localities. They are commonly rich in unusual constituents and contain numerous zirconium, titanium, and rare-earth minerals.

II. Sedimentary Rocks

Sedimentary rocks are secondary in their origin; the materials of which they are composed have been derived from the weathering of some previously existing rock-mass. They are deposited in areas of accumulation by the action of water or, less frequently, by glacial or wind action. Weathering includes both chemical decomposition and mechanical disintegration, and thus the end products consist of clay minerals, various soluble salts, and grains of inert minerals such as quartz, zircon, rutile, and magnetite. The sedimentary rocks may be divided into two classes, depending upon whether their origin has been mechanical or chemical in its nature. Sedimentary rocks of mechanical origin are composed of particles of clay minerals, or grains of minerals which have resisted chemical attack. These materials have been mechanically transported by streams into a body of water, where they have been deposited in layers. Sedimentary rocks of chemical origin have had the materials of which they are composed dissolved by waters circulating through the rocks and brought ultimately by these waters into the sea or a lake, where, through some chemical or organic process, they are precipitated.

All sedimentary rocks are, in general, characterized by a parallel arrangement of their constituent particles forming layers or beds which are distinguished from each other by differences in thickness, size of grain, or color. In all the coarser-grained sedimentary rocks there is some material which acts as a cement and surrounds the individual mineral particles, binding them together. This cement is usually silica, calcium carbonate, or iron oxide.

Mechanical Sedimentary Rocks

Conglomerate. Conglomerates may be considered consolidated gravels. They are composed of coarse pebbles, usually rounded by stream transportation. The individual pebbles may be composed of quartz entirely, or may be rock fragments that have not been decomposed. Fine conglomerates grade into coarse sandstones.

Sandstone. Beds of sand that have been consolidated into rock masses are called sandstones. The constituent grains are usually rounded and water-worn, but may be more or less angular. The cement which binds the sand grains together may be silica, a carbonate (usually calcite), an iron oxide (hematite or limonite), or fine-grained argillaceous material. The color of the rock depends in large measure upon the character of the cement. The rocks which have silica or calcite as their binding material are light in color, usually pale yellow, buff, white to gray, while those that contain an iron oxide are red to reddish brown. It is to be noted that when a sandstone breaks it is usually the cement that is fractured, the individual grains remaining unbroken, so that the fresh surfaces of the rock have a granular appearance and feeling. The chief mineral of sandstones is quartz; if the rock contains notable amounts of feldspar it is termed *arkose*. In the finer-grained sandstones there may be considerable clayey material; such rocks grade into the shales.

Shale. The shales are very fine-grained sedimentary rocks which have been formed by the consolidation of beds of mud, clay, or silt. They have usually a thinly laminated structure. Their color is commonly some tone of gray, although they may be white, yellow, brown, or green to black. They are composed chiefly of the clay minerals and mica, but are too fine grained to permit the recognition of their mineral constituents by the eye alone. By the introduction of quartz and an increase in the size of grain they grade into the sandstones, and with the presence of calcite they grade into the limestones.

Chemical Sedimentary Rocks

The sedimentary rocks that are formed by chemical processes are here divided into three groups: (1) those produced by direct precipitation from an aqueous solution; (2) those in which organisms have been the active agent in extracting the rock-forming materials from solution; (3) those in which the final rock is the result of a partial or complete replacement of an earlier-formed sedimentary rock.

1. Precipitation. When a saline solution evaporates, the dissolved salts are precipitated in a definite order, the least soluble first, the most soluble last. There are thus several types of sedimentary rocks which have formed through precipitation from evaporating sea water. Gypsum, anhydrite, and rock salt are the most important.

Gypsum is the first mineral to precipitate in large amounts on the evaporation of sea water, and under appropriate conditions thick beds of gypsum may be built up. As a rock, gypsum is usually fine grained but in places shows a fibrous or platy habit. Because of its method of formation, gypsum is frequently associated with other saline deposits and with limestone and shale.

Anhydrite follows gypsum in the sequence of the precipitation of salts from sea water. It thus is found in beds similar to gypsum and associated with it and saline deposits. Anhydrite may alter to gypsum.

Rock Salt. Granular aggregates of the mineral halite commonly occur in beds of considerable thickness and in this form are known as *rock salt.* Halite follows gypsum and anhydrite in the sequence of precipitation from an evaporating sea water, and thus commonly overlies beds of these minerals. In some deposits the more soluble salts such as sylvite, carnallite, and polyhalite are associated with halite; the deposit may then become a source of potash.

Oölitic Limestone. This variety of limestone, composed of small spherical concretions resembling fish roe, is believed to have been chemically precipitated. Each tiny concretion has a nucleus of a sand grain, shell fragment, or some foreign particle around which deposition has taken place. Oölitic sand is forming at the present time on the floor of the Great Salt Lake which, on consolidation, would produce an oölitic limestone.

Travertine is a calcareous material deposited from spring waters under atmospheric conditions. If the deposit is porous it is known as *calcareous tufa.* Such deposits are prevalent in limestone regions where circulating ground water containing carbon dioxide has taken considerable calcium carbonate in solution. When the ground water reaches the surface as springs some of the carbon dioxide is given off, resulting in the precipitation of some of the calcium carbonate. In this way travertine deposits are built up.

Siliceous Sinter. In certain volcanic regions hot springs deposit an opaline material known as *siliceous sinter* or *geyserite.* The deposit is apparently due both to evaporation and to secretion of silica by algae.

2. Organic Precipitation. *Limestone.* Many organisms living in the sea secrete calcium carbonate from the water to build up hard, protective shells. On the death of the organisms the hard calcareous parts accumulate on the sea floor. When marine life is abundant great thicknesses of shells and other hard parts may build up, which, when consolidated, produce limestone. There are several varieties of limestone, depending on the type of fossil from which it is made, or on the texture. *Chalk* is a variety of porous, fine-grained limestone composed for the most part of foraminiferal shells. *Coquina* is a limestone, found on the coast of Florida, consisting of shells and shell fragments only partially consolidated. *Lithographic limestone* is an extremely fine-grained rock from Solenhofen, Bavaria.

Limestones are made up dominantly of calcite but may contain small amounts of other minerals. If impurities of clay are abundant, limestone grades toward shale and would be called an *argillaceous limestone.* When dolomite becomes an important constituent of a limestone the rock grades toward the rock known as *dolomite.*

Limestone is a common type of sedimentary rock and in many regions is not only of great areal extent but of great vertical thickness as well.

Diatomaceous Earth. Diatoms are minute one-celled organisms which live in both fresh and sea water and have the power of secreting shells of opaline material. When the organisms die their tiny shells accumulate to build up a chalklike deposit of diatomaceous earth. If compacted, the rock is known as *diatomite.*

3. Replacement. Some sedimentary rocks, particularly limestones, have, after their formation, been replaced in whole or in part through reaction with elements in sea water or in circulating ground waters. The rocks resulting from such reactions are considered here.

Dolomite. The rock *dolomite* resembles limestone so closely in all its physical properties that it is usually impossible to distinguish between them without a chemical test. Moreover, dolomite as a rock name is not restricted to a material of the composition of the mineral dolomite but may have admixed calcite. Dolomites have formed not as original rocks but by the alteration of a pure limestone in which part of the calcium is replaced by magnesium. This process of *dolomitization* is believed to have been brought about either by the action of sea water shortly after original deposition, or by the action of circulating ground water after the rock has been consolidated and raised above sea level.

Magnesite. As a sedimentary rock *magnesite* is much more restricted in its distribution than dolomite. It has been formed by the almost complete replacement by magnesium of the calcium of an original limestone. Such magnesite rocks are found in Austria and in the Ural Mountains, U.S.S.R.

III. Metamorphic Rocks

Metamorphic rocks are those which have undergone some chemical or physical change subsequent to their original formation. In general, metamorphic rocks are divided into two groups: (1) those formed by regional metamorphism, (2) those formed by contact metamorphism.

Regional Metamorphic Rocks

Various geologic agencies acting over wide areas bring about changes in great masses of rocks. The metamorphosis is brought about by means of high temperature and high pressure aided by the action of water and other chemical agents. The changes involve the formation of new minerals, the adding or subtracting of chemical constituents, and a physical readjustment of the mineral particles to conform to the new condition. The original rock from which a metamorphic rock has been derived may be either igneous or sedimentary, but the process of metamorphism may completely alter the original features. As rocks become involved in movements of the earth's crust, they are subjected to extreme pressures accompanied usually by high temperatures. The result will frequently be to transform the existing minerals into others more stable under the new conditions. The physical structure of the rock will also ordinarily be changed during the process. Because of the pressure to which the rock is subjected the mineral particles will be more or less broken and flattened or will recrystallize to form in parallel layers. This banded or laminated character given by the parallel arrangement of minerals is the most striking peculiarity of a metamorphic rock. Because of this structure a metamorphic rock can be distinguished from an igneous rock. Further, most metamorphic rocks have a texture of interlocking crystals which distinguishes them from sedimentary rocks. There are, of course, all gradations from a typical metamorphic rock into an unaltered sedimentary rock on the one hand and into an unaltered igneous rock on the other. The most common types of metamorphic rocks are briefly described below.

Gneiss. When the word gneiss is used alone it refers to a coarsely foliated metamorphic rock. The banding is caused by the segregation of quartz and feldspar into layers alternating with layers of dark minerals. Since the metamorphism of many igneous or sedimentary rocks may result in a gneiss, there are many varieties, with varied mineral associations. Thus such names as *granite gneiss, diorite gneiss, syenite gneiss* are used to indicate the composition, while *biotite gneiss* or *hornblende gneiss* would be used to indicate rocks unusually rich in a given mineral. Granite gneisses, that is, rocks derived from the metamorphism of granites, are common, especially in regions in which rocks of Archean age are found.

Schists. Schists are metamorphic rocks which are distinguished from gneisses by the absence of coarse banding and the presence of lamination or " schistosity " along which the rock may be easily broken. There are several varieties, the most important of which is *mica schist,* composed essentially of quartz and a mica, usually either muscovite or biotite. The mica is the prominent mineral, occurring in irregular leaves and in foliated masses. The mica plates all lie with their cleavage planes parallel to each other and give to the rock a striking laminated appearance. The mica schists frequently carry characteristic accessory minerals, such as garnet, staurolite, kyanite, andalusite, epidote, hornblende; thus the rock may be called *garnet schist*, *staurolite schist*, etc. They may have been derived from either an igneous or a sedimentary rock. Next to the gneisses the mica schists are the most common metamorphic rocks.

There are various other kinds of schistose rocks, which are chiefly derived by the metamorphism of the igneous rocks rich in ferromagnesian minerals. The most important types are *talc schist*, *chlorite schist*, *amphibolite* or *hornblende schist*. They are characterized, as their names indicate, by the preponderance of some metamorphic ferromagnesian mineral.

Quartzite. As its name indicates, a quartzite is a rock composed essentially of quartz. It has been derived from a sandstone by intense metamorphism. It is a common and widely distributed rock in which solution and redeposition of silica have yielded a compact rock of interlocking quartz grains. It is distinguished from a sandstone by noting the fracture, which in a quartzite passes through the grains but in a sandstone passes around them.

Slate. Slates are exceedingly fine-grained rocks which have a remarkable property known as *slaty cleavage* that permits them to be split into thin, broad sheets. Their color is commonly gray to black, but may be green, yellow, brown, and red. Slates are usually the result of the metamorphism of shales. Their characteristic slaty cleavage may or may not be parallel to the bedding planes of the original shales. Slate is rather common in occurrence.

Marble. A marble is a metamorphosed limestone. It is a crystalline rock composed of grains of calcite, or more rarely dolomite. The individual grains may be so small that they cannot be distinguished by the eye, and again they may be coarse and show clearly the characteristic calcite cleavage. Like limestone, a marble is characterized by its softness and its effervescence with acids. When pure, marble is white in color, but it may show a wide range of color, due to various impurities that it contains. It is a rock which is found in many localities and may be in thick and extensive beds. Commercially *marble* is used to indicate any lime carbonate rock capable of taking a polish and thus includes some limestones.

Serpentine. Serpentine, as a rock, is composed essentially of the mineral serpentine derived by the metamorphism of a peridotite. Such rocks are compact, of a green to greenish yellow color, and may have a slightly greasy feel. Serpentines may be a source for associated chromite and platinum, as in the Ural Mountains, or a source of nickel from the associated garnierite, as in New Caledonia.

Contact Metamorphism

When a magma is intruded into the earth's crust, it causes through the attendant heat and accompanying solutions a greater or less alteration in the surrounding rock. This alteration of the rocks lying next to an igneous intrusion is known as *contact metamorphism* and usually consists in the development of characteristic mineral species. The minerals that are formed under these conditions are called *contact metamorphic minerals,* and are found at or near the contact between the rock in which they lie and an igneous rock. Two kinds of contact metamorphism are recognized: (1) *thermal,* due to the heating up of the country rock by the intrusion; (2) *hydrothermal,* where solutions, as well as heat, emanating from the igneous rock have reacted with the country rock and formed contact metamorphic minerals.

Any rock into which an igneous mass is intruded will be affected in a greater or lesser degree, the amount and nature of the change depending chiefly upon the size of the intruded mass and upon the chemical and physical character of the surrounding rock. Sandstones are converted to quartzites, and shales changed to " hornfels," a dense rock containing biotite, andalusite, staurolite, cordierite, garnet, and scapolite. The most striking and important contact metamorphic changes take place when the igneous rock is intruded into limestones. When a pure limestone is subjected to thermal metamorphism, it is recrystallized and converted into a marble, but without any development of new species. On the other hand, in an impure limestone the heat caused by the igneous intrusion may serve to develop new and characteristic minerals in the rock. An impure limestone will ordinarily contain, besides the calcium carbonate of the rock, varying amounts of dolomite, quartz, clay, iron oxide. Under the influence of the heat and pressure these materials will combine with the calcium carbonate to form new minerals. For instance, the calcite and quartz may combine to form wollastonite. The reaction of dolomite with quartz may produce diopside. If clay is present, aluminum will enter into the reaction and such minerals as corundum, spinel, and grossularite garnet may result. If any carbonaceous materials are present, the effect of the thermal metamorphism may convert them into graphite. The common thermal contact metamorphic minerals found in limestone are as follows: *graphite, spinel, corundum, wollastonite, tremolite, diopside,* and the lime garnets, *grossularite* and *andradite.*

The greatest changes are produced in a limestone by *hydrothermal contact metamorphism.* In this process, solutions given off by the intruded magma react with the limestone to produce new minerals containing elements not present in the limestone. At the contact with the intrusive the limestone may be completely replaced, farther away only partly replaced, and at a distance the only evidence may be a recrystallization of the limestone. In this type of contact metamorphism, ore minerals are frequently present and the deposit may be of economic importance. Such deposits may grade into hydrothermal vein deposits.

The introduction of material into the hydrothermal contact metamorphic deposits gives rise to a greater abundance and variety of minerals than are formed by pure thermal metamorphism. The most important silicates are *quartz*, *grossularite* and *andradite* garnet, *diopside*, *epidote*, *zoisite*, *idocrase*, *wollastonite*, *tremolite*, *olivine*. Scapolite, chondrodite, axinite, topaz, tourmaline, and fluorite may be present and contain hydroxyl, fluorine, chlorine, or boron and are commonly spoken of as *pneumatolytic minerals*. The sulfide ore minerals found in contact metamorphic deposits include *pyrite*, *chalcopyrite*, *bornite*, *sphalerite*, *pyrrhotite*, *molybdenite*, and *arsenopyrite*. The oxides include *magnetite*, *ilmenite*, *hematite*, *spinel*, and *corundum*.

VEINS AND VEIN MINERALS

Many mineral deposits, especially those of economic importance, exist as tabular or lenticular bodies known as *veins*. The veins have been formed by the filling with mineral material of a pre-existing fracture or fissure.

The shape and general physical character of a vein depends upon the type of fissure in which its minerals have been deposited, and the type of fissure in turn depends upon the character of the rock in which it lies and the kind of force which originally caused its formation. In a firm, homogeneous rock, like a granite, a fissure will be fairly regular and clean cut in character. It is likely to be comparatively narrow in respect to its horizontal and vertical extent and reasonably straight in its course. On the other hand, if a rock that is easily fractured and splintered, like a slate or a schist, is subjected to a breaking stress, a zone of narrow and interlacing fissures is more likely to have formed than one straight crack. In an easily soluble rock like a limestone, a fissure will often be extremely irregular in its shape and size owing more or less to solution of its walls by the waters that have flowed through it.

A typical vein consists of a mineral deposit which has filled a fissure solidly from wall to wall, and shows sharply defined boundaries. There are, however, many variations from this type. Frequently irregular openings termed *vugs* may occur along the center of the vein. It is from these vugs that many well-crystallized mineral specimens are obtained. Again, the walls of a vein may not be sharply defined. The mineralizing waters that filled the fissure may have acted upon the wall rocks and partially replaced them with the vein minerals. Consequently, there may be an almost complete gradation from the unaltered rock to the pure vein filling with no sharp line of division between. Some deposits have been largely formed by the deposition of vein minerals in the wall rocks and are known as *replacement deposits.* They are more likely to be found in, but by no means confined to, the soluble rocks like limestones. There is every gradation possible from a true vein with sharply defined walls to a replacement deposit with indefinite boundaries.

It is now almost universally believed that the mineral matter in veins has been deposited from aqueous solutions. Some deposits have formed by the method of *lateral secretion* in which ground waters circulating through the rocks have dissolved disseminated mineral matter which is later deposited in veins. However, the deposits of greatest economic importance are believed to have been deposited from hot ascending magmatic solutions which originated from a cooling and crystallizing magma. As such hydrothermal solutions move upward the pressure and temperature become less and deposition of dissolved material results. It has been shown that certain minerals characteristically form under given conditions of temperature and pressure. Lindgren has thus divided the hydrothermal vein deposits into the following three groups, each with characteristic mineral associations.

1. **Hypothermal deposits;** deposited at great depth at high pressure and high temperature (300°-500° C.±). Several types of hypothermal veins exist, each with characteristic mineral associations: (*a*) cassiterite, wolframite and molybdenite veins; (*b*) gold-quartz veins; (*c*) copper-tourmaline veins; (*d*) lead-tourmaline veins.

The minerals of greatest importance are, therefore, cassiterite, wolframite and scheelite, molybdenite, native gold, chalcopyrite, and galena. Often associated ore minerals are pyrite, pyrrhotite, arsenopyrite, bismuthinite, and magnetite. Quartz is the predominant gangue mineral but is frequently accompanied by fluorite, tourmaline, topaz, axinite, and other minerals containing volatiles. The chief metals won from hypothermal deposits are tin, tungsten, gold, molybdenum, copper, and lead.

2. **Mesothermal deposits;** formed at intermediate depths at high pressure and temperature (200°-300° C.±). The chief ore minerals are pyrite, chalcopyrite, arsenopyrite, galena, sphalerite, tetrahedrite, and native gold. Quartz is the chief gangue mineral, but carbonates such as

calcite, ankerite, siderite, rhodochrosite are also common. The chief metals mined are gold, silver, copper, lead, and zinc.

3. **Epithermal deposits**; formed at slight depth under moderate pressure and temperature (50°–200° C.±). Typical ore minerals of epithermal deposits are native gold, marcasite, pyrite, cinnabar, and stibnite, while the gangue minerals include quartz, opal, chalcedony, calcite, aragonite, fluorite, and barite. The chief metals found in these deposits are gold, silver, and mercury.

Alteration of Vein Minerals

Secondary Vein Minerals. In many mineral veins, it is obvious that certain minerals belong to the original vein deposit while certain others have been formed subsequently. These two classes of minerals are known respectively as *primary* (or *hypogene*) and *secondary* (or *supergene*) *minerals.* The primary vein minerals are those which were originally deposited by the ascending waters in the vein fissure. The primary sulfide minerals found in veins are comparatively few in number, the more important being pyrite, chalcopyrite, galena, and sphalerite. The secondary minerals have been formed from the primary minerals by some chemical reactions. These changes are ordinarily brought about through the influence of oxidizing waters which, coming from the surface of the earth, descend through the upper portions of the vein. Under these conditions, various new minerals are formed, many of them being oxidized compounds. Sphalerite alters to hemimorphite and smithsonite; galena to anglesite and cerussite; copper sulfides to malachite, azurite, cuprite, and native copper. Many other rarer oxidized minerals are found at some localities. As the descending waters lose their oxygen content within a comparatively short distance of the earth's surface, the secondary minerals are found only in the upper part of a vein.

Secondary Enrichment. Together with the formation of secondary minerals, there is frequently a downward migration of the valuable metals in the vein. This is brought about by the solution of the minerals in the uppermost portion of the vein and a subsequent reprecipitation a little farther down. As the surface of the earth is gradually lowered by erosion, the upper part of a vein is continually being worn away; but the metallic content of the uppermost part of the vein may be carried downward by the descending oxidizing waters. In this way, the metallic content of the upper part of many veins may be notably enriched if in a short vertical distance most of the original contents of hundreds, perhaps thousands, of feet of the vein, which have been slowly worn away by the general erosion of the country, are concentrated. Consequently, the zone of the secondary minerals is frequently a zone of secondary enrichment. This is an important fact to be borne in mind since, because of it, the upper portion of a vein may be the richest portion of a deposit. The ore below that depth gradually grades into its original unaltered and unenriched state and may frequently prove too low in value to warrant its being mined. The prevalent idea that the ore of a vein must increase in value with increasing depth is not true in the great majority of veins.

It will be of interest to consider the more important primary vein minerals and the secondary minerals that are commonly formed from them in the process of secondary enrichment.

1. *Iron Minerals.* The common primary vein mineral of iron is pyrite, FeS_2. Marcasite, FeS_2, though not so common in occurrence is also a primary mineral. When oxidized, these minerals yield ordinarily the hydrated oxide limonite, $Fe_2O_3 \cdot nH_2O$. The upper portion of a vein that was originally rich in pyrite will thus be converted into a cellular and rusty mass of limonite. This limonite deposit near the surface is commonly termed *gossan.* The yellow, rusty appearance of the outcrop of many veins enables one frequently to locate them and to trace them across the country.

2. *Copper Minerals.* The most common primary copper mineral is chalcopyrite, $CuFeS_2$, but bornite, Cu_5FeS_4, tetrahedrite, $(Cu,Fe,Zn,Ag)_{12}Sb_4S_{13}$, and enargite, Cu_3AsS_4, are frequently present. The oxidation of these minerals yields at the surface of a copper deposit limonite, malachite, azurite, cuprite, native copper, chrysocolla, and antlerite. The zone of oxidation usually extends downward to the water table where secondary sulfides appear.

The breakdown of the copper sulfides and associated pyrite produces ferric sulfate and sulfuric acid which react with the copper to form copper sulfate which is soluble and is carried downward. When the copper sulfate solution reaches a reducing environment it reacts with the sulfides there present to form on them a coating of covelite, CuS, or chalcocite, Cu_2S. Such long-continued action may give rise to massive chalcocite bodies at the water table. Many of the " porphyry copper deposits " of the western United States are commercial because of a slight supergene enrichment of this type.

MINERAL USES

Minerals are extremely important from an economic point of view, for all the inorganic materials of commerce are either minerals or substances derived from minerals. In the present section the minerals are, as far as possible, grouped according to use. It is impossible, however, to adhere to a completely rigorous classification, for many minerals have minor uses which do not fall under any general heading. The uses of minerals are discussed under the following headings:

Gem Minerals.
Ornamental Minerals.
Abrasives.
Fluxes.
Lime, Plaster, Cement.
Refractories.
Pottery, Glass, Enamel.
Fertilizers.
Optical and Scientific Apparatus.
Natural Pigments.
Ores of the Metals.
In the Chemical Industry.

GEM MINERALS

The physical properties of minerals that make them valuable as gem stones are color, luster, dispersion, and hardness. The gem value of some minerals may be attributed to but one of these properties — for example, color, in the case of turquois. On the other hand, diamond, ruby, sapphire, and emerald combine all the properties, and they are thus prized above all other gems and are known as the *precious stones.* In addition to the physical properties mentioned, popular gem stones must be relatively rare, but at the same time abundant enough so that a demand can be created for them.

Diamond. For centuries the diamond has been the most highly prized of gem stones. Before the early part of the eighteenth century, when diamonds were discovered in Brazil, the world's supply had come from placers in India. The Brazilian diamonds were also found in placers, and it was not until 1867, after considerable placer mining in South Africa, that diamonds were discovered there in the rock in which they crystallized. Since the discovery of diamonds in South Africa that country has been the chief producer.

Most diamonds used as gems are clear and colorless, but fine colored red, blue, green, and yellow stones are of greater value.

Corundum. The gem stones ruby and sapphire are varieties of corundum. The color of the ruby is red; the most highly prized are stones of a deep purplish red. The true sapphire is blue, but all gem corundum of a color other than red is called sapphire. Names of stones cut from corundum of more unusual color are often prefixed by " oriental," as *oriental amethyst* and *oriental topaz,* in allusion to the color of the more common gem stone. Some corundum when viewed in the direction of the *c* axis has a stellate appearance. Stones cut en cabochon from such material show a six-pointed " star " and are thus called star sapphires or star rubies. The finest rubies come from Upper Burma, Siam, and Ceylon. Sapphires of fine quality are found in Siam and Kashmir, India. In the United States rubies have been found in North Carolina, and both rubies and sapphires have been found in Montana.

Synthetic rubies and sapphires have been produced in recent years which, when cut into gems, rival the beauty of the natural stones. Indeed, it is impossible for the untrained observer to distinguish between them.

Beryl. The emerald is the most highly prized of the gem varieties of beryl, and a transparent stone of a deep emerald-green color commands a higher price than a diamond of corresponding size.

Aquamarine, the most common gem variety of beryl, is usually of a blue to blue-green color. Morganite is a pink variety, and golden beryl is the variety with a golden-yellow color.

Most of the world's emeralds have come from Colombia, South America. Fine emeralds have also come from the Ural Mountains east of Sverdlovsk. Aquamarine and the gem varieties of beryl other than emerald are found in granite pegmatites, notably in Minas Geraes, Brazil; Madagascar; the Ural Mountains; and in the United States in Maine, Connecticut, California, North Carolina, and Colorado.

Spodumene. The two transparent gem varieties of spodumene are known as *kunzite* and *hiddenite.* Kunzite is a pink to lilac color; it has been found at Pala, California, and in Madagascar. Hiddenite, an emerald-green variety, is found in North Carolina.

Tourmaline. Several color varieties of clear transparent tourmaline are used as gems. The more important are: rubellite, red or pink; indicolite, dark blue; Brazilian emerald, green. The green variety is commonly called by the mineral name, tourmaline. Gem tourmaline is usually found in pegmatites. Notable localities are: Island of Elba; Madagascar; Southwest Africa; Brazil; and in the United States, Maine, Massachusetts, Connecticut, and California.

Spinel. Gem quality spinel is found in several colors — red, pink, yellow, purple, blue. The deep red variety, *ruby spinel,* is the most important. Most of the gem spinel comes from Ceylon, Burma, and Siam. Synthetic spinel, indistinguishable from the natural stones except by the expert, is now made.

Chrysoberyl. The variety known as *alexandrite* is an emerald-green color in daylight but a red color in artificial light. *Cat's-eye,* or *cymo-*

phane, is a variety, with an opalescent luster, across whose surface a narrow beam of light plays. Alexandrite has been found in the Ural Mountains and in Ceylon. The variety cat's-eye has been found in Ceylon and Brazil.

Garnet. Several garnets of different composition are used as gems. The red pyrope and almandite are most commonly cut, but are so abundant that their value is small. The green andradite, known as *demantoid*, has a high dispersion which gives the cut stone a striking and beautiful appearance. Red garnets of gem quality are found in many places throughout the world. The green demantoid is found in the Ural Mountains and Hungary.

Topaz. Clear, colorless topaz is common and of little value as a gem. Wine-yellow is considered by jewelers to be the topaz color, and hence stones of that color are most valuable. Golden brown, pale blue, and pink stones are also used as gems. Noted localities for gem topaz are the Ural Mountains, U.S.S.R., and Minas Geraes, Brazil.

Zircon. Zircon of gem quality is found in many colors. The yellow, red, and brown varieties are known as hyacinth, while most of the other colors are called jargon. The blue color of many cut zircons is produced by heat treatment. The high index of refraction gives zircon a luster and fire that in some stones compares favorably with diamond. Most gem zircons have come from Indo-China and Ceylon.

Opal. The gem value of opal lies in the property, possessed by some varieties known as precious opal, of breaking white light into its spectral colors and thus giving the stone a beautiful play of colors. Many names are given to the different-appearing varieties. Precious opal is found in New South Wales and in Queensland, Australia; Honduras; Mexico; and in the United States in Humboldt County, Nevada.

Olivine. The olive-green gem variety of olivine is known as peridot. Most peridot has come from St. John's Island in the Red Sea. Small amounts have been found in surface gravels in Arizona and New Mexico.

Turquois. The color of turquois is various shades of green and blue, but the blue is considered the most desirable. Most of the fine turquois has come from Persia, but at present localities in Arizona, New Mexico, and California are important.

Quartz. Many varieties of quartz are used as gems, most of which are relatively inexpensive. The principal coarsely crystalline varieties are: rock crystal, clear and colorless; amethyst, purple or violet; smoky quartz, dark brown to black; rose quartz, pale to deep rose-pink; rutilated quartz, with fine needles of rutile; aventurine, quartz including brilliant scales of hematite or mica. The principal cryptocrystalline varieties of quartz are: carnelian, red chalcedony; chrysoprase, apple-green chalcedony; heliotrope or bloodstone, green chalcedony with red spots in it; agate, variegated chalcedony with curved or concentric bands; onyx, like agate but with plane and parallel colored layers.

Minor Gem Minerals. Some minerals other than those already mentioned are found occasionally in specimens of gem quality, but not frequently enough to be generally thought of as gem minerals. The more important of these are: sphene, benitoite, cassiterite, apatite, kyanite, feldspar (moonstone), axinite, cordierite, dioptase, diopside, euclase, fluorite, idocrase, andalusite.

The production of gem stones in the United States is small. The greatest annual production, valued at $534,000, was in 1909, and the least, valued at $3,000, was in 1934. It is estimated that in 1938 the value of gem stones produced in the United States was $127,000. During 1938 imports of diamonds were valued at $17,000,000.

ORNAMENTAL MINERALS

Many minerals have been used for ornamental purposes, but a considerable number of them have been employed only locally. The ornamental minerals of more general use are:

Calcite. Marble, onyx marble, and travertine are the chief ornamental varieties of calcite. Marble is a recrystallized limestone and is usually coarser grained; commercially, however, marble implies any calcium carbonate rock that will take a polish. Some varieties have irregular color bands or streaks which give a pleasing effect to the polished surface. The chief use of marble is for interior decorations as in floors, wainscotting, and baseboards. It is used to a lesser extent in table tops, statuary, and sanitary equipment.

Onyx marble, known as " Mexican onyx," is a banded calcareous material used for interior decoration in a manner similar to marble. It is also used for paper weights, lamp bases, penholders, and other small objects. Onyx marble comes mostly from Lower California, Mexico.

Travertine is a porous open-textured spring deposit of calcareous material. Its chief use is for interior decoration of public buildings. Italy is the chief producer, and Italian travertine has been in use for centuries. In the United States workable deposits are found in Montana, Colorado, and Florida.

Serpentine. Serpentine, known as *verde antique marble,* is used for interior decorating. It is usually green or yellowish green, and frequently has a mottled appearance. Calcite, dolomite, magnesite, and other minerals may be present in varying amounts. Workable serpentine deposits occur along the Appalachian Mountains, notably in

Pennsylvania, Maryland, and Georgia. Serpentine is also found in California and Washington.

Malachite. The use of malachite for ornamental purposes has been largely confined to Russia where deposits in the Ural Mountains have furnished considerable material. It is usually sawed into thin plates for mosaic and inlaid work such as table tops, vases, and small objects. More rarely it is used for interior decorating.

Lazurite. Lazurite is the principal constituent of *lapis lazuli*, valued because of its deep blue color. It has been used since ancient times for small ornaments and inlaying. Important localities of lapis lazuli are in Afghanistan; near Lake Baikal, Siberia; and Chile.

Feldspar. Some feldspar shows a beautiful play of colors which makes it a desirable ornamental material. This property is shown in labradorite found in Labrador, and in anorthoclase in a rock known as *larvikite* from southern Norway. The rocks containing these minerals are used extensively for exterior work on public buildings.

Rhodonite. Because of its beautiful rose color rhodonite is used for mosaic work in table tops, vases, and small objects, and to a lesser extent in interior decorating. Rhodonite has been chiefly used in Russia, where considerable quantities have been found in the Ural Mountains. Small amounts found at Franklin, New Jersey, have been used for gem purposes.

Gypsum. The fibrous variety of gypsum, *satin spar*, and the fine granular variety, *alabaster*, are used for ornamental purposes. Satin spar is used in cheap jewelry although it is extremely soft. Alabaster is used for statuary and carved ornamental objects. Most alabaster is mined and carved in Italy. Some found in Michigan, Colorado, and Tennessee is of sufficient quality for working.

Jade. The term jade is applied to the two minerals, jadeite (a pyroxene) and nephrite (an amphibole). Both minerals are extremely tough and vary in color from white to green. Jade has been used since prehistoric times for weapons, ornaments, and utensils. It is also used for bells and sounding plates. In China jade is prized above all precious stones, and there it has been most extensively worked and carved into beautiful and elaborate forms. Jadeite is found in Upper Burma, Tibet, and China, and nephrite in China, New Zealand, and Siberia.

Agate. Agate is used for small ornamental objects such as paper knives, buttons, inkstands, and penholders. It usually shows concentric bands of varying color and texture. The natural color is frequently unattractive, and therefore most commercial agate is artificially colored. Cameos are cut from onyx, an agate with parallel plane bands. The agate-cutting industry was early developed in the Idar-Oberstein district of Germany where there was originally an abundance of material. At present most agate comes from Brazil and Uruguay and is cut in Germany.

ABRASIVES

Diamond. Because of its extreme hardness (10) diamond is one of the most important abrasives. It is used as a powder to cut and polish gems, and to impregnate wheels used in cutting rocks and other hard materials. Larger diamonds are used in making diamond drills. The black variety, carbonado, or carbon, is especially valuable for this purpose since it is tough as well as hard. These diamonds come mainly from Bahia, Brazil. Diamonds are also used as dies in the wire-drawing industry, in glass cutting, and in tools for truing grinding wheels.

Corundum. Because of the introduction of artificial abrasives, corundum has been little used during the present century. As *emery,* a mechanical mixture of corundum and magnetite or hematite, it is at present used to some extent in the manufacture of grinding wheels, abrasive powders, emery cloth. Emery is imported into the United States chiefly from Naxos and other islands in the Grecian Archipelago.

Quartz. Ground quartz and quartz sand are used as abrasive materials in sawing stone, making sandpaper, grinding glass, and sandblasting. Silica rocks for grindstones come largely from Ohio and West Virginia. Oil stones and whetstones are made from novaculite from Arkansas and sandstone from Ohio and Indiana. Flint pebbles used in certain ore-dressing operations are imported into the United States from France and Denmark.

Garnet. As an abrasive, garnet is used chiefly in the manufacture of garnet paper and cloth employed in dressing leather and wood. Within recent years an extremely fine-grained garnet rock used in the sharpening of razor blades and microtome knives has been imported from Belgium.

Polishing Materials. Considerable diatomite, opaline remains of diatoms, and tripoli, altered chert, are used for polishing. Several artificially produced oxides such as rouge, tin oxide, chromium oxide, magnesium oxide, manganese oxide are also used for polishing.

Artificial Abrasives. The value of artificial abrasives produced annually in the United States far exceeds the production of natural abrasives. *Carborundum,* a silicon carbide, and *Alundum,* artificial Al_2O_3, are the two most important artificial abrasives. Carborundum is produced in an electric furnace from a charge composed of approximately 60 per cent silica and 40 per cent petroleum coke with a small amount of wood sawdust and sodium chloride. Alundum is produced from calcined bauxite in an arc-type electric furnace. Harder than

Carborundum and Alundum is a boron carbide, B_4C, produced in an electric furnace from coke and dehydrated boric acid. In the United States in 1938 the total production of natural abrasives was valued at $2,721,000, while the value of artificial abrasives was $6,238,000.

FLUXES

Calcite. Calcite in the form of limestone is used extensively in smelting operations with oxide and siliceous ores to yield fusible slags. The bulk of it is used in the metallurgy of iron. In 1938 approximately 494,000 tons of limestone were used in metallurgical processes.

Fluorite. About 75 per cent of the fluorite produced is used as a flux in the steel industry. The principal source in the United States is the Illinois-Kentucky district. A small amount of fluorite is imported, chiefly from France. For use as a flux, approximately 139,000 tons of fluorite, valued at $2,535,000, were produced in 1939. This amount shows a considerable increase over production in 1938 when 52,000 tons, valued at $912,000, were produced.

Quartz. A small amount of quartz is used as a flux in copper smelting.

LIME, CEMENT, AND PLASTER

Calcite. Limestone, made up chiefly of the mineral calcite, is the principal constituent of lime and of most cements. The lime industry as well as the cement industry uses limestone as the principal raw material. Some dolomite is also used. The manufacture of lime includes the crushing, sizing, and calcination of the limestone. The calcination or burning to drive off carbon dioxide takes place at a temperature of 898° C. in calcium carbonate (756° in dolomite). The resulting CaO is known as quicklime. When water is added to the quicklime an exothermic reaction takes place [$CaO + H_2O = Ca(OH)_2$], slaked or hydrated lime being formed.

Lime has many and varied uses. About 10 per cent of the production is used in agriculture as a soil conditioner to correct acidity. About 20 per cent of lime produced is used in building construction in mortar, plaster, stucco, concrete, and whitewash. Various industrial and chemical processes take about 60 per cent of the lime. The most important are metallurgical, paper manufacture, water purification, glass manufacture, and leather tanning.

Lime has been produced in all but six states of the United States, although Ohio, Pennsylvania, and Missouri supply 50 per cent of the total. In 1939, 4,254,000 tons of lime, valued at approximately $30,000,000, were produced in the United States.

Portland cement, which comprises the bulk of the cement produced, is obtained by calcining a finely ground and properly proportioned mixture of limestone or other calcareous substances, and argillaceous material. The clinker produced by such a process is pulverized, and a small amount (up to $3\frac{1}{2}$ per cent) of gypsum, or a mixture of gypsum and anhydrite, is added to control setting. Shale or clay are the chief argillaceous materials used to furnish the necessary silica and alumina. Marl and oyster shells are employed in some Portland cement as a source of the lime. Some argillaceous limestones, cement rock, contain essentially the required proportions of lime and clay without admixtures of additional material.

The chemical proportions are usually about 75 per cent calcium carbonate and 25 per cent aluminum silicates. During the fusion lime combines with aluminum and silica to form anhydrous calcium silicates and calcium aluminates. On addition of water, complex hydrous compounds form, some of which are crystalline and interlock, resulting in a hard massive substance.

Portland cement was produced in 1938 in all but thirteen of the United States, Pennsylvania, California, Michigan, and Texas being the chief producers. The total production was 105,000,000 barrels, valued at more than $154,000,000.

Gypsum. Gypsum is used primarily in the production of plaster of Paris, which in turn is used in wall plasters, stucco, whitewash, pottery molds, wallboard, gypsum lath, etc. When gypsum is heated at about 120° C. it loses a portion of its water of hydration; Thus: $CaSO_4 \cdot 2H_2O +$ heat $= CaSO_4 \cdot \frac{1}{2}H_2O + 1\frac{1}{2}H_2O\uparrow$. If finely ground, the calcined gypsum has the property of recombining with water, and the set of the plaster is due to the formation of interlocking rehydrated crystals.

Crude gypsum is used in Portland cement as a retarder, as mentioned above.

In the United States in 1938, 3,226,737 tons of crude gypsum were mined and 1,308,078 tons imported which produced 2,881,269 tons of calcined gypsum valued at $14,620,597. The principal producing states are New York, Michigan, Iowa, and Nevada.

REFRACTORIES

Magnesite. Dead-burned magnesite, i.e., magnesite that has been calcined at a high temperature and contains less than 1 per cent CO_2, is used in manufacturing bricks for furnace linings. The U.S.S.R., Austria, and the United States are the chief producers of magnesite. In 1938 consumption was considerably below the average of the past decade, and 65,000 tons of dead-burned magnesite, valued at $1,100,000, were used in the United States.

Dolomite. Dead-burned dolomite is used as a refractory in furnace linings in a manner similar to magnesite. It is less satisfactory than magnesite, but is cheaper.

Kyanite, Andalusite, Dumortierite. All three of these minerals are used in making high-grade porcelain such as is used in spark plugs, laboratory porcelain, and thermocouple tubing. Kyanite is produced largely in North Carolina and Georgia; andalusite, in California; dumortierite, in Nevada.

Graphite. Some crucibles used in the manufacture of steel are made of a mixture of natural crystalline graphite and a refractory clay. Until recently Ceylon has been the principal producer of crystalline graphite, but in recent years Madagascar has been an important producer. Neither the amorphous natural nor artificial graphite is satisfactory for crucibles. An average of about 2,500 tons of crystalline graphite is imported each year into the United States.

Bauxite. A small amount of the bauxite produced is used in the manufacture of aluminous refractories. Bauxite is ground, mixed with a binder, pressed into forms, and baked. Such refractories are more expensive than corresponding fire-clay refractories, but are more resistant to heat and abrasion and are, therefore, being increasingly used.

Chromite. Although chromite is chiefly used as a source of chromium for alloy steels, a considerable amount is consumed in the manufacture of chromite bricks for furnace linings.

Zircon. A small amount of refractory brick is made from zircon.

Asbestos. The term asbestos is given to several fibrous varieties of amphibole and to the fibrous serpentine, chrysotile. At present, however, about 95 per cent of the asbestos produced is chrysotile. The asbestos of long enough fiber to permit spinning is made into heat-resisting fabrics for various purposes, the most important of which is brake lining for automobiles. The lower-grade, shorter-fiber asbestos is used for insulating purposes, asbestos shingles, etc.

The production of asbestos in the United States is low, only about 6 per cent of the amount consumed. The chief producing countries are Canada, U.S.S.R., Southern Rhodesia, Union of South Africa. In 1939, 242,561 tons of asbestos, valued at $9,095,000, were imported into the United States.

Talc. As slabs of the rock soapstone, talc is used for laboratory table tops, electric switchboards, and sanitary appliances. Powdered talc is used as foundry facings and as steam-pipe and boiler coverings. Other important uses are in the manufacture of paper, paint, roofing material, pottery, and porcelain. The chief producing states are New York, Vermont, North Carolina, and California. In 1939 the production of sawed and manufactured talc was 1,871 tons valued at $77,915; the production of ground talc was 236,383 tons valued at $2,540,000.

Clay. Brick made from fire-clay is used extensively for refractory purposes. The production of fire-clay brick has varied considerably; the output in 1920, the peak of production, was 1,304 million bricks, valued at $53,416,000; in 1932, 217 million, valued at $7,611,000; in 1937, 711 million, valued at $33,731,000.

Mica. Muscovite and phlogopite are used extensively as sheet mica for electrical insulation purposes, as in electric toasters, irons, and lamp sockets. Much split mica is also used for electrical apparatus. Thin folia are cemented together and pressed into sheets of any desired thickness which can be punched and molded into various shapes and forms. Clear, transparent muscovite is used in many places where it is essential to have heat-resisting material, as in stove fronts and furnace windows. The altered biotite, *vermiculite*, which will expand when heated, is used for heat insulation.

Other uses for mica, chiefly in the ground form, are in the manufacture of roofing material, both in the body of the material and as a backing to prevent sticking of rolled asphalt; to give luster to wallpaper; to prevent sticking in rubber manufacture; in making Christmas tree " snow."

India is the leading world producer of muscovite, chiefly as split mica. Canada and Madagascar are the chief producers of phlogopite. The United States produces approximately 20,000 tons of mica per year; the leading producing states are North Carolina, Connecticut, and New Hampshire.

POTTERY, GLASS, ENAMEL

Clay. Clay is one of the most important of the natural substances used in industry, and many and varied products are made from it. A few of the clay products are: common brick, tile, porcelain china, pottery, sanitary ware, electrical apparatus. There are many different kinds of clays having slightly different properties each of which is best suited for a particular purpose. The chief value of clay lies in the fact that when wet it can be easily molded into any desired shape, and then, when heated, part of the combined water is driven off, producing a hard, durable substance.

Quartz. Quartz as a sand or sandstone is used extensively in the manufacture of glass. Ordinary glass is made by fusing iron-free quartz sand with calcium carbonate (limestone) and soda-ash. In 1938, 2,109,000 tons of quartz sand, valued at $3,601,000, were used in the glass industry in the United States.

Feldspar. Over 50 per cent of the feldspar produced in the United States is used by the glass industry to contribute aluminum to the glass batch. Feldspar is also used in the glaze on pottery, china, tile, etc. It fuses at a lower temperature than clay, and upon cooling will produce a hard, clear glass. Feldspar is also used in the body of some floor tile and pottery, and in enamel and sanitary ware. In 1939, 259,194 tons of ground feldspar, valued at $2,862,000, were sold in the United States.

Nepheline. In recent years nepheline has been gradually replacing feldspar as a source of aluminum in the glass industry. It has the advantage of contributing more aluminum per unit of weight than feldspar. All the nepheline used in the United States at present is imported from Canada.

Fluorite. A small amount of fluorite is used in making opalescent, opaque, and colored glass. Fluorite is also used in making enamels for coating sanitary ware, stoves, etc.

FERTILIZERS

Phosphorus, potassium, and nitrogen are essential to plant growth. These substances are found in certain minerals that are mined on a large scale and from which fertilizer is made.

Apatite. The Kola Peninsula, U.S.S.R., is the only place where apatite is being mined at present. There extensive deposits of granular apatite are mined, separated from associated nepheline, and treated for use as a phosphate fertilizer.

Collophanite. This is the most important constituent of rock phosphate, which is used most extensively as a source of phosphorus. The rock is treated with sulfuric acid and changed to superphosphate to render it more soluble in the dilute acids of the soil. In the United States, Florida is the principal producer, followed by Tennessee and Idaho. In 1939, 3,757,000 long tons of phosphate rock, valued at $12,294,000, were produced in the United States.

Sylvite. Although this mineral is the chief source of potassium, other minerals are also used. Until recently most of the potassium salts were imported from Stassfurt, Germany. Now large deposits are being worked near Carlsbad, New Mexico, and in 1939 the United States produced 525,000 tons and imported only 255,000 tons. In 1939 potassium salts averaged approximately $19 per ton.

Soda Niter. The only important source of nitrates is in northern Chile, where large deposits of soda niter are found in the desert regions.

The world is becoming less dependent upon the Chilean nitrates owing to the perfection of various methods of artificial production of nitrogen compounds by fixation from the air.

Lime. Calcined limestone or lime is used on the soil to neutralize an acid condition.

Gypsum. Gypsum is used as land plaster in arid regions.

OPTICAL AND SCIENTIFIC APPARATUS

Quartz. The piezoelectric property of quartz gives rise to specialized uses. It can be used in the measurement of instantaneous high pressures such as result from firing a heavy gun or the blow of a hammer. The piezoelectric effect is also used for stabilizing the frequency of amplifier tube currents and in oscillators in radios. Quartz wedges, cut from flawless, transparent quartz crystals, are used as an accessory of the polarizing microscope.

Fluorite. Fluorite is used in lenses to correct spherical and chromatic aberration. It is also used in optical apparatus, especially spectrograph prisms, where it is necessary to have material transparent to ultra-violet and infra-red light. Optical fluorite is very rare. A small amount has been produced in the Kentucky-Illinois district.

Calcite. Iceland spar, the clear, colorless optical calcite, is used in optical apparatus for obtaining polarized light. The birefringence of calcite is so strong that a prism (the nicol prism) can be constructed which eliminates one of the rays, rendering the light on emergence from the prism plane-polarized. Iceland has yielded most of the optical calcite and is still producing a small amount, but recently the greatest supply of Iceland spar has come from South Africa.

Gypsum. Small flakes of clear, transparent gypsum, *selenite,* are used in the *gypsum plate,* an accessory of the polarizing microscope.

Mica. Cleavage flakes of mica are used in making the *mica plate,* another accessory of the polarizing microscope.

Tourmaline. Tourmaline is used in a device known as *tourmaline tongs* to demonstrate the production of polarized light by absorption.

NATURAL PIGMENTS

Most pigments used in paint, plaster, rubber, linoleum, etc., are made from processed or manufactured materials. However, a few minerals are used as pigments in their natural state after purification and concentration.

Limonite is the common natural yellow and brown pigment. Yellow ocher is limonite mixed usually with clay and silica. The higher the percentage of iron oxide, the darker the color.

Hematite is the natural red pigment, and various hues are caused by the addition of impurities. Soft varieties of both limonite and hematite are best suited for use as pigments since they must be finely ground to insure uniform color. The Clinton iron ore of eastern United States is commonly used for this purpose.

Chemically manufactured inorganic pigments include white lead, lithopone, Venetian red, chrome yellow, Prussian blue, and red and yellow iron oxides.

ORES OF THE METALS

Aluminum

Diaspore, $AlO(OH)$
Bauxite
Cliachite, $Al(OH)_3$
Gibbsite, $Al(OH)_3$
Boehmite, $Al(OH)_3$
Cryolite, Na_3AlF_6

Aluminum is the most abundant of the metals, for it is an essential constituent of most of the rock-forming silicates and of clays derived from their alteration. However, the enormous amounts of aluminum contained in the various silicates are not yet available because of the difficulty and expense of extraction, and only the rock, bauxite, a mixture of hydrous aluminum oxides, is at present an important ore.

Bauxite is produced in the United States chiefly from Arkansas, Alabama, Georgia, and Tennessee. The most important deposits are found in Pulaski and Saline Counties, Arkansas, which produce 95 per cent of the domestic output. They have an average thickness of 10 to 15 feet. In one district the beds lie directly upon a body of kaolin, which in turn rests upon a syenite rock-mass, and it is probable that both minerals have been derived from the decomposition of the syenite. The Alabama-Georgia district extends from Jacksonville, Alabama, to Cartersville, Georgia. The ore occurs as pockets or lenses in a clay which has been derived by weathering processes from a dolomite limestone. The bauxite is either pisolitic or claylike in texture. In 1939 the domestic production amounted to 45 per cent and imports to 55 per cent of the total consumption. Most of the bauxite imported came from South America.

Cryolite, imported from Greenland, has been used as an ore of aluminum and also as a flux in the electrolytic process by which most of the metal is obtained.

The usual process at present by which aluminum is extracted from the bauxite ores is briefly as follows: The ore is heated to low redness with sodium carbonate, forming sodium aluminate. This compound is leached out by water, and by passing CO_2 gas into the solution the aluminum is precipitated as the hydroxide. On being heated the hydroxide is converted into the oxide of the metal. The pure metal is prepared from this oxide by an electrolytic process which takes place in a bath of fused cryolite or an artificial sodium-aluminum fluoride. The tank in which the reaction takes place is lined with carbon and forms the cathode, graphite rods suspended in the bath serving as the anode. The metal collects in the bottom of the tank. About 4 tons of bauxite are needed to make 2 tons of the oxide, which in turn makes about 1 ton of aluminum.

Because of its great strength and low density, aluminum has been adapted to many uses. Sheets, tubes, and castings of aluminum are used wherever a light-weight metal is desired, as in the manufacture of automobiles, airplanes, railway cars, and machinery. It is used extensively in cooking utensils and household appliances and furniture. Aluminum is a good electrical conductor and to some extent is replacing copper in power transmission lines. Numerous aluminum alloys are in common use. *Duraluminum,* 96 per cent aluminum, 3 per cent copper, and 1 per cent magnesium, is the trade name of the most important. It has only one-third the weight of steel and yet possesses most of its desirable properties. *Aluminum bronze* contains 10 per cent aluminum, 90 per cent copper. Aluminum is also alloyed with zinc, nickel, silicon, silver, tin. Other uses of aluminum are in paint, aluminum foil, and as a constituent of numerous salts.

The world production of aluminum for 1939 was the greatest in history and is estimated at 647,400 metric tons. The countries leading in production in 1938 were:

	METRIC TONS
Germany	161,100
United States	130,100
Canada	66,000
U.S.S.R.	43,900
France	45,300

In 1939 the price of aluminum in New York was 20 cents per pound.

Antimony

Native antimony, Sb **Stibnite,** Sb_2S_3

Antimony occurs in a considerable number of minerals, especially those belonging to the group known as the sulfo salts, which are largely combinations of copper, lead, or silver with antimony and sulfur. These minerals are mined, however, for the other metals that they contain, and any antimony that is produced from them is in the nature of a by-product. Stibnite, practically the only mineral which is mined for its antimony, has been found in the United States in a comparatively few deposits. It has been mined on a small scale in California, Nevada, and Idaho. The greater part of the antimony produced in the United States is derived from antimonial lead which is obtained from the smelting of lead ores that contain small amounts of antimony minerals. Considerable amounts of antimony and antimony ores are imported, chiefly from Mexico, China, France, Italy, and Japan.

Antimony is used in alloys, such as type metal (lead, antimony, and bismuth), babbitt or anti-friction metal (antimony, tin, etc.), britannia metal (tin with antimony and copper), with lead in battery plates for storage batteries, in bullets, and in cable coverings. Antimony oxide is used as a pigment and in the glazing of enameled ware. The sulfide is used in fireworks, in safety matches, in percussion caps, and in vulcanizing rubber. Other compounds are used in medicine and for various purposes in the arts.

In 1939 the United States produced 328 tons of antimony and imported over 10,000 tons, chiefly from Mexico and Bolivia. In 1939 the world production of antimony was approximately 35,300 tons. The countries leading in antimony production are:

	1937	1939
	METRIC TONS	
China	14,702	6,497
Mexico	9,788	7,243
Bolivia	6,556	9,255
United States	1,056	328

The average price of antimony in New York during 1939 was 12.36 cents per pound.

Arsenic

Native arsenic, As	Orpiment, As_2S_3
Realgar, AsS	**Arsenopyrite,** FeAsS

Arsenic in minerals ordinarily plays the part of a nonmetallic element, similar to sulfur in its chemical relations. It forms three classes of compounds, the arsenides, the sulfarsenides, and the arsenates. The number of minerals which contain arsenic is considerable, but only a few can be considered as distinctively arsenic minerals. Arsenopyrite is the only one which at present serves as an ore. Most of the arsenic oxide produced comes as a by-product in the smelting of arsenical ores for copper, gold, lead, and silver. Large amounts of the oxide are obtained from the smelting of the copper ores at Butte, Montana, the mineral enargite, Cu_3AsS_4, being its chief source. The oxide is also produced at smelting plants in Washington and Utah. Arsenopyrite has been mined at Brinton, Virginia.

Metallic arsenic is used in some alloys, particularly with lead in shot metal. Arsenic is chiefly used, however, in the form of white arsenic, or arsenious oxide. This is employed in medicine, as a poison, as a preservative, in making Paris green (an arsenate and acetate of copper), as a pigment, and in glass manufacture.

The amount of arsenious oxide sold in the United States in 1939 was 22,439 tons, valued at $495,500.

Bismuth

Native bismuth, Bi	Bismuthinite, Bi_2S_3

The most important bismuth mineral is the native metal, but it is rarely abundant enough to permit mining for it alone. Bismuth, therefore, is produced mostly as a by-product in the smelting of gold and silver ores. Only a comparatively small amount is obtained in the United States, chiefly from Colorado and Utah. The most important deposits are at Tasna near Potosi, Bolivia. However, the largest production at present is in Peru where bismuth is produced as a by-product of copper mining.

Bismuth is used in alloys which it forms with lead, tin, and cadmium. These fuse at low temperatures and are used for electric fuses and safety plugs in water sprinkling systems. About 75 per cent of the bismuth produced is used in medicine and cosmetics. Bismuth nitrate is opaque to x-rays and is taken internally when the digestive organs are to be photographed.

Figures on bismuth production are not available, but it is estimated that the world production in 1939 was over 3,000,000 pounds. During 1939 the price of bismuth at New York was approximately $1.00 per pound.

Cadmium

Greenockite, CdS

Greenockite, the only cadmium mineral of importance, is very rare in occurrence. The cadmium of commerce is obtained from zinc ores that carry a small amount of the metal. Practically the entire output of cadmium in the United States comes from the zinc ores of the Joplin, Missouri, district, which frequently contain some 0.3 per cent of the metal. Some cadmium is also recovered from the ores at Butte, Montana. The zinc ores of Silesia have for a long time been a prominent source of cadmium.

Cadmium is alloyed with lead, tin, and bismuth in the manufacture of low-fusing metals. Used in automatic sprinkler systems, electric fuses, steam boilers, and fire alarms. Stereotype plates are made from *cliché* metal, an alloy containing 22.5 per cent cadmium or bismuth. Small amounts, less than 1.5 per cent, are used to harden copper and silver. Cadmium has recently been extensively used in plating; it forms an alloy with the metal, usually iron, which is very resistant to chemical attack. Various cadmium salts are used in photography, fireworks, rubber, fluorescent paint, and glass and porcelain. Cadmium sulfide, known as *cadmium yellow,* is used extensively as a pigment.

Complete figures of cadmium production are not available, but it is estimated that the world production was 4,200 metric tons in 1937. Of this the United States produced about 1,900 tons. In 1939 the average price of cadmium was $0.64 per pound, compared with $0.98 in 1938, $1.22 in 1937 and $0.55 in 1934.

Chromium

Chromite, $FeCr_2O_4$ Crocoite, $PbCrO_4$

Chromite, or chromic iron ore, is the chief source of chromium. Its production in the United States is very small, coming mostly from Shasta County, California. It has also been found in workable deposits in Pennsylvania, Maryland, Montana, North Carolina, Oregon, Washington, and Wyoming. Domestic needs are met by ore imported from Cuba, Southern Rhodesia, Turkey, and the U.S.S.R.

The chief use of chromium is in making chrome steel. It gives to the alloy the combined properties of high hardness, great toughness, and resistance to chemical attack. Such steel is thus used in automobiles, airplanes, and trains where it is desirable to decrease the weight without sacrificing strength. Chromium is used in acid-resisting and stainless steels. " Nichrome " is an alloy of nickel and chromium used for resistance in electrical heating equipment. " Stellite " is an alloy of cobalt, chromium, and tungsten or molybdenum, used in high-speed cutting tools.

Because of its resistant nature, and because it yields a brilliant surface on polishing, chromium is used extensively in plating decorative hardware, plumbing fixtures, and automobile accessories. Since the layer of metal needed is so thin (0.000002–0.0005 inch) little metal is used in this way. Various red, orange, and green pigments and dyes are made from chromium compounds. Other chromium compounds are used as mordants in dyeing and in tanning leather.

In 1938 only 812 long tons of chromite, valued at $10,730, were produced in the United States, compared with imports of 352,085 long tons valued at $4,854,892.

Cobalt

Cobaltite, $CoAsS$
Smaltite, $CoAs_2$
Linnaeite, Co_3S_4
Erythrite, $Co_3As_2O_8 \cdot 8H_2O$

Cobalt is a rare element which is usually found in small amounts associated with nickel minerals. It is produced chiefly in the Belgian Congo, Northern Rhodesia, French Morocco, and, in the past, from the silver ores of Cobalt, Ontario. Much of the cobalt of commerce is a by-product of other ores.

Metallic cobalt is used most extensively in "stellite," an alloy of cobalt, chromium, and molybdenum or tungsten. This material is used in high-speed cutting tools, surgical instruments, razor blades, and other instruments where it is desirable to maintain a cutting edge in noncorrosive material. Cobalt steel is similar to tungsten and molybdenum steel in that it retains its cutting edge at a red heat. Cobalt is also used in the blue pigment *smalt*, employed in coloring pottery, enamel, and glass.

It is estimated that the world production of cobalt in 1939 was 6,000 metric tons. The United States is the chief consumer, although there is no domestic production. The price for 97–99 per cent metal in 1939 was $1.50 per pound.

Copper

Native copper, Cu
Chalcocite, Cu_2S
Bornite, Cu_5FeS_4
Chalcopyrite, $CuFeS_2$
Covellite, CuS
Tetrahedrite, $(Cu,Fe,Zn,Ag)_{12}Sb_4S_{13}$
Enargite, Cu_3AsS_4
Cuprite, Cu_2O
Atacamite, $Cu_2Cl(OH)_3$
Malachite, $Cu_2CO_3(OH)_2$
Azurite, $Cu_3(CO_3)_2(OH)_2$
Antlerite, $Cu_3(SO_4)(OH)_4$
Chalcanthite, $CuSO_4 \cdot 5H_2O$
Chrysocolla, $CuSiO_3 \cdot 2H_2O$

Copper is a common and widely distributed element. It is found in a number of important minerals which usually occur in veins. Chalcopyrite and bornite are the most important primary copper-ore minerals. Chalcocite, the other important sulfide, is usually, although not always, the result of secondary enrichment. Solutions that have leached out the copper content of the upper portion of a copper deposit will react with the unoxidized chalcopyrite farther down to enrich it in respect to the amount of copper it contains and convert it into chalcocite. In this way copper deposits often show in the upper part, just below the oxidized zone, a body of enriched sulfides. The veins at Butte, Montana, are notable examples, as well as the porphyry copper ores which are worked on a large scale for their content of low-grade disseminated secondary copper sulfides. Pyrite often contains small amounts of copper minerals and when it occurs in large bodies is mined for its copper, as at Rio Tinto, Spain.

Copper is second only to iron as a metal essential to modern civilization, and thus has many uses. Its greatest use is for electrical purposes, mostly as wire. It is extensively used in the form of sheets and nails. It has important uses in various alloys, as brass (copper and zinc), bronze and bell metal (copper and tin, and in some cases zinc, also), German silver (copper, zinc and nickel). Copper sulfate, or blue vitriol, is used in calico printing and in galvanic cells.

Copper is produced in considerable quantity in fifteen to twenty of the states and territories of the United States. The copper yielded by the chief producing states for the years 1920, 1930, and 1938 is as follows:

	1920 Pounds	1930 Pounds	1938 Pounds
Alaska	66,093,924	36,380,038	33,492,746
Arizona	552,988,731	570,897,080	420,351,310
California	11,822,028	26,262,447	1,680,754
Colorado	4,282,616	12,943,857	30,563,654
Idaho	1,922,116	2,713,681	5,611,392
Michigan	153,483,952	142,985,522	75,281,469
Montana	177,743,747	198,795,883	156,249,794
Nevada	55,580,322	87,475,019	93,655,642
New Mexico	52,159,751	74,187,966	43,913,133
Tennessee	16,727,803	....	....
Utah	110,357,748	205,769,698	229,876,860
Washington	....	1,404,893	12,494,297
Other states	5,898,302	34,573,243	21,485,488
	1,209,061,040	1,394,389,327	1,124,656,539

The price of copper varies considerably from year to year. One pound was worth about 16.75 cents in 1900; 13 cents in 1910; 18.4 cents in 1920; 13.0 cents in 1930; 9.8 cents in 1938.

The United States furnished about one-fourth of the total world's production in 1938. Other countries that produce notable amounts of copper are Chile, Canada, Northern Rhodesia, Belgian Congo, U.S.S.R., Japan.

Gold

Native gold, Au, with small amounts of Ag	
Calaverite, $AuTe_2$	Krennerite, $AuTe_2$
Petzite, $(Ag,Au)_2Te$	Sylvanite, $AuAgTe_4$

By far the greater part of gold occurs as the native metal. It enters into only one series of compounds, the tellurides, which in a few districts, as at Cripple Creek, Colorado, form rich ore deposits. For the occurrence and associations of the gold ores see under Gold, page 133; Calaverite, page 175; and Sylvanite, page 175.

The uses of gold for jewelry, plating, and coins are well known. The standard gold for United States coin is composed of 9 parts gold and 1 part copper. The gold used in jewelry is alloyed with copper and silver in order to harden it. The purity of gold is given in carats, 24 carats being the pure metal. Most of the gold used is 18 carats fine, or 18/24 gold and 6/24 other metals. Gold is used as the standard of international exchange and 1 troy ounce is worth $35 at present (1940). The value of the gold production in the principal producing states of the United States for the years 1920, 1930, and 1938 is as follows:

	1920 Value[1]	1930 Value[1]	1938 Value[1]
Alaska	$8,535,700	$8,420,800	$23,274,055
Arizona	4,961,900	3,073,500	10,676,505
California	14,810,900	9,308,300	45,889,515
Colorado	7,508,400	4,511,800	12,861,380
Idaho	468,600	438,200	3,622,955
Montana	1,897,700	969,500	7,115,955
Nevada	3,626,900	2,898,600	10,375,190
Philippine Islands	1,276,600	3,828,600	31,614,275
South Dakota	4,337,800	8,398,900	20,819,645
Utah	2,128,700	4,319,100	7,022,050
Other states	1,633,700	1,080,300	7,704,480
	51,186,900	47,247,600	180,976,005

[1] Values for 1920 and 1930 are for $20.60 per troy ounce; for 1938, $35 per troy ounce.

Iron

Hematite, Fe_2O_3	Limonite, $FeO(OH)\cdot nH_2O$
Magnetite, Fe_3O_4	Siderite, $FeCO_3$
Goethite, $FeO(OH)$	

Iron, next to aluminum, is the most abundant metal in the crust of the earth. It very rarely occurs in the native state, being found chiefly in the form of oxides, sulfides, and silicates. It is found in varying amounts in many rocks, especially in those rich in amphiboles, pyroxenes, micas, or olivine. The mineral species that contain iron are very numerous, but the minerals of importance as ores number only three or four. Iron occurs in large amounts in the sulfides, pyrite, FeS_2, being the most common of all sulfides. These, however, rarely serve as ores of the metal because of the injurious effects of the presence of sulfur upon the iron. The minerals used as ores are the various oxides and the carbonate.

The various iron ores are formed under different conditions, and as a rule occur alone or in association with only small amounts of any one of the others. For discussion of the occurrence of the iron ores see, therefore, under Hematite, page 191; Magnetite, page 195; Goethite, page 205; and Siderite, page 228.

Hematite is by far the most important ore of iron, forming in the United States about nine-tenths of the ore produced. Goethite and magnetite form each about one-twentieth of the total, while the amount of siderite produced is almost negligible. Hematite ore comes chiefly from the various Lake Superior districts and to a much less extent from Alabama. Goethite is found in the Appalachian states, and magnetite in New York, New Jersey, and Pennsylvania. Siderite is obtained from Ohio.

Nearly one-half of the world's production of iron ore comes from the United States; the amount produced from Minnesota alone nearly, if not quite, equals that produced in any other country. Germany, Great Britain, Spain, France, and Sweden are notable producers of iron.

The uses of iron and steel are too well known to need discussion. Copperas, or green vitriol, $FeSO_4 \cdot 7H_2O$, is the most important salt of iron, being used in dyeing; in making inks, Prussian blue, and rouge; and as a disinfectant. Rouge, Fe_2O_3, is used as a polishing powder and as a red paint. Considerable amounts of soft iron ore, known as paint ore, are ground for mineral paints, such as ocher, umber, and sienna.

Lead

Galena, PbS
Cerussite, $PbCO_3$
Phosgenite, $Pb_2Cl_2CO_3$
Pyromorphite, $Pb_5Cl(PO_4)_3$
Mimetite, $Pb_5Cl(AsO_4)_3$
Vanadinite, $Pb_5Cl(VO_4)_3$
Anglesite, $PbSO_4$
Crocoite, $PbCrO_4$
Wulfenite, $PbMoO_4$

Galena is the usual primary ore of lead and furnishes by far the greater part of the metal. Cerussite and anglesite are secondary minerals which occur in smaller amounts in the oxidized zone of lead deposits.

Galena occurs most commonly associated with zinc ores, especially sphalerite, or with silver ores. Lead which is derived from ores that are free from silver is known as " soft lead "; " desilverized " lead, which is obtained from silver ores, is known as " hard lead." Lead ores are commonly found as replacement deposits in limestone, either in the form of beds or irregular bodies, or as small masses disseminated through a stratum of the rock. Lead is also mined from rich veins of massive galena as at Coeur d'Alene, Idaho. For the associations and distribution of lead ores see under Galena, page 153.

Metallic lead is used to make storage batteries, cable coverings, pipes, foil, weights, bullets, and shot. It is a constituent of various alloys such as solder (lead and tin), type metal (lead and antimony), low-fusing alloys (lead, bismuth, and tin). A large amount of lead is used in the form of the basic carbonate, $(Pb{\cdot}OH)_2Pb(CO_3)_2$, which is known as white lead and is very valuable as a paint pigment. The oxides of lead, litharge, PbO, and minium, Pb_3O_4, are used in making fine grades of glass, in glazing earthenware, and as pigments. Lead chromates are used as yellow and red paints. Lead acetate, known as sugar of lead, has important uses in various industries.

The production of lead in the United States in 1938 was 383,669 short tons, valued at $35,398,000. The average price was 4.6 cents per pound.

Magnesium

Carnallite, $KMgCl_3{\cdot}6H_2O$

Several magnesium minerals, notably magnesite and dolomite, are potential sources of the metal. However, these are not used in commercial production, and magnesium is produced by the electrolysis of magnesium chloride, $MgCl_2$, and carnallite, $KMgCl_3{\cdot}6H_2O$, derived from brines.

Magnesium is the lightest metal (G. = 1.74) that remains stable under ordinary conditions. Moreover, it has considerable strength and thus finds structural uses where lightness is an essential factor. It is usually alloyed with aluminum and copper. Such alloys are more extensively used each year in making castings for various airplane parts and accessories, in vacuum cleaners, portable typewriters, cameras, optical instruments, and artificial limbs. Sheets, rods, and tubes of magnesium have many similar uses. Magnesium is also used to a large extent in the metallurgical industry as a deoxidizing and desulfurizing agent. At present the Dow Chemical Company is the only producer of magnesium in the United States. Its high-magnesium alloys are sold under the trade name *Dowmetal.*

The production of magnesium in the United States in 1939 was 10,650,121 pounds, the largest in history. The price of magnesium castings in 1939 averaged $1.31 per pound.

Manganese

Franklinite, $(Fe,Zn,Mn)(Fe,Mn)_2O_4$
Alabandite, MnS
Pyrolusite, MnO_2
Wad, mixture of oxides
Manganite, $MnO(OH)$
Psilomelane, $H_4R_2Mn_8O_{20}$
Rhodochrosite, $MnCO_3$
Rhodonite, $MnSiO_3$
Braunite, $Mn(Mn,Si)O_3$

Manganese is an element that is widely distributed in small amounts. At least traces of it are to be found in most rocks. It most commonly occurs in silicates, oxides, and carbonates. The oxides are the most abundant, and practically all the metal is derived from them.

The ore deposits of manganese are ordinarily of secondary origin. The manganese existing in the rock-forming silicates, through the agency of weathering processes, is changed to an oxide. By some process of concentration these minerals are often gathered together into irregular bodies lying in residual clays. The manganese oxides may occur associated with iron oxides, and when this happens the two are smelted together to form directly an iron-manganese alloy, *spiegeleisen,* used in making steel. Manganese minerals also frequently occur as gangue minerals associated with silver ores and if abundant, as at Butte, Montana, are used as a source of manganese. A manganese ore to be of commercial value should contain at least 40 per cent of metallic manganese and be low in percentages of phosphorus and silica.

Over 90 per cent of the manganese produced is used in the manufacture of steel. It is usually added to the steel in the form of *spiegeleisen,* an alloy of iron and manganese containing below 20 per cent of manganese, or *ferromanganese,* which contains manganese ranging in amount from 20 to 90 per cent. The manganese serves to remove oxygen that might be in the iron, and to introduce carbon into the steel by preventing its oxidation. It also counteracts the bad effects of sulfur and phosphorus. Manganese has in addition a hardening influence on steel. For these reasons manganese steels have a wide use.

Chemical uses of manganese compounds include the use of the oxide, pyrolusite, MnO_2, as an oxidizer in the manufacture of chlorine, bromine, and oxygen, as a drier in paints and varnishes, as a decolorizer of glass, and as a depolarizer in dry-cell batteries. Potassium permanganate is used as a disinfectant. Manganese is used in fertilizer, in printing calico, and for coloring bricks, pottery, and glass.

Approximately 94 per cent of the manganese used in the United States is imported. In 1938, 25,321 long tons of manganese ore with 35 per cent or more manganese, valued at $1,540,000, were produced in the United States. The chief producing states are Montana, Tennessee, Georgia, Arkansas, and Virginia.

Manganese ores are imported chiefly from the U.S.S.R., British India, Union of South Africa, Gold Coast, and Brazil.

Mercury

Cinnabar, HgS

Mercury, or quicksilver, is neither abundant nor widespread in its occurrence. The native metal is found and other rare minerals of mercury are occasionally noted, but practically the only ore of the metal is the sulfide, cinnabar. For the occurrence and distribution of mercury, therefore, see under Cinnabar, page 163.

The most important use of mercury has been in the amalgamation process for recovering gold and silver from their ores, but other methods of extraction have lessened its use in this connection. It is used in thermometers, barometers, and various scientific and electrical equipment, and in the form of an amalgam with silver for dental work and with tin in " silvering " mirrors. Several plants in the United States use mercury vapor instead of steam for the generation of power. This is a great potential use for mercury. Important military uses include the manufacture of fulminate of mercury for detonating high explosives and in paint for ship bottoms.

The unit of measure of commercial mercury is a flask of 76 pounds. In 1939, 18,633 flasks were produced in the United States, chiefly from California, Oregon, and Nevada. This amount was nearly enough to meet domestic demands, for only 3,499 flasks were imported. The average price per flask in New York in 1939 was $103.94. However, the price has recently risen greatly and early in 1940 reached $182.

Molybdenum

Molybdenite, MoS_2 Wulfenite, $PbMoO_4$

The sulfide molybdenite is today the source of the rare element molybdenum. See under Molybdenite, page 174, for its occurrence and distribution. Wulfenite has served as a minor ore. Because of the large deposit of molybdenite at Climax, Colorado, the United States produces over 90 per cent of the world's total output.

Molybdenum is used chiefly as an alloy, both alone and with other ferroalloying elements, in iron and steel. Its chief use is to replace part of the tungsten in high-speed tool steels, thus increasing the toughness of the steel.

In the form of ammonium molybdate, molybdenum is used as a chemical reagent, as a fireproofing material, and as a disinfectant. Molybdenum compounds are also used to color leather and rubber.

It is estimated that 33,297,000 pounds of molybdenum, valued at $22,567,000, were produced in the United States in 1938.

Nickel

Nickeliferous Pyrrhotite
Niccolite, $NiAs$
Millerite, NiS
Pentlandite, $(Fe,Ni)S$
Gersdorffite, $NiAsS$
Chloanthite, $NiAs_2$
Garnierite, $(Ni,Mg)SiO_3 \cdot nH_2O$
Genthite, $Ni_2Mg_2Si_3O_{10} \cdot 6H_2O$ (?)

Nickel is a comparatively rare element, often found associated with cobalt. Its minerals are frequently found in small amounts associated with magnesian igneous rocks. Only a few localities produce the metal in commercial quantities, the world's output coming mostly from the nickeliferous pyrrhotite ores of Sudbury, Ontario, Canada, and from the residual garnierite ores of New Caledonia. The production of nickel from ores mined in the United States is very small.

The chief use of nickel is in steel. Nickel steel contains from 2½ to 3½ per cent nickel, which greatly increases the strength and toughness of the alloy. By its use, therefore, lighter machines can be made without loss of strength. Nickel is also an essential constituent of stainless steel. The manufacture of *monel* metal (68 per cent nickel) and *nichrome* (35–85 per cent nickel) consumes a large amount of the nickel produced. Other alloys are German silver (nickel, zinc, and copper); metal for coinage — the 5-cent coin of the United States is 25 per cent nickel, 75 per cent copper; low-expansion metals for watch springs and other instruments. Nickel is used in plating; although chromium now largely replaces it for the surface layer, nickel is used for a thicker underlayer.

The world production of nickel in 1939 has been estimated at 121,000 metric tons, the greatest in history, of which Canada produced 85 per cent. The price of nickel in 1939 was 35 cents per pound.

Platinum

Native Platinum, Pt
Sperrylite, $PtAs_2$

Platinum is a rare element which usually occurs in the native state. Its only known natural compound is the arsenide, sperrylite, which has been found sparingly in two or three localities in association with copper and nickel ores. Native platinum is characteristically associated with peridotites that contain the platinum in disseminated particles. The greatest deposit of this type is in the Ural Mountains, U.S.S.R., which until 1934 was the chief platinum-producing region of the world. At present Canada is the chief producer of platinum. It is found there associated with the nickel ore of the Sudbury, Ontario, District.

The industrial uses of platinum depend chiefly upon its high fusing point (1,755° C.) and its resistance to chemical attack. It is valuable for crucibles, dishes, spoons, and all sorts of laboratory apparatus; when used for such purposes a small amount of iridium is usually added to increase its hardness and durability. Platinum vessels at one time were extensively used in the concentration of sulfuric acid made by the chamber process. At present cheaper materials are used. In the contact process for the manufacture of sulfuric acid, platinum is the best catalyst, but it has been partly replaced by cheaper but less efficient materials. Platinum is used in the platinum resistance thermometer and the rhodium-platinum thermocouple, devices for measuring high temperatures. It is also used in electrical apparatus for contact-points of bells, magnetos, and induction coils. Considerable platinum is used in jewelry and in dentistry, but because of the increased price of the metal, gold and gold alloys are gradually taking its place. Platinum is used in making photographic prints and is superior to silver in that it gives a greater variety of tone and is permanent.

It is estimated that during 1938 over 550,000 ounces of platinum were produced. The leading producing countries were Canada, U.S.S.R., South Africa, United States (mostly from Alaska), and Colombia.

The price of platinum has fluctuated greatly, but in general increased until 1928, when foreign platinum sold for as much as $143 an ounce. From this peak the price declined rapidly, reaching the lowest point, $16.50 an ounce, in 1931. During 1939 the maximum price for platinum was $40.80 an ounce, and the minimum price was $19.39, compared with a maximum in 1938 of $43 and a minimum of $24.

Silver

Native Silver, Ag
Argentite, Ag_2S
Stromeyerite, $(Ag,Cu)_2S$
Sylvanite, $(Au,Ag)Te_2$
Polybasite, $Ag_{16}Sb_2S_{11}$
Stephanite, Ag_5SbS_4
Pyrargyrite, Ag_3SbS_3
Proustite, Ag_3AsS_3
Cerargyrite, AgCl
Embolite, Ag(Cl,Br)

From the above list it will be noted that a large percentage of the silver minerals are sulfo salts, but that native silver and argentite are also important ores. Besides the distinctively silver minerals, several minerals of other metals may contain sufficient silver as an impurity to make them valuable ores of the metal. Most important among these are the argentiferous varieties of galena, tetrahedrite, chalcocite, bornite, and chalcopyrite. These minerals form the most common ores of silver. Silver is also associated with native gold, and a considerable amount is recovered from gold mining operations. Over half the world's silver comes as a by-product of the mining of other metals.

It is difficult to point to any mine in the United States that is worked for its silver values alone. Notable gold-silver districts are the Comstock Lode and Tonopah, Nevada; the San Juan, Aspen, and Boulder County regions, Colorado. The Cocur d'Alene District of Idaho is an important lead-silver producer.

Copper deposits where silver is also produced in notable amount are at Butte, Montana; Bingham and Tintic districts, Utah; Bisbee and Jerome districts, Arizona; Shasta County, California; and at various places in Nevada, Montana, and Arizona. In 1938 the chief states in order of silver production were Idaho, Utah, Colorado, Arizona, and Montana.

The uses of silver for coinage, for various useful and ornamental objects, and for plating are too well known to need discussion. The standard silver coin of the United States contains nine parts of silver to one of copper. Silver salts are extensively used in photographic work.

It is estimated that the world production of silver in 1938 was 267,135,000 ounces. The leading producers were:

	OUNCES
Mexico	81,018,809
United States	61,688,834
Canada	22,977,751
Peru	20,424,466
Australia	13,311,237

The U.S. government price of silver during 1938 was 64.6+ cents per ounce. The price of silver in London in 1938 was about 45 cents per ounce.

Tin

Stannite, Cu_2FeSnS_4 **Cassiterite,** SnO_2

The only important ore of tin is the oxide, cassiterite. This is a mineral which, although occurring in small quantities in many localities, is found only in a comparatively few commercial deposits. For the occurrence and distribution of the mineral see page 199. The United States at present produces only a small amount of tin ore.

The chief use of tin is in the manufacture of *tin plate* and *terne plate* for food containers. Terne plate is made by applying a coating of tin and lead instead of pure tin. Experiments are going forward to find suitable materials to substitute for tin used in this way. Aluminum, silver, and organic lacquers are being used. Tin is used in solders with lead, in babbitt metal with antimony and copper, and in bronze and bell-metal with copper. " Phosphor bronze " contains 89 per cent copper, 10 per cent tin, and 1 per cent phosphorus. The artificial oxide of tin is used as a polishing powder.

It is estimated that the world production of tin in 1938 was 147,500 metric tons. The chief producers were:

	METRIC TONS
Federated Malay States	41,077
Bolivia	25,484
Netherlands Indies	21,000
Siam	13,616
China	11,606

The price of tin in 1938 varied from 41 to 35 cents per pound.

Titanium

Ilmenite, $FeTiO_3$
Rutile, TiO_2

Brookite, TiO_2
Octahedrite, TiO_2
Sphene, $CaTiSiO_5$

Titanium is a rare element, but is widely distributed in small quantities. In the form of the minerals rutile and sphene it is present in most igneous rocks. Ilmenite is commonly found in the mafic igneous rocks, and is often associated with magnetic iron ores.

Increasing amounts of titanium ore are each year mined in the United States. The largest production of both rutile and ilmenite is in Virginia. The Adirondack magnetite deposits contain considerable ilmenite, but the bulk of this mineral is imported from British India.

Titanium has become an important industrial substance because of the use of the oxide as a pigment. Titanium oxide has an opacity greater than zinc oxide or white lead. Titanium was formerly used in steel and cast iron, in which it served to eliminate the oxygen and nitrogen. It also gave a high tensile strength and great ductility to the steel. It is used to some extent in the manufacture of electrodes for arc lights. The oxide is used to give a yellow color to porcelain, and to give a natural color to false teeth.

Figures for titanium production are not available. In 1939 the price of TiO_2 was 14 cents per pound.

Tungsten

Wolframite, $(Fe,Mn)WO_4$
Ferberite, $FeWO_4$
Huebnerite, $MnWO_4$
Scheelite, $CaWO_4$

Tungsten is a rare acid-forming heavy metal found chiefly in the iron-manganese and calcium tungstates, wolframite and scheelite. For the occurrence and distribution of these minerals see under Wolframite, page 266, and Scheelite, page 267.

The most important use of tungsten is as a steel-hardening metal. Tungsten steels hold their temper at high temperatures and are therefore valuable for the making of high-speed tools. Because of its high fusing point metallic tungsten has several uses, chiefly as a filament in incandescent electric lights, of which more than 500,000,000 are sold in the United States annually. It is also used in crucibles, electrical contacts, and spark plugs. " Carboloy " is a tungsten carbide with a hardness considerably above 9 in the Mohs scale. It is used in place of diamond in some core drills, and is used in cutting glass and hard steels.

Sodium tungstate is used in fireproofing cloth. Calcium tungstate is used as the luminous screen in x-ray apparatus.

It is estimated that 32,000 metric tons of tungsten were produced in 1938. China is the chief producer, followed by the United States. During 1938 tungsten concentrates containing 65–70 per cent WO_3 varied in price from $16 to $25 per short ton.

Vanadium

Vanadinite, $Pb_5Cl(VO_4)_3$
Carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 8H_2O$
Roscoelite, $K_2V_4Al_2Si_6O_{20}(OH)_4$

Vanadium is an acid-forming metal which is known in a number of very rare minerals. The three listed above are the only ones which occur in sufficient quantities in the United States to be available for ores. Roscoelite is a green micaceous mineral containing about 2 per cent of metallic vanadium. It is found in a soft sandstone near Placerville, Colorado. Carnotite is a sulfur-yellow pulverulent mineral of doubtful composition which is found in sandstones in several districts in Colorado and Utah, near the boundary line between the two states. Vanadinite is a secondary lead mineral which is found sparingly in the oxidized zones of certain lead deposits in Arizona and New Mexico. All these ores are low grade, and are worked only in a small way and at intervals. The chief supply of vanadium ores at present comes from Peru, where there are large deposits of an impure carbonaceous material containing a vanadium sulfide of doubtful composition known as *patronite.*

Vanadium is used chiefly in steel. It aids the removal of the oxygen and yields a fine-grained, tough, and resistant alloy. Metavanadic acid, HVO_3, is used as a yellow pigment, known as vanadium bronze. Vanadium oxide, V_2O_5, has replaced platinum to a large extent in the manufacture of sulfuric acid by the contact process.

In 1939 the United States produced 1,984,068 pounds of vanadium, while 2,132,548 pounds were imported from Peru. The price of vanadium ore in 1939 was 27.5 cents per pound of contained V_2O_5.

Zinc

Sphalerite, ZnS
Zincite, ZnO
Franklinite, $(Fe,Zn,Mn)(Fe,Mn)_2O_4$

Smithsonite, $ZnCO_3$
Hemimorphite, $Zn_4Si_2O_7(OH)_2 \cdot H_2O$
Willemite, Zn_2SiO_4

The sulfide, sphalerite, is the one common primary ore of zinc. The carbonate, smithsonite, and the silicate, hemimorphite, are usually associated with sphalerite deposits as secondary minerals. The three minerals zincite, franklinite, and willemite are found in a unique deposit at Franklin, New Jersey. In general, sphalerite, the chief ore of zinc, is found in irregular replacement deposits in limestone. It is very frequently intimately associated with lead minerals. For its occurrence and distribution see page 155.

Metallic zinc, or spelter, as it is called, is used chiefly for galvanizing iron, as an alloy with copper in brass, and in storage and telegraph batteries. Zinc dust or zinc shavings are used to precipitate gold from its solution in the cyanide process. Large amounts of zinc are used in the pigments zinc oxide and lithopone (a mixture of barium sulfide and zinc sulfate). Zinc chloride is used as a wood preservative.

In 1938 in the United States 516,699 short tons of zinc were produced. The chief producing states were:

	SHORT TONS
Oklahoma	112,924
New Jersey	85,839
Kansas	73,024
Idaho	44,030
Utah	33,658
New York	29,896

The world smelter production of zinc in 1938 is estimated at 1,558,000 metric tons. The chief producing countries are:

	SHORT TONS
United States	404,912
Belgium	209,983
Germany	192,000
Canada	155,973
Poland	108,071

In 1938 the average price of zinc at New York was 4.99 cents and at London 3.05 cents per pound.

MINERALS USED IN THE CHEMICAL INDUSTRY

Salt

Ordinary salt (halite) finds its greatest use in the chemical industry, where it serves as the source of sodium and chlorine. Some of the important manufactured alkali products are soda ash, bicarbonate of soda, caustic soda, sal soda, and modified sodas for the laundry, textile, lumber, and tanning trades. Numerous other manufactured salts are used in many diversified industries. Metallic sodium, hydrochloric acid, and chlorine are produced from salt.

Salt is used extensively in the natural state in tanning hides, in fertilizers, stock feeds, and as a weed killer. In addition to its familiar uses in the home, salt enters into the preparation of foods of many kinds, such as the preservation of butter, cheese, fish, and meat. It is also used as a refrigerant in refrigerator cars and in freezing and packing ice cream. There are many other uses for salt, but the above are the principal ones, and illustrate its importance in human activity.

Salt is produced in fifteen states of the United States, either from rock-salt deposits or evaporation of saline waters. The total production in 1939 of 9,277,911 tons, valued at $24,509,680, was the largest on record. However, sodium compounds manufactured from salt were estimated to have a value of nearly $100,000,000.

Sulfur

Sulfur, S Pyrite, FeS_2

Sulfur found in the native state is today the chief source of that element. The area in Texas and Louisiana bordering on the Gulf of Mexico is the principal producing district of the world. The sulfur is found in limestone that forms part of the caprock over salt domes. It is extracted by the Frasch process. This consists of pumping superheated water to the sulfur-bearing rock; the sulfur thus melted is brought to the surface with the aid of compressed air and allowed to solidify. Pyrite is also a source of sulfur and is mined on a large scale at Rio Tinto, Spain. Sulfur is used in the chemical industry chiefly in the manufacture of sulfuric acid. It is also used in fertilizers and insecticides, paper, explosives, coal-tar products, and rubber. The greatest sulfur production was in 1937 when approximately 2,466,000 long tons, valued at $44,300,000, were produced in the United States. In 1939 the output was 2,233,817 long tons valued at $35,500,000.

Lithium

Triphylite, $LiFePO_4$
Amblygonite, $Li(AlF)PO_4$
Lepidolite, $K_2Li_3Al_4Si_7O_{21}(OH,F)_3$
Spodumene, $LiAlSi_2O_6$

Of the above minerals spodumene is the most important as a source of lithium, although some amblygonite is used. Both spodumene and amblygonite are pegmatite minerals found in many places but in most localities in only small amounts. Nearly all the lithium produced from minerals in the United States comes from the Etta Mine near Keystone in the Black Hills of South Dakota. Large spodumene crystals are mined with smaller amounts of amblygonite and other lithium minerals. The Stewart Mine at Pala, California, has in the past produced considerable amounts of lepidolite and amblygonite. In 1938 lithium was for the first time recovered as a by-product (lithium phosphate) from the brines of Searles Lake, California.

Lithium finds its largest use in manufactured salts. They are widely used in pharmaceutical products such as lithia water and lithia tablets. The chloride and fluoride are used as fluxes in welding; the hydroxide for treating cellulose for rayon manufacture; the borate in dental cement. Small quantities of metallic lithium are alloyed with aluminum, magnesium, lead, and zinc to give them greater hardness and toughness.

The production of lithium products in the United States was 1,357 tons in 1937, 892 tons in 1938, and 1,990 tons in 1939, valued respectively at $36,206, $47,088, and $97,000. The greatly increased value for the lesser tonnage in 1938 is because of the lithium phosphate produced at Searles Lake which contains about ten times as much lithium as natural minerals.

Borax and Boric Acid

Boracite, $Mg_7Cl_2B_{16}O_{30}$

Borax, $Na_2B_4O_7 \cdot 10H_2O$

Kernite, $Na_2B_4O_7 \cdot 4H_2O$

Ulexite, $NaCaB_5O_9 \cdot 8H_2O$

Colemanite, $Ca_2B_6O_{11} \cdot 5H_2O$

In the United States the minerals borax, ulexite, colemanite, and kernite have successively been used as the chief source of borax and boric acid. At present most of the production is from a deposit of mixed kernite and borax at Kramer, California.

Borax has many uses which depend on its easy solubility in water yielding an antiseptic solution, its low melting point, and its superior fluxing properties. Some of the common uses of borax and boric acid are in medicine, food preservatives, disinfectants, deodorants, soaps, and soap powders. Borax is of considerable industrial importance as a solvent of casein and is thus used in the manufacture of coated paper, plywood, plaster, paint, and calcimine. It is an essential constituent of porcelain enamels used in coating iron and in the manufacture of tile and sanitary ware. It is used in the manufacture of heat-resisting glass and as a flux in welding and soldering operations.

The production of borates in the United States was 358,898 short tons in 1937 and 219,513 in 1938, valued at $7,232,897 and $4,570,316, respectively.

Strontium

Celestite, $SrSO_4$

Strontianite, $SrCO_3$

Celestite and strontianite are the only strontium minerals of importance. Although celestite is more abundant, and thus the chief ore, strontianite is of greater value because of the ease with which it can be treated. In certain areas disseminated strontium minerals are found as original precipitates from sea water. The more concentrated deposits are believed to be the result of the solution of these minerals by circulating ground water and subsequent reprecipitation. In the United States celestite and strontianite are found in many localities, but there has been no domestic production since 1918. The demand has been met by imports, chiefly from Germany and England.

Strontium is used chiefly as the hydrate for desaccharizing beet-sugar molasses. After the sugar has been precipitated the strontium hydrate can be recovered. Strontium nitrate is used as the source of the red flame in fireworks, flares, and warning signals.

The total amount of strontium salts and ore imported into the United States in 1939 was about 3,000 tons, valued at $58,000.

Other Minerals

Many other minerals in addition to those mentioned above are used in the chemical industry as the source of various constituents. Many of the ores of the metals are among these and have been mentioned elsewhere. Special mention should be made of the following:

Bauxite is used for the production of aluminum sulfate, aluminum hydrate, aluminum chloride, and sodium aluminate.

Fluorite is the source of fluorine for the manufacture of hydrofluoric acid and various fluorine compounds used as insecticides, preservatives, and dyestuffs.

Potash salts are used chiefly in fertilizer but in addition are important in the chemical industry in the manufacture of potassium hydroxide, potassium iodide, potassium ferricyanide, potassium chlorate, and potassium permanganate.

LIST OF MINERALS SUITABLE FOR A SMALL MINERAL COLLECTION

For the convenience of those who desire to possess a small but representative mineral collection the following list is given. The names of the more important species are printed in bold-face type, and the names of other desirable but less important minerals in ordinary type. The first group includes 63 names, while the complete list numbers 112.

Gold in quartz
Silver
Copper
Sulfur
Graphite
Argentite
Chalcocite
Bornite
Galena
Sphalerite
Chalcopyrite
Pyrrhotite
Niccolite
Millerite
Cinnabar
Realgar
Orpiment
Stibnite
Pyrite
Marcasite
Arsenopyrite
Molybdenite
Tetrahedrite
Proustite
Cuprite
Zincite
Corundum
Hematite
Ilmenite
Spinel
Magnetite
Franklinite
Chromite
Chrysoberyl
Cassiterite
Rutile
Pyrolusite
Goethite
Bauxite
Halite
Cryolite
Fluorite
Calcite
Dolomite
Siderite
Rhodochrosite
Smithsonite
Aragonite
Witherite
Strontianite
Cerussite
Malachite
Azurite
Borax
Kernite
Ulexite
Colemanite
Apatite
Pyromorphite
Amblygonite
Wavellite
Turquois
Barite
Celestite
Anglesite
Anhydrite
Gypsum
Scheelite
Wulfenite
Quartz (several varieties)
Opal
Orthoclase
Albite
Oligoclase
Labradorite
Leucite
Sodalite
Scapolite
Heulandite
Stilbite
Chabazite
Natrolite
Analcime
Talc
Serpentine
Apophyllite
Chlorite
Prehnite
Muscovite
Biotite
Phlogopite
Lepidolite
Amphiboles (several varieties)
Pyroxenes (several varieties)
Spodumene
Rhodonite
Tourmaline
Beryl
Hemimorphite
Olivine
Willemite
Garnet
Idocrase
Epidote
Zircon
Datolite
Topaz
Andalusite
Kyanite
Staurolite
Sphene
Axinite

V. DETERMINATIVE MINERALOGY

Determinative tables for minerals are of two kinds: (1) those which rely chiefly upon chemical tests, and (2) those which make use solely of physical tests. Obviously, since the chemical composition of a mineral is its most fundamental property, those tables which emphasize chemical tests are much more satisfactory. Moreover, the tables which depend wholly upon physical tests have distinct limitations beyond which it is impossible to use them. These latter tables have, however, the important advantages that their tests are simpler, more readily and quickly performed, and do not require the equipment of a laboratory. For these reasons physical determinative tables probably have a wider use, in spite of their limitations, than those that involve chemical tests.

The limited scope of this book forbids the inclusion of elaborate chemical tables and requires instead the introduction of physical tables of as simple a form as possible. Such tables, however, must be used with a thorough understanding of their nature and their inherent disadvantages. Many of the physical properties of minerals are not entirely fixed in their character. Color, for instance, is frequently an extremely variable property. Hardness, though more definite, may vary to a slight extent and, by a change in the state of aggregation of a mineral, may appear to vary much more widely. Cleavage is a property which may often be obscured by the physical condition of the mineral. Consequently, in making a determination of a mineral by means of its physical properties alone, it is necessary to have a fairly typical specimen and one which is of sufficient size to enable its properties to be easily observed. Moreover, it often will be impossible by the aid of such tables to differentiate positively between two or three similar species. Frequently, however, the descriptions of these possible minerals given in the section on descriptive mineralogy will enable one to make a definite decision. Moreover, the tables that follow, used in connection with the chemical tests given under the description of the individual minerals, together with the more detailed explanations of the various tests to be found in the section on chemical mineralogy, may serve as a substitute for more elaborate chemical tables.

The determinative tables given beyond have been made as brief and simple as possible. Only the common species or those which, though rarer in occurrence, are of economic importance have been included. The chances of having a mineral to determine that is not included in these tables are small, but it must be borne in mind that there is such a possibility. The names of the minerals have been printed in three different styles of type, as **CHALCOCITE**, ARGENTITE and Stephanite, in order to indicate their relative importance and frequency of occurrence. Whenever it was felt that difficulty might be experienced in placing a mineral correctly, it has been included in the two or more possible divisions.

On page 415 will be found a general classification of the tables. The proper division in which to look for a mineral can be determined by means of the tests indicated there. The tables are divided into two main sections on the basis of luster. The first division includes those minerals which have a metallic or submetallic luster. By that is meant those minerals which on their thinnest edges remain opaque and which consequently will give black or dark-colored " streaks " when they are rubbed across a piece of unglazed porcelain, the so-called streak plate. The second division includes minerals with a nonmetallic luster, or those which are transparent upon their thinnest edges, and which therefore give either a colorless or a light-colored streak. It should be noted that the color of the streak cannot always be foretold from the color of the mineral itself. Frequently a dark-colored mineral will be found to give a light-colored streak.

The tables are next subdivided according to hardness. For metallic minerals: (1) minerals of a hardness less than 2½ (soft enough to leave a mark on paper); (2) greater than 2½, less than 5½ (can be scratched by a knife but will not leave a mark on paper); (3) greater than 5½ (cannot be scratched by a knife). For nonmetallic minerals: (1) less than 2½ (can be scratched by the fingernail); (2) 2½–3 (cannot be scratched by the fingernail but can be scratched by a copper coin); (3) 3–5½ (cannot be scratched by a copper coin but can be scratched by a knife); (4) 5½–7 (cannot be scratched by a knife but can be scratched by quartz); (5) greater than 7 (cannot be scratched by quartz). In applying the tests for hardness, certain precautions should be observed. Before deciding upon the relative hardness of a mineral, it is well to try the test if possible in two ways. For instance, if a mineral is apparently scratched by the knife make sure on the other hand that the knife cannot be scratched by the mineral. Further, the copper coin and the knife blade used in making the tests should be bright and clean; otherwise the rubbing off of a layer of dirt or tarnish might be mistaken for a scratch. The possession of specimens of the minerals of the Mohs scale, so that the hardness of a mineral can be closely determined, would frequently be of great assistance in the use of the tables. Lastly, it is to be remembered that the physical condition of a mineral may apparently change its hardness. For instance, minerals that may occur in pulverulent or fibrous forms will under these conditions appear to be much softer than when in their more compact form.

The minerals with nonmetallic luster are, in general, further subdivided according to whether or not they show a prominent cleavage. This will frequently be a difficult decision to make. It will require some practice and experience before one can always make the determination rapidly and accurately. Note that the minerals are divided according to whether or not they show a *prominent* cleavage. Minerals in which the cleavage is imperfect or ordinarily obscure are included with those that have no cleavage. It will always be best, if it is possible, actually to try to produce a cleavage upon the specimen rather than to judge from its appearance alone. If a mineral shows a cleavage, the number of the cleavage planes and their relations to each other and to any crystal forms present should be noted. As far as possible, the minerals in which the cleavage may become obscure, because of certain conditions in the state of aggregation, have been included in both divisions.

The minerals which fall in any one of the different divisions of the tables have been arranged according to various methods. In some cases, those that possess similar cleavages have been grouped together; frequently color determines their order, etc. The column farthest to the left will indicate the method of arrangement used in each section. Most of the different properties listed need no special explanation. A few words, however, may be said concerning the column headed **G.** (specific gravity). For a discussion of specific gravity and the methods for its accurate determination, see page 73. If the specimen to be determined is of sufficient size and is pure, its approximate specific gravity can be determined by simply weighing it in the hand. This, however, will require some experience. Below is given a list of common minerals which show a wide range of specific gravity. By experimenting with specimens of these one can become expert in the approximate determination of the specific gravity of any mineral.

Halite, 2.16
Gypsum, 2.32
Orthoclase, 2.57
Calcite, 2.72
Fluorite, 3.18
Topaz, 3.53
Corundum, 4.02
Chalcopyrite, 4.20
Barite, 4.45
Pyrite, 5.02
Chalcocite, 5.75
Cerussite, 6.55
Cassiterite, 6.95
Galena, 7.50
Cinnabar, 8.10
Copper, 8.9
Silver, 10.5

It should be emphasized that specimens of minerals should be pure no matter what method is used in determining specific gravity. It is usually better to use a small specimen since it is easier to obtain small than large fragments of pure material.

Following the tables on determinative mineralogy a list of the common minerals is given, arranged according to increasing specific gravity.

GENERAL CLASSIFICATION OF THE TABLES

LUSTER — METALLIC OR SUBMETALLIC

I. Hardness: < 2½. (Will leave a mark on paper.) Page 416.

II. Hardness: > 2½, < 5½. (Can be scratched by knife; will not readily leave a mark on paper.) Page 417.

III. Hardness: > 5½. (Cannot be scratched by knife.) Page 423.

LUSTER — NONMETALLIC

I. Streak definitely colored. Page 425.

II. Streak colorless.

- A. Hardness: < 2½. (Can be scratched by fingernail.) Page 428.
- B. Hardness: > 2½, < 3. (Cannot be scratched by fingernail; can be scratched by cent.)
  - 1. Cleavage prominent. Page 431.
  - 2. Cleavage not prominent.
    - *a.* A small splinter is fusible in the candle flame. Page 433.
    - *b.* Infusible in candle flame. Page 434.
- C. Hardness: > 3, < 5½. (Cannot be scratched by cent; can be scratched by knife.)
  - 1. Cleavage prominent. Page 435.
  - 2. Cleavage not prominent. Page 439.
- D. Hardness: > 5½, < 7. (Cannot be scratched by knife; can be scratched by quartz.)
  - 1. Cleavage prominent. Page 443.
  - 2. Cleavage not prominent. Page 445.
- E. Hardness: > 7. (Cannot be scratched by quartz.)
  - 1. Cleavage prominent. Page 449.
  - 2. Cleavage not prominent. Page 450.

LUSTER: METALLIC OR SUBMETALLIC

I. Hardness: $< 2\frac{1}{2}$. (Will leave a mark on paper.)

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Black	Iron-black	4.7	1–2	Usually splintery or in radiating fibrous aggregates.	**PYROLUSITE** p. 202 MnO_2 Tetragonal
	Steel-gray to iron-black	2.3	$1–1\frac{1}{2}$	Cleavage perfect basal $\{0001\}$. May be in hexagonal-shaped plates. Greasy feel.	**GRAPHITE** p. 148 C Hexagonal
Black to greenish black	Blue-black	4.7	$1–1\frac{1}{2}$	Cleavage perfect basal $\{0001\}$. Micaceous, may be in hexagonal-shaped leaves. Greenish streak on glazed porcelain (graphite, black). Greasy feel.	MOLYBDENITE p. 174 MoS_2 Hexagonal
Gray-black	Blue-black to lead-gray	7.6	$2\frac{1}{2}$	Cleavage perfect cubic $\{100\}$. In cubic crystals. Massive granular.	**GALENA** p. 153 PbS Isometric
	Blue-black	4.5	2	Cleavage perfect pinacoidal $\{010\}$. Bladed with cross striations. Fuses in the candle flame.	**STIBNITE** p. 166 Sb_2S_3 Orthorhombic
Bright red	Red to vermilion	8.1	$2–2\frac{1}{2}$	Cleavage perfect prismatic $\{10\bar{1}0\}$. Luster adamantine. Usually granular massive.	**CINNABAR** p. 163 HgS Rhombohedral
Red-brown	Red to vermilion	5.2	1+	Earthy. Frequently as pigment in rocks. Crystalline hematite is harder.	**HEMATITE** p. 191 Fe_2O_3 Rhombohedral
Yellow-brown	Yellow-brown	3.6 to 4.0	1+	Earthy. Limonite is usually harder.	LIMONITE p. 208 $FeO(OH)\cdot nH_2O+Fe_2O_3\cdot nH_2O$ Amorphous

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Black. May leave a slight mark on paper	Gray-black	7.3	2–2½	Usually massive or earthy. Distinguished by being easily sectile, i.e., can be cut with a knife like lead. Bright steel-gray on fresh surfaces; darkens on exposure.	ARGENTITE p. 150 Ag_2S Isometric
	Indigo-blue; may tarnish to blue-black	4.6	1½–2	Usually in platy masses or in thin 6-sided platy crystals. Moistened with water turns purple.	Covellite p. 163 CuS Hexagonal

LUSTER: METALLIC OR SUBMETALLIC

II. Hardness: > 2½, < 5½

(Can be scratched by a knife; will not readily leave a mark on paper).

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Black; may have brown tinge	Steel-gray. May tarnish to dead black on exposure	4.7 to 5.0	3–4½	Massive or in tetrahedral crystals. Often associated with silver ores.	**TETRAHEDRITE** p. 181 $(Cu,Fe,Zn,Ag)_{12}Sb_4S_{13}$ Isometric
Gray-black		5.7	2½–3	Somewhat sectile. Usually compact massive. Associated with other copper minerals.	**CHALCOCITE** p. 151 Cu_2S Orthorhombic
Black. May leave a mark on paper	Steel-gray on fresh surface. Tarnishes to dull gray on exposure	7.3	2–2½	Easily sectile. Usually massive or earthy. Rarely in cubic crystals.	ARGENTITE p. 150 Ag_2S Pseudoisometric
	Iron-black	4.7	1–2	Usually splintery or in radiating fibrous aggregates.	**PYROLUSITE** p. 202 MnO_2 Tetragonal

LUSTER: METALLIC OR SUBMETALLIC

II. Hardness: > 2½, < 5½

(Can be scratched by a knife; will not readily leave a mark on paper.) (*Continued*)

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Black	Steel-gray on fresh surface. Tarnishes to dull gray on exposure	6.2	2–2½	Fuses easily in candle flame. Usually in small irregular masses, often earthy. A rare mineral.	Stephanite p. 179 Ag_5SbS_4 Orthorhombic
	Gray-black	4.4	3	Cleavage prismatic {110}. Usually in bladed masses showing cleavage. Associated with other copper minerals.	**ENARGITE** p. 182 Cu_3AsS_4 Orthorhombic
		5.5 to 6.0	2–3	Fuses easily in candle flame. Characteristically in fibrous, featherlike masses.	Jamesonite p. 183 $Pb_4FeSb_6S_{14}$ Monoclinic
		5.8 to 5.9	2½–3	Fuses easily in candle flame. In stout prismatic crystals; characteristically twinned with re-entrant angles giving a "cogwheel" effect.	Bournonite p. 184 $PbCuSbS_3$ Orthorhombic
		6.2	2½	Fuses easily in candle flame. Often in thin 6-sided crystal plates with triangular marking. Also massive and earthy.	Polybasite p. 178 $Ag_{16}Sb_2S_{11}$ Monoclinic
	Steel-gray	4.4	4	Decrepitates and fuses in candle flame. Irregular massive.	Stannite p. 159 Cu_2FeSnS_4 Tetragonal
Gray-black. Will mark paper	Lead-gray	2.6	2	Cleavage perfect pinacoidal {010}. Fuses easily in candle flame. Characterized by bladed crystal aggregates with cross striations.	**STIBNITE** p. 166 Sb_2S_3 Orthorhombic

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Gray-black. Will mark paper	Lead-gray	6.8	2½	Cleavage perfect pinacoidal {010}. Fuses easily in candle flame. Resembles stibnite and can be told from it only by test for bismuth.	Bismuthinite p. 168 Bi_2S_3 Orthorhombic
		7.5	2½	Cleavage perfect cubic {100}. In cubic crystals and granular masses. If a fragment is held in the candle flame, it does not fuse but is slowly reduced and small globules of metallic lead collect on the surface.	**GALENA** p. 153 PbS Isometric
Gray-black	Tin-white; tarnishes to dark gray	5.7	3½	Cleavage perfect basal {0001}, rarely seen. Usually occurs in fibrous botryoidal masses. Heated in the candle flame gives off white fumes and yields a strong garlic odor.	Arsenic p. 141 As Rhombohedral
	Tin-white	8 to 8.2	2	Cleavage pinacoidal {010}. Fuses easily in candle flame. Often as thin coatings and in lath-shaped crystals.	Sylvanite p. 175 $(Au,Ag)Te_2$ Monoclinic
		9.4	2½	Fuses easily in candle flame. In irregular masses or in thin deeply striated lath-shaped crystals. Told from sylvanite by its lack of cleavage.	Calaverite p. 175 $AuTe_2$ Monoclinic
Black	Usually pale copper-red. May be silver-white with pink tone	7.8	5–5½	Usually massive. May be coated with green nickel bloom. Associated with cobalt and nickel minerals.	NICCOLITE p. 161 NiAs Hexagonal
	Fresh surface brownish bronze; tarnishes purple	5.1	3	Usually massive. Associated with other copper minerals, chiefly chalcocite and chalcopyrite.	**BORNITE** p. 152 Cu_5FeS_4 Isometric

LUSTER: METALLIC OR SUBMETALLIC

II. Hardness: $> 2\frac{1}{2}$, $< 5\frac{1}{2}$

(Can be scratched by a knife; will not readily leave a mark on paper.) (*Continued*)

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Black	Brownish bronze	4.6	4	Small fragments magnetic. Usually massive. Often associated with chalcopyrite and pyrite.	**PYRRHOTITE** p. 160 $Fe_{1-x}S$ Hexagonal
		4.6 to 5.0	$3\frac{1}{2}$–4	Cleavage octahedral. Resembles pyrrhotite with which it usually is associated. Distinguished by cleavage.	Pentlandite p. 162 (Fe,Ni)S Isometric
	Brass-yellow	4.1 to 4.3	$3\frac{1}{2}$–4	Usually massive, but may be in sphenoidal crystals resembling tetrahedrons. Associated with other copper minerals and pyrite.	**CHALCOPYRITE** p. 157 $CuFeS_2$ Tetragonal
	Brass-yellow. Almost greenish when in very slender crystals	5.5	3–$3\frac{1}{2}$	Cleavage rhombohedral $\{10\bar{1}1\}$, rarely seen. Usually in radiating groups of hairlike crystals.	MILLERITE p. 161 NiS Rhombohedral
Dark brown to black	Steel-gray to iron-black	4.3	4	In radiating fibrous or crystalline masses. Distinct prismatic crystals often grouped in bundles. Frequently associated with pyrolusite.	MANGANITE p. 207 MnO(OH) Orthorhombic
	Iron-black to brownish black	4.6	$5\frac{1}{2}$	Luster pitchy. Frequently accompanied by yellow or green oxidation products. Usually in granular masses in peridotites.	**CHROMITE** p. 197 $FeCr_2O_4$ Isometric
	Brown to black	7.0 to 7.5	5–$5\frac{1}{2}$	Cleavage perfect pinacoidal $\{010\}$. With greater amounts of manganese the streak and color are darker.	WOLFRAMITE p. 260 $(Fe,Mn)WO_4$ Monoclinic

Streak	**Color**	**G.**	**H.**	**Remarks**	**Name, Composition, Crystal System**
Black	Indigo-blue; may tarnish to blue-black	4.6	1½–2	Usually in platy masses or in thin 6-sided platy crystals. Moistened with water turns purple.	Covellite p. 163 CuS Hexagonal
Usually black. May be brownish	Black	3.7 to 4.7	5–6	Massive botryoidal and stalactitic. Usually associated with pyrolusite.	PSILOMELANE p. 210 $H_4R_2Mn_8O_{20}$. R essentially Ba Appears amorphous
Light to dark brown	Dark brown to coal-black. More rarely yellow or red	3.9 to 4.1	3½–4	Cleavage perfect dodecahedral $\{110\}$ (6 directions). Usually cleavable granular; may be in tetrahedral crystals. The darker the specimen the higher the percentage of iron. The streak is always of a lighter color than the specimen.	**SPHALERITE** p. 155 ZnS Isometric
Red brown to Indian red	Dark brown to steel-gray to black	4.8 to 5.3	5½–6½	Usually harder than knife. Massive, radiating, reniform, micaceous.	**HEMATITE** p. 191 Fe_2O_3 Rhombohedral
	Deep red to black	5.85	2½	Cleavage rhombohedral $\{10\bar{1}1\}$. Easily fusible in candle flame. Dark "ruby silver" and shows dark ruby-red color in thin splinters. Associated with other silver minerals.	Pyrargyrite p. 180 Ag_3SbS_3 Rhombohedral
	Red-brown to deep red. Ruby-red if transparent	6.0	3½–4	Massive or in cubes or octahedrons. May be in very slender crystals (chalcotrichite). Associated with other oxidized copper minerals as malachite, azurite, native copper.	CUPRITE p. 187 Cu_2O Isometric
Bright red	Ruby-red	5.55	2–2½	Cleavage rhombohedral $\{10\bar{1}1\}$. Easily fusible in candle flame. Light "ruby silver." Associated with pyrargyrite.	Proustite p. 180 Ag_3AsS_3 Rhombohedral
Yellow brown. Yellow ocher	Dark brown to black	3.6 to 4.0	5–5½	Vitreous luster. Usually contains about 15% water while goethite contains 10%.	LIMONITE p. 208 $FeO(OH) \cdot nH_2O + Fe_2O_3 \cdot nH_2O$ Amorphous

LUSTER: METALLIC OR SUBMETALLIC

II. Hardness: $> 2\frac{1}{2}$, $< 5\frac{1}{2}$

(Can be scratched by a knife; will not readily leave a mark on paper.) (*Continued*)

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Yellow brown. Yellow ocher	Dark brown to black	4.37	5–5½	Cleavage pinacoidal $\{010\}$. In radiating fibers, mammillary and stalactitic forms. Rarely in crystals. Definitely distinguished from limonite by presence of cleavage or crystal form.	**GOETHITE** p. 205 $FeO(OH)$ Orthorhombic
Dark red. (Some varieties mark paper.)	Dark red to vermilion	8.10	2½	Cleavage prismatic $\{10\bar{1}1\}$. Usually granular or earthy. Commonly impure and of a dark red or brown color. When pure, translucent or transparent and bright red.	**CINNABAR** p. 163 HgS Rhombohedral
Copper-red, shiny	Copper-red on fresh surface; tarnishes black	8.9	2½–3	Malleable. Usually in irregular grains. May be in branching crystal group or in rude isometric crystals.	COPPER p. 137 Cu Isometric
Silver-white, shiny	Silver-white on fresh surface. Gray to black tarnish	10.5	2½–3	Malleable. Usually in irregular grains. May be in wire, plates, branching crystal groups.	SILVER p. 136 Ag Isometric
Gray, shiny	White or steel-gray	14 to 19	4–4½	Malleable. Irregular grains or nuggets. Unusually hard for a metal. Rare.	Platinum p. 139 Pt Isometric
Silver-white, shiny	Silver-white with reddish tone	9.8	2–2½	Cleavage perfect basal $\{0001\}$ and rhombohedral $\{10\bar{1}1\}$. Sectile. Easily fusible in candle flame. When hammered, at first malleable but soon breaks up into small pieces.	Bismuth p. 142 Bi Rhombohedral
Gold-yellow, shiny	Gold-yellow	15.0 to 19.3	2½–3	Malleable. Irregular grains, nuggets, leaves. Very heavy; specific gravity varies with silver content.	GOLD p. 133 Au Isometric

LUSTER: METALLIC OR SUBMETALLIC

III. Hardness: > 5½. (Cannot be scratched by a knife.)

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Black	Silver- or tin-white	6.0 to 6.2	5½–6	Usually massive. Crystals pseudorthorhombic.	**ARSENOPYRITE** p. 173 FeAsS Monoclinic
		6.1 to 6.9	5½–6	Usually massive. Crystals pyritohedral. May be coated with pink nickel bloom.	Smaltite-Chloanthite p. 176 $CoAs_2$—$NiAs_2$ Isometric
		6.33	5½	Commonly in pyritohedral crystals with pinkish cast. Also massive.	Cobaltite-Gersdorffite p. 171 CoAsS—NiAsS Isometric
	Pale copper-red. May be silver-white with pink tone	7.5	5–5½	Usually massive. May be coated with green nickel bloom.	NICCOLITE p. 161 NiAs Hexagonal
	Pale brass-yellow	5.0	6–6½	Often in pyritohedrons or striated cubes. Massive granular. Most common sulfide.	**PYRITE** p. 169 FeS_2 Isometric
	Pale yellow to almost white	4.9	6–6½	Frequently in " cock's comb " crystal groups and radiating fibrous masses.	**MARCASITE** p. 171 FeS_2 Orthorhombic
	Black	5.18	6	Strongly magnetic. Crystals octahedral. May show octahedral parting.	**MAGNETITE** p. 195 Fe_3O_4 Isometric
Dark brown to black	Black	9.0 to 9.7	5½	Luster pitchy. Massive granular, botryoidal crystals.	Uraninite p. 268 Isometric
		4.7	5½–6	May be slightly magnetic. Often associated with magnetite. Massive granular; platy crystals; as sand.	**ILMENITE** p. 192 $FeTiO_3$ Rhombohedral

LUSTER: METALLIC OR SUBMETALLIC

III. Hardness: > $5\frac{1}{2}$.

(Cannot be scratched by a knife.) *(Continued)*

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Dark brown to black	Black	3.7 to 4.7	5–6	Compact massive, stalactitic, botryoidal. Associated with other manganese minerals and told by greater hardness.	PSILOMELANE p. 210 $H_4R_2Mn_8O_{20}$. R essentially Ba. Appears amorphous
		5.3 to 7.3	6	Luster black and shiny on fresh surface. May have slight bluish tarnish. Granular or in stout prismatic crystals.	Columbite-Tantalite p. 203 $(Fe,Mn)(Cb,Ta)_2O_6$ Orthorhombic
Dark brown	Iron-brown to brownish black	7.0 to 7.5	5–$5\frac{1}{2}$	Cleavage perfect pinacoidal {010}. With greater amounts of manganese the streak and color are darker.	WOLFRAMITE p. 266 $(Fe,Mn)WO_4$ Monoclinic
		4.6	$5\frac{1}{2}$	Luster pitchy. Frequently accompanied by yellow or green oxidation products. Usually in granular masses in peridotites.	**CHROMITE** p. 197 $FeCr_2O_4$ Isometric
		5.15	6	May be slightly magnetic. Granular or in octahedral crystals. Found commonly only at Franklin, N. Y., associated with zincite (red) and willemite (green).	FRANKLINITE p. 196 $(Fe,Zn,Mn)(Fe,Mn)_2O_4$ Isometric
Red-brown, Indian red	Dark brown to steel-gray to black	4.8 to 5.3	$5\frac{1}{2}$–$6\frac{1}{2}$	Radiating, reniform, massive, micaceous. Rarely in steel-black rhombohedral crystals. Some varieties softer.	**HEMATITE** p. 191 Fe_2O_3 Rhombohedral
Yellow-brown to yellow-ocher	Dark brown to black	3.6 to 4.0	5–$5\frac{1}{2}$	Vitreous luster. Usually contains about 15% water while goethite contains 10%.	LIMONITE p. 208 $FeO(OH)\cdot nH_2O + Fe_2O_3\cdot nH_2O$ Amorphous
		4.37	5–$5\frac{1}{2}$	Cleavage pinacoidal {010}. In radiating fibers, mammillary and stalactitic forms. Rarely in crystals. Definitely distinguished from limonite by presence of cleavage or crystal form.	**GOETHITE** p. 205 $Fe_2O_3\cdot H_2O$ Orthorhombic

LUSTER: NONMETALLIC

I. Streak definitely colored.

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Dark red	Dark red to vermilion	8.10	2½	Cleavage prismatic {10$\bar{1}$0}. Usually granular or earthy. Commonly impure and of a dark red or brown color. When pure, translucent or transparent and bright red.	**CINNABAR** p. 163 HgS Rhombohedral
	Red-brown. Ruby-red when transparent	6.0	3½–4	Massive or in cubes or octahedrons. May be in very slender crystals. (chalcotrichite). Associated with other oxidized copper minerals such as malachite, azurite, native copper.	CUPRITE p. 187 Cu_2O Isometric
Red-brown, Indian brown	Dark brown to steel-gray to black	4.8 to 5.3	5½–6½	Radiating, reniform, massive, micaceous. Rarely in steel-black rhombohedral crystals. Some varieties softer.	**HEMATITE** p. 191 Fe_2O_3 Rhombohedral
	Deep red to black	5.8	2½	Cleavage rhombohedral {10$\bar{1}$1}. Easily fusible in candle flame. Dark "ruby silver" and shows dark ruby-red color in thin splinters. Associated with other silver minerals.	Pyrargyrite p. 180 Ag_3SbS_3 Rhombohedral
Bright red	Ruby-red	5.55	2–2½	Cleavage rhombohedral {10$\bar{1}$1}. Easily fusible in candle flame. Light "ruby silver." Associated with pyrargyrite.	Proustite p. 180 Ag_3AsS_3 Rhombohedral
Pink	Red to pink	2.95	1½–2½	Cleavage perfect pinacoidal {010}. Usually in reniform shapes or as pulverulent or earthy crusts. Found as coatings on cobalt minerals.	Erythrite p. 253 (cobalt bloom) $Co_3As_2O_8 \cdot 8H_2O$ Monoclinic
Yellow brown to yellow ocher	Dark brown to black	3.6 to 4.0	5–5½	Usually hard, with vitreous luster. Usually contains about 15% water while goethite contains 10%.	LIMONITE p. 208 $FeO(OH) \cdot nH_2O +$ $Fe_2O_3 \cdot nH_2O$ Amorphous

LUSTER: NONMETALLIC

I. Streak definitely colored. *(Continued)*

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Yellow-brown to yellow-ocher	Dark brown to black	4.4	5–5½	Cleavage pinacoidal {010}. In radiating fibers, mammillary and stalactitic forms. Rarely in crystals. Definitely distinguished from limonite only by presence of cleavage or crystal form. Usually metallic.	**GOETHITE** p. 205 $FeO(OH)$ Orthorhombic
Brown	Dark brown	7.0 to 7.5	5–5½	Cleavage perfect pinacoidal {010}. With greater amounts of manganese the streak and color are darker.	WOLFRAMITE p. 266 $(Fe,Mn)WO_4$ Monoclinic
Light brown	Light to dark brown	3.9 to 4.1	3½–4	Cleavage perfect dodecahedral {110} (6 directions). Usually cleavable granular; may be in tetrahedral crystals. The darker the specimen the higher the percentage of iron. The streak is always of a lighter color than the specimen.	**SPHALERITE** p. 155 ZnS Isometric
	Brown to black	6.8 to 7.1	6–7	Occurs in twinned crystals. Fibrous, reniform and irregular masses; in rolled grains.	**CASSITERITE** p. 199 SnO_2 Tetragonal
	Reddish brown to black	4.18 to 4.25	6–6½	Crystals vertically striated; often acicular. Twinning common.	**RUTILE** p. 200 TiO_2 Tetragonal
Orange-yellow	Deep red to orange-yellow	5.68	4–4½	Cleavage basal {0001}. Found only at Franklin, N. J., associated with franklinite and willemite	ZINCITE p. 188 ZnO Hexagonal
	Bright red	5.9 to 6.1	2½–3	Luster adamantine. In long slender crystals, often interlacing groups. Decrepitates in candle flame.	Crocoite p. 259 $PbCrO_4$ Monoclinic
	Deep red	3.48	1½–2	Frequently earthy. Associated with orpiment. Fusible in candle flame.	REALGAR p. 164 AsS Monoclinic

Streak	Color	G.	H.	Remarks	Name, Composition, Crystal System
Pale yellow	Lemon-yellow	3.49	1½–2	Cleavage pinacoidal {010}. Luster resinous. Associated with realgar. Fusible in candle flame.	ORPIMENT p. 165 As_2S_3 Monoclinic
	Pale yellow	2.05 to 2.09	1½–2½	Burns with blue flame, giving odor of SO_2. A mass held in the hand close to the ear will be heard to crackle. Crystallized, granular, earthy.	**SULFUR** p. 143 S Orthorhombic
Light green	Dark emerald green	3.75 to 3.77	3–3½	One perfect cleavage {010}. In granular cleavable masses or small prismatic crystals.	Atacamite p. 219 $Cu_2Cl(OH)_3$ Orthorhombic
		3.9±	3½–4	One good cleavage {010}. In small prismatic crystals or granular masses.	Antlerite p. 260 $Cu_3(SO_4)(OH)_4$ Orthorhombic
	Bright green	3.9 to 4.03	3½–4	Radiating fibrous, mammillary. Associated with azurite and may alter to it. Effervesces in cold acid.	**MALACHITE** p. 236 $Cu_2CO_3(OH)_2$ Monoclinic
Light blue	Intense azure-blue	3.77	3½–4	In small crystals, often in groups. Radiating fibrous, usually as alteration from malachite. Effervesces in cold acid.	**AZURITE** p. 237 $Cu_3(CO_3)_2(OH)_2$ Monoclinic
		2.12 to 2.30	2½	Soluble in water. Metallic taste. In crystals, massive, stalactitic.	Chalcanthite p. 264 $CuSO_4 \cdot 5H_2O$ Triclinic
Very light blue	Light green to turquois blue	2.0 to 2.4	2–4	Massive compact. Associated with oxidized copper minerals.	CHRYSOCOLLA p. 327 $CuSiO_3 \cdot 2H_2O$ Uncertain
Grayish blue	Very dark blue. Bluish green	2.58 to 2.68	1½–2	One perfect cleavage {010}. Usually in prismatic crystals.	Vivianite p. 252 $Fe_3(PO_4)_2 \cdot 8H_2O$ Monoclinic

LUSTER: NONMETALLIC

II. Streak colorless

A. Hardness: < 2½. (Can be scratched by fingernail.)

Cleavage, Fracture	Color	G.	H.	Remarks	Name, Composition, Crystal System
Perfect cleavage in one direction The micas or related micaceous minerals, which possess such a perfect cleavage that they can be split into exceedingly thin sheets. They may occur as aggregates of minute scales, when the micaceous structure may not be readily apparent.	Pale brown, green, yellow, white	2.76 to 3.0	2–2½	In foliated masses and scales. Crystals tabular with hexagonal or diamond-shaped outline. Cleavage flakes elastic. Common mica.	**MUSCOVITE** p. 311 $KAl_3Si_3O_{10}(OH)_2$ Monoclinic
	Usually dark brown, green to black; may be yellow	2.95 to 3	2½–3	Usually in irregular foliated masses. Crystals have hexagonal outline, but rare. Cleavage flakes elastic.	**BIOTITE** p. 313 $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$ Monoclinic
	Yellowish brown, green, white	2.86	2½–3	Often in 6-sided tabular crystals; in irregular foliated masses. May show copperlike reflection from cleavage. Occurs in marble.	PHLOGOPITE p. 314 $KMg_2Al_2Si_3O_{10}(OH)_2$ Monoclinic
	Green of various shades	2.6 to 2.9	2–2½	Usually in irregular foliated masses. May be in compact masses of minute scales. Thin sheets flexible but not elastic.	**CHLORITE** p. 309 $(Mg,Fe)_5(Al,Fe''')_2Si_3O_{10}(OH)_8$ Monoclinic
	White, apple-green, gray. When impure, as in soapstone, dark gray, dark green to almost black	2.7 to 2.8	1	Greasy feel. Frequently distinctly foliated or micaceous. Cannot be positively identified by physical tests.	**TALC** p. 303 $Mg_3Si_4O_{10}(OH)_2$ Monoclinic
		2.8 to 2.9	1–2		Pyrophyllite p. 302 $Al_2Si_4O_{10}(OH)_2$ Monoclinic
	White, gray, green	2.39	2½	Pearly luster on cleavage face, elsewhere vitreous. Sectile. Commonly foliated massive, may be in broad tabular crystals. Thin sheets flexible but not elastic.	BRUCITE p. 210 $Mg(OH)_2$ Rhombohedral

Cleavage, Fracture	Color	G.	H.	Remarks	Name, Composition, Crystal System
Pinacoidal {010}	Blue, bluish green to colorless	2.58 to 2.68	1½–2	Streak grayish blue. Usually in prismatic crystals.	Vivianite p. 252 $Fe_3(PO_4)_2\cdot 8H_2O$ Monoclinic
	Colorless to white	1.75	2–2½	Occurs in crusts and capillary fibers. Soluble in water.	Epsomite p. 263 $MgSO_4\cdot 7H_2O$ Orthorhombic
Cubic {100}	Colorless or white	1.99	2	Soluble in water, bitter taste. Resembles halite but usually softer. In granular cleavable masses or cubic crystals.	Sylvite p. 214 KCl Isometric
{010} perfect, {100} $\{\bar{1}11\}$ good	Colorless, white, gray. May be colored by impurities	2.32	2	Occurs in crystals, broad cleavage flakes. May be compact massive without cleavage, or fibrous with silky luster.	**GYPSUM** p. 262 $CaSO_4\cdot 2H_2O$ Monoclinic
Rhomb. $\{10\bar{1}1\}$ poor	Colorless or white	2.29	1–2	Occurs in saline crusts. Readily soluble in water; cooling and salty taste. Fusible in candle flame.	SODA NITER p. 237 $NaNO_3$ Rhombohedral
Prismatic {110} seldom seen. F. Conchoidal		2.09 to 2.14	2	Usually in crusts, silky tufts and delicate acicular crystals. Readily soluble in water; cooling and salty taste. Fusible in the candle flame.	Niter p. 238 KNO_3 Orthorhombic
{001} perfect; seldom seen. F. earthy	White; may be darker	2.6 to 2.63	2–2½	Generally claylike and compact. When breathed upon gives argillaceous odor. Will adhere to the dry tongue.	**KAOLINITE** p. 302 $Al_2Si_2O_5(OH)_4$ Monoclinic
Fract. uneven	Pearl-gray or colorless. Turns to pale brown on exposure to light	5.5±	2–3	Perfectly sectile. Translucent in thin plates. In irregular masses, rarely in crystals. Distinguished from other silver halides only by chemical tests.	CERARGYRITE p. 215 AgCl Isometric

LUSTER: NONMETALLIC

II. Streak colorless

A. Hardness: $< 2\frac{1}{2}$. (Can be scratched by fingernail.) (*Continued*)

Cleavage, Fracture	Color	G.	H.	Remarks	Name, Composition, Crystal System
F. uneven	Pale yellow	2.05 to 2.09	$1\frac{1}{2}$–$2\frac{1}{2}$	Burns with blue flame, giving odor of SO_2. A mass held in the hand close to the ear will be heard to crackle. Crystallized, granular, earthy.	**SULFUR** p. 143 S Orthorhombic
	Yellow, brown, gray, white	2.0 to 2.55	1–3	In rounded grains, often earthy and claylike. Usually harder than $2\frac{1}{2}$.	**BAUXITE** p. 209 $Al_2O_3 \cdot nH_2O$ Amorphous
Seldom seen	White	1.65	1	Usually in rounded masses of fine fibers and acicular crystals.	ULEXITE p. 241 $NaCaB_5O_9 \cdot 8H_2O$ Triclinic
F. conchoidal	White, gray, yellowish	2.0	2–$2\frac{1}{2}$	Fine textured, compact. Smooth feel. When dry will float on water.	Sepiolite p. 304 $Mg_2Si_3O_8 \cdot 2H_2O$ Uncertain
F. uneven	Apple-green to white	2.2 to 2.8	2–3	In incrustations and earthy masses.	Garnierite p. 307 $(Ni,Mg)SiO_3 \cdot nH_2O$ Amorphous

LUSTER: NONMETALLIC

II. Streak colorless

B. Hardness: $> 2\frac{1}{2}$, < 3. (Cannot be scratched by fingernail; can be scratched by cent.)

1. Cleavage prominent

Cleavage, Fracture		Color	G.	H.	Remarks	Name, Composition, Crystal System
Perfect cleavage in one direction See also the minerals of the mica group, p. 428 which may be harder than the fingernail.	{001}	Lilac, grayish white	2.8 to 3.0	$2\frac{1}{2}$–4	Crystals 6-sided prismatic. Usually in small irregular sheets and scales. A pegmatite mineral associated with colored tourmalines.	LEPIDOLITE p. 314 $K_2Li_3Al_4Si_7O_{21}(OH,F)_3$ Monoclinic
	{001}	Pink, gray, white	3.0 to 3.1	$3\frac{1}{2}$–5	Usually in irregular foliated masses; folia brittle. Associated with emery.	MARGARITE p. 309 $CaAl_4Si_2O_{10}(OH)_2$ Monoclinic
	{010}	Blue, bluish green to colorless	2.58 to 2.68	$1\frac{1}{2}$–2	Prismatic crystals often in stellate groups. Also fibrous, earthy. Streak grayish blue. A rare mineral.	Vivianite p. 252 $Fe_3(PO_4)_2 \cdot 8H_2O$ Monoclinic
	{010}	Colorless or white	4.3	$3\frac{1}{2}$	Usually massive, with radiating habit. Effervesces in cold acid.	**WITHERITE** p. 233 $BaCO_3$ Orthorhombic
	{100}	Red	2.78	$2\frac{1}{2}$–3	Occurs in compact granular or fibrous masses. Occurs with other soluble salts.	Polyhalite p. 261 $K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$ Triclinic
	{001}	Pale yellow or gray	2.7 to 2.85	$2\frac{1}{2}$–3	Crystals tabular. Found associated with other salts in salt lake deposits.	Glauberite p. 254 $Na_2Ca(SO_4)_2$ Monoclinic
Cleavage in 2 directions	{001} {100}	Colorless or white to gray	1.95	3	Occurs in cleavable crystalline aggregates.	KERNITE p. 240 $Na_2B_4O_7 \cdot 4H_2O$ Monoclinic

LUSTER: NONMETALLIC

II. Streak colorless

B. Hardness: $> 2\frac{1}{2}$, < 3. (Cannot be scratched by fingernail; can be scratched by cent.)

1. Cleavage prominent. (*Continued*)

Cleavage, Fracture		Color	G.	H.	Remarks	Name, Composition, Crystal System
Cleavage in 3 directions at right angles	Cubic {100}	Colorless, white, red, blue	2.1 to 2.3	2½	Common salt. Soluble in water, taste salty, fusible in candle flame. In granular cleavable masses or in cubic crystals.	**HALITE** p. 212 NaCl Isometric
	Cubic {100}	Colorless or white	1.99	2	Resembles halite, but distinguished from it by more bitter taste and lesser hardness.	Sylvite p. 214 KCl Isometric
	{001} {010} {100}	Colorless, white, blue, gray, red	2.89 to 2.98	3–3½	Commonly in massive fine aggregates, not showing cleavage; then can be distinguished only by chemical tests.	**ANHYDRITE** p. 258 $CaSO_4$ Orthorhombic
Cleavage in 3 directions not at right angles. Rhombohedral {$10\bar{1}1$}		Colorless, white, and variously tinted	2.72	3	Effervesces in cold acid. Crystals show many forms. Occurs in large masses as limestone and marble. Clear varieties show strong double refraction.	**CALCITE** p. 221 $CaCO_3$ Rhombohedral
		Colorless, white, pink	2.85	3½–4	Usually harder than copper coin. Often in curved rhombohedral crystals with pearly luster. In coarse masses as dolomitic limestone and marble. Powdered mineral will effervesce in cold acid.	**DOLOMITE** p. 226 $CaMg(CO_3)_2$ Rhombohedral
Cleavage in 3 directions. Basal {001} at right angles to prismatic {110}		Colorless, white, blue, yellow, red	4.5	3–3½	Frequently in aggregates of platy or tabular crystals. Pearly luster on basal cleavage. Characterized by high specific gravity for nonmetallic mineral, and thus distinguished from celestite.	**BARITE** p. 255 $BaSO_4$ Orthorhombic

Cleavage, Fracture	Color	G.	H.	Remarks	Name, Composition, Crystal System
Cleavage in 3 directions. Basal {001} at right angles to prismatic {110}	Colorless, white, blue, red	3.95 to 3.97	3–3½	Very similar to barite but lower specific gravity. May be necessary to get crimson strontium flame to distinguish it.	**CELESTITE** p. 257 $SrSO_4$ Orthorhombic
	Colorless or white. Gray and brown when impure	6.2 to 6.4	3	Adamantine luster. Usually massive but may be in small tabular crystals. Alteration of galena. When massive may need test for SO_4 to distinguish from cerrusite ($PbCO_3$).	**ANGLESITE** p. 257 $PbSO_4$ Orthorhombic

2. Cleavage not prominent

a. A small splinter is fusible in the candle flame

Color	G.	H.	Remarks	Name, Composition, Crystal System
Colorless or white	1.7±	2–2½	Soluble in water. One good cleavage, seldom seen. In crusts and prismatic crystals. Found only in dry regions. In candle flame swells and then fuses. Sweetish alkaline taste.	**BORAX** p. 239 $Na_2B_4O_7 \cdot 10H_2O$ Monoclinic
	2.95 to 3.0	2½	Massive. Characterized by peculiar translucent appearance. Fine powder insoluble but becomes nearly invisible when placed in water. Ivigtut, Greenland, only important locality. Pseudocubic parting.	**CRYOLITE** p. 216 Na_3AlF_6 Monoclinic
	6.55	3–3½	Luster adamantine. In granular masses and platy crystals, usually associated with galena. Effervesces in cold nitric acid. Reduced in candle flame, producing small globules of lead.	**CERUSSITE** p. 234 $PbCO_3$ Orthorhombic
Colorless, white, red	1.6	1	Bitter taste. Commonly massive granular. In candle flame swells, then fuses. Soluble in water.	Carnallite p. 219 $KMgCl_3 \cdot 6H_2O$ Orthorhombic
Colorless, yellow, orange, brown	7.0 to 7.2	3½	Luster resinous. In small prismatic crystals. Prism faces may be curved, giving barrel shapes. In granular masses.	Mimetite p. 247 $Pb_5Cl(AsO_4)_3$ Hexagonal

LUSTER: NONMETALLIC

II. Streak colorless

B. Hardness: > $2\frac{1}{2}$, < 3. (Cannot be scratched by fingernail; can be scratched by cent.)

2. Cleavage not prominent

b. Infusible in candle flame.

Color	G.	H.	Remarks	Name, Composition, Crystal System
Colorless or white	4.3	$3\frac{1}{2}$	Often in radiating masses; granular; rarely in pseudohexagonal crystals. Effervesces in cold acid.	**WITHERITE** p. 233 $BaCO_3$ Orthorhombic
	2.6 to 2.63	$2-2\frac{1}{2}$	Usually compact, earthy. When breathed upon gives an argillaceous odor. The basis of most clays.	**KAOLINITE** p. 302 $Al_2Si_2O_5(OH)_4$ Monoclinic
White, gray, yellowish	2.0	$2-2\frac{1}{2}$	Fine textured compact. Smooth feel. When dry will float on water.	Sepiolite p. 304 $Mg_2Si_3O_8 \cdot 2H_2O$ Uncertain
Honey-, citron- or orange-yellow	4.9	$3-3\frac{1}{2}$	Usually found as a coating of fine powder on sphalerite. Rarely in crystals. A rare mineral.	Greenockite p. 159 CdS Hexagonal
Yellow, brown, gray, white	2.0 to 2.55	1–3	Usually pisolitic; in rounded grains and earthy masses. Often impure.	**BAUXITE** p. 209 A mixture of aluminum hydroxides
Ruby-red, brown, yellow	6.7 to 7.1	3	Luster resinous. In slender prismatic and cavernous crystals; in barrel-shaped forms.	Vanadinite p. 247 $Pb_5Cl(VO_4)_3$ Hexagonal
Yellow, green, white, brown	2.33	$3\frac{1}{2}-4$	Characteristically in radiating hemispherical globular aggregates. Cleavage seldom seen.	Wavellite p. 251 $Al_3(OH)_3(PO_4)_2 \cdot 5H_2O$ Orthorhombic
Olive- to blackish-green, yellow-green, white	2.2	2–5	Massive. Fibrous in the asbestos variety, chrysotile. Frequently mottled green in the massive variety.	**SERPENTINE** p. 305 $Mg_3Si_2O_5(OH)_4$ Monoclinic

C. Hardness: > 3, < 5½. (Cannot be scratched by cent; can be scratched by knife.)

1. Cleavage prominent

Cleavage		Color	G.	H.	Remarks	Name, Composition, Crystal System
One cleavage direction	{100}	Blue, usually darker at center of crystal. May be white gray or green	3.56 to 3.66	5–7	In bladed aggregates with cleavage parallel to length. Can be scratched by knife parallel to the length of the crystal but not in a direction at right angles to this.	**KYANITE** p. 350 Al_2SiO_5 Triclinic
	{010}	White, yellow, brown, red	2.1 to 2.2	3½–4	Characteristically in sheaflike crystal aggregates. May be in flat tabular crystals. Luster pearly on cleavage face.	**STILBITE** p. 297 $(Ca,Na,K)_3Al_5(Al,Si)Si_{14}O_{40}\cdot 15H_2O$ Monoclinic
	{001}	Colorless, white, pale green, yellow, rose	2.3 to 2.4	4½–5	In prismatic crystals vertically striated. Crystals often resemble cubes truncated by the octahedron. Luster pearly on base, elsewhere vitreous.	**APOPHYLLITE** p. 307 $Ca_4K(Si_4O_{10})F_2\cdot 8H_2O$ Tetragonal
	{010}	White, yellow, red	2.18 to 2.20	3½–4	Luster pearly on cleavage face, elsewhere vitreous. Crystals often tabular parallel to cleavage plane. A zeolite, found in cavities in igneous rocks.	HEULANDITE p. 297 $(Ca,Na,K)_6Al_{10}(Al,Si)Si_{29}O_{80}\cdot 25H_2O$ Monoclinic
	{010}	Colorless, white	2.42	4–4½	In crystals and in cleavable aggregates. Decrepitates violently in the candle flame.	COLEMANITE p. 241 $Ca_2B_6O_{11}\cdot 5H_2O$ Monoclinic
	{010}	Colorless, white	4.3	3½	Often in radiating crystal aggregates; granular. Rarely in pseudohexagonal crystals. Effervesces in cold acid.	**WITHERITE** p. 233 $BaCO_3$ Orthorhombic
	{010} {110} poor	Colorless, white	2.95	3½–4	Effervesces in cold acid. Falls to powder in the candle flame. Frequently in radiating groups of acicular crystals; in pseudohexagonal twins. Cleavage indistinct.	**ARAGONITE** p. 231 $CaCO_3$ Orthorhombic

LUSTER: NONMETALLIC

II. Streak colorless

C. Hardness: > 3, < $5\frac{1}{2}$. (Cannot be scratched by cent; can be scratched by knife.)

1. Cleavage prominent. (*Continued*)

Cleavage		Color	G.	H.	Remarks	Name, Composition, Crystal System
Two cleavage directions	{001} {010}	Light blue, green, gray, salmon to clove-brown	3.42 to 3.56	$4\frac{1}{2}$–5	Commonly cleavable massive. Found in pegmatites with other lithium minerals.	Triphylite-Lithiophilite p. 244 $Li(Fe,Mn)PO_4$ Orthorhombic
	{001} {100}	Colorless, white, gray	2.8 to 2.9	5–$5\frac{1}{2}$	Usually cleavable massive to fibrous. Also compact. Associated with crystalline limestone.	WOLLASTONITE p. 326 $CaSiO_3$ Triclinic
	{001} {100}	Colorless, white, gray	2.7 to 2.8	5	Commonly fibrous in radiating aggregates of sharp acicular crystals. Associated with zeolites in cavities in igneous rocks.	Pectolite p. 326 $Ca_2NaSi_3O_8(OH)$ Triclinic
	{110}	Colorless, white	2.25	5–$5\frac{1}{2}$	In slender prismatic crystals, prism faces vertically striated. Often in radiating groups. A zeolite, found lining cavities in igneous rocks.	**NATROLITE** p. 299 $Na_2Al_2Si_3O_{10}{\cdot}2H_2O$ Monoclinic
	{110}	Colorless, white	3.7	$3\frac{1}{2}$–4	Occurs in prismatic crystals and pseudohexagonal twins. Also fibrous and massive. Effervesces in cold acid.	**STRONTIANITE** p. 234 $SrCO_3$ Orthorhombic
	{110}	White, pale green, blue	3.4 to 3.5	$4\frac{1}{2}$–5	Often in radiating crystal groups. Also stalactitic, mammillary. Prismatic cleavage seldom seen.	**HEMIMORPHITE** p. 332 $Zn_4Si_2O_7(OH)_2{\cdot}H_2O$ Orthorhombic
	Prismatic at angles of 55° and 125°	White, green, black	3.0 to 3.3	5–6	Crystals usually slender, fibrous, asbestiform. Tremolite (white, gray, violet), actinolite (green) are common in metamorphic rocks. Hornblende and arfvedsonite (dark green to black) are common in igneous rocks. The group is characterized by its broad cleavage angle.	**AMPHIBOLE GROUP** p. 315 Essentially calcium magnesium silicates Monoclinic

Cleavage		Color	G.	H.	Remarks	Name, Composition, Crystal System
Two cleavage directions	Prismatic at angles of 55° and 125°.	Gray, clove-brown, green	2.85 to 3.2	5½–6	An amphibole. Distinct crystals rare. Commonly in aggregates and fibrous massive.	Anthophyllite p. 316 $(Mg,Fe)_7Si_8O_{22}(OH)_2$ Orthorhombic
	Prismatic at nearly 90° angles	White, green, black	3.1 to 3.5	5–6	In stout prisms with rectangular cross-section. Often in granular crystalline masses. Diopside (colorless, white, green), aegirite (brown, green), augite (dark green to black) are rock-forming minerals. Characterized by rectangular cross-section and cleavage.	**PYROXENE GROUP** p. 319 Essentially calcium magnesium silicates Monoclinic
		Rose-red, pink, brown	3.58 to 3.70	5½–6	Color diagnostic. Usually massive, cleavable to compact, in imbedded grains; in large rough crystals with rounded edges.	**RHODONITE** p. 325 $MnSiO_3$ Triclinic
Three cleavage directions	Three directions not at right angles. Rhombohedral $\{10\bar{1}1\}$	Colorless, white, and variously tinted	2.72	3	Effervesces in cold acid. Crystals show many forms. Occurs in large masses as limestone and marble. Clear varieties show strong double refraction.	**CALCITE** p. 221 $CaCO_3$ Rhombohedral
		Colorless, white, pink	2.85	3½–4	Often in curved rhombohedral crystals with pearly luster. In coarse masses as dolomitic limestone and marble. Powdered mineral will effervesce in cold acid.	**DOLOMITE** p. 226 $CaMg(CO_3)_2$ Rhombohedral
		White, yellow, gray, brown	3.0 to 3.2	3½–5	Commonly in dense compact masses; also in fine to coarse cleavable masses. Effervesces in hot hydrochloric acid.	**MAGNESITE** p. 227 $MgCO_3$ Rhombohedral
		Light to dark brown	3.83 to 3.88	3½–4	In cleavable masses or in small curved rhombohedral crystals. Becomes magnetic after heating in the candle flame.	**SIDERITE** p. 228 $FeCO_3$ Rhombohedral
		Pink, rose-red, brown	3.45 to 3.6	3½–4½	In cleavable masses or in small rhombohedral crystals. Characterized by its color.	RHODOCROSITE p. 229 $MnCO_3$ Rhombohedral

LUSTER: NONMETALLIC

II. Streak colorless

C. Hardness: $> 3, < 5\frac{1}{2}$. (Cannot be scratched by cent; can be scratched by knife.)

1. Cleavage prominent. *(Continued)*

Cleavage		Color	G.	H.	Remarks	Name, Composition, Crystal System
Three cleavage directions	Three directions not at right angles. Rhombohedral {10$\bar{1}$1}	Brown, green, blue, pink, white	4.35 to 4.40	5	Usually in rounded botryoidal aggregates and in honeycombed masses. Effervesces in cold hydrochloric acid. Cleavage rarely seen.	**SMITHSONITE** p. 230 $ZnCO_3$ Rhombohedral
		White, yellow, flesh-red	2.05 to 2.15	4–5	Characteristically in small rhombohedral crystals with nearly cubic angles. A zeolite, found lining cavities in igneous rocks.	CHABAZITE p. 298 $(Ca,Na,K)_7Al_{12}(Al,Si)_2Si_{26}O_{80}\cdot 40H_2O$ Rhombohedral
	{001} {010} {100}	Colorless, white, blue, gray, red	2.89 to 2.98	3–3½	Commonly in massive fine aggregates, not showing cleavage, and can be distinguished only by chemical tests.	**ANHYDRITE** p. 258 $CaSO_4$ Orthorhombic
	{001} at rt. angles to {110}	Colorless, white, blue, yellow, red	4.5	3–3½	Frequently in aggregates of platy or tabular crystals. Pearly luster on basal cleavage. Characterized by high specific gravity for nonmetallic mineral, and thus distinguished from celestite.	**BARITE** p. 255 $BaSO_4$ Orthorhombic
		Colorless, white, blue, red	3.95 to 3.97	3–3½	Very similar to barite but lower specific gravity. May be necessary to get crimson strontium flame to distinguish it.	**CELESTITE** p. 257 $SrSO_4$ Orthorhombic
Four cleavage directions	{111} Oct.	Colorless, violet, green, yellow, pink. Usually has a fine color	3.18	4	In cubic crystals often in penetration twins. Characterized by cleavage.	**FLUORITE** p. 216 CaF_2 Isometric

Cleavage		Color	G.	H.	Remarks	Name, Composition, Crystal System
Four cleavage directions	{100} {110}	White, pink, gray, green, brown	2.65 to 2.74	5–6	In prismatic crystals, granular or massive. Commonly altered. Prismatic cleavage obscure.	SCAPOLITE p. 295 Essentially sodium-calcium aluminum silicate Tetragonal
Six cleavage directions	Dodecahedral {110}	Yellow, brown, white	3.9 to 4.1	3½–4	Luster resinous. Small tetrahedral crystals rare. Usually in cleavable masses. If massive, difficult to determine.	**SPHALERITE** p. 155 ZnS Isometric
		Blue, white, gray, green	2.15 to 2.3	5½–6	Massive or in imbedded grains; rarely in crystals. A feldspathoid associated with nepheline, never with quartz.	SODALITE p. 294 $Na_4Al_3Si_3O_{12}Cl$ Isometric

2. Cleavage not prominent

Color	G.	H.	Remarks	Name, Composition, Crystal System
Colorless, pale green, yellow	2.8 to 3.0	5–5½	Usually in crystals with many brilliant faces. Occurs with zeolites lining cavities in igneous rocks.	DATOLITE p. 346 $CaBSiO_4(OH)$ Monoclinic
White, pale green, blue	3.4 to 3.5	4½–5	Often in radiating crystal groups. Also stalactitic, mammillary. Prismatic cleavage seldom seen.	**HEMIMORPHITE** p. 332 $Zn_4Si_2O_7(OH)_2 \cdot H_2O$ Orthorhombic
White, pink, gray, green, brown	2.65 to 2.74	5–6	In prismatic crystals, granular or massive. Commonly altered. Prismatic cleavage obscure.	SCAPOLITE p. 295 Essentially sodium-calcium aluminum silicate Tetragonal
Colorless, white	2.95	3½–4	Effervesces in cold acid. Falls to powder in the candle flame. Frequently in radiating groups of acicular crystals; in pseudohexagonal twins. Cleavage indistinct.	**ARAGONITE** p. 231 $CaCO_3$ Orthorhombic
	2.27	5–5½	Usually in trapezohedrons with vitreous luster. A zeolite, found lining cavities in igneous rocks.	ANALCIME p. 300 $NaAlSi_2O_6 \cdot H_2O$ Isometric

LUSTER: NONMETALLIC

II. Streak colorless

C. Hardness: > 3, < 5½. (Cannot be scratched by cent; can be scratched by knife.)

2. Cleavage not prominent. (*Continued*)

Color	G.	H.	Remarks	Name, Composition, Crystal System
Colorless, white	3.7	3½–4	Occurs in prismatic crystals and pseudohexagonal twins. Also fibrous and massive. Effervesces in cold acid.	**STRONTIANITE** p. 234 $SrCO_3$ Orthorhombic
	3.0 to 3.2	3½–5	Commonly in dense compact masses showing no cleavage. Effervesces in hot hydrochloric acid.	**MAGNESITE** p. 227 $MgCO_3$ Rhombohedral
	4.3	3½	Often in radiating masses; granular; rarely in pseudohexagonal crystals. Effervesces in cold hydrochloric acid.	**WITHERITE** p. 233 $BaCO_3$ Orthorhombic
	2.7 to 2.8	5	Commonly fibrous in radiating aggregates of sharp acicular crystals. Associated with zeolites in cavities in igneous rocks.	Pectolite p. 326 $Ca_2NaSi_3O_8(OH)$ Triclinic
	2.25	5–5½	In slender prismatic crystals, prism faces vertically striated. Often in radiating groups. A zeolite, found lining cavities in igneous rocks. Poor prismatic cleavage.	NATROLITE p. 299 $Na_2Al_2Si_3O_{10}\cdot 2H_2O$ Monoclinic
White, grayish red	2.6 to 2.8	4	May be in rhombohedral crystals. Usually massive granular. Definitely determined only by blowpipe tests. Cleavage pinacoidal, usually obscure.	ALUNITE p. 265 $KAl_3(OH)_6(SO_4)_2$ Rhombohedral
Colorless, white, yellow, red, brown, green, gray, blue	1.9 to 2.2	5–6	Conchoidal fracture. Precious opal shows internal play of colors. Gravity and hardness less than fine-grained quartz.	**OPAL** p. 281 $SiO_2\cdot nH_2O$ Amorphous
Brown, green, blue, pink, white	4.35 to 4.40	5	Usually in rounded botryoidal aggregates and in honeycombed masses. Effervesces in cold hydrochloric acid. Cleavage rarely seen.	**SMITHSONITE** p. 230 $ZnCO_3$ Rhombohedral

Color	G.	H.	Remarks	Name, Composition, Crystal System
Brown, gray, green, yellow	3.4 to 3.55	5–5½	Adamantine to resinous luster. In thin wedge-shaped crystals with sharp edges. Prismatic cleavage seldom seen.	**SPHENE** p. 352 (Titanite) $CaTiSiO_5$ Monoclinic
Colorless, white, yellow, red, brown	2.72	3	May be fibrous or fine granular, banded. Effervesces in cold hydrochloric acid. Mexican onyx variety of calcite.	**CALCITE** p. 221 $CaCO_3$ Rhombohedral
Yellowish to reddish brown	5.0 to 5.3	5–5½	In small crystals or as rolled grains. Found in pegmatites.	Monazite p. 243 $(Ce,La,Di)PO_4$ Monoclinic
Light to dark brown	3.83 to 3.88	3½–4	Usually cleavable but may be in compact concretions in clay or shale — clay ironstone variety. Becomes magnetic on heating.	**SIDERITE** p. 228 $FeCO_3$ Rhombohedral
Pale green to brown	3.1 to 3.3	3½–4	Subadamantine luster. Usually in pyramidal crystals, also earthy.	Scorodite p. 250 $FeAsO_4 \cdot 2H_2O$ Orthorhombic
White, yellow, green, brown	5.9 to 6.1	4½–5	Luster vitreous to adamantine. Massive and in octahedral-like crystals. Frequently associated with quartz. Will fluoresce.	SCHEELITE p. 267 $CaWO_4$ Tetragonal
Yellow, orange, red, gray, green	6.8±	3	Luster adamantine. Usually in square tabular crystals. Also granular massive. Characterized by color and high specific gravity.	WULFENITE p. 268 $PbMoO_4$ Tetragonal
Colorless, yellow, orange, brown	7.0 to 7.2	3½	Resinous luster. In small hexagonal prisms. Faces often curved, giving barrel shapes. In granular masses. Fuses slowly in candle flame.	Mimetite p. 247 $Pb_5Cl(AsO_4)_3$ Hexagonal
White, yellow, brown, gray	2.6 to 2.9	3–5	The chief constituent of rock phosphate. Difficult to identify without chemical tests. Occurs massive.	COLLOPHANITE p. 248 $Ca_3(PO_4)_2 \cdot H_2O$ Amorphous
Yellow, brown, gray, white	2.0 to 2.55	1–3	Usually pisolitic; in rounded grains and earthy masses. Often impure.	**BAUXITE** p. 209 A mixture of aluminum hydroxides

LUSTER: NONMETALLIC

II. Streak colorless

C. Hardness: > 3, < 5½. (Cannot be scratched by cent; can be scratched by knife.)

2. Cleavage not prominent. (*Continued*)

Color	G.	H.	Remarks	Name, Composition, Crystal System
Green, blue, violet, brown, colorless	3.15 to 3.20	5	Usually in hexagonal prisms with pyramid. Also massive. Poor basal cleavage.	**APATITE** p. 245 $Ca_5(F,Cl)(PO_4)_3$ Hexagonal
Green, brown, yellow, gray	6.5 to 7.1	3½–4	In small hexagonal crystals, often curved and barrel-shaped. Crystals may be cavernous. Often globular and botryoidal.	Pyromorphite p. 248 $Pb_5Cl(PO_4)_3$ Hexagonal
Yellow, green, white, brown	2.33	3½–4	Characteristically in radiating hemispherical globular aggregates. Cleavage seldom seen.	Wavellite p. 251 $Al_3(OH)_3(PO_4)_2 \cdot 5H_2O$ Orthorhombic
Olive- to blackish green, yellow-green, white	2.2	2–5	Massive. Fibrous in the asbestos variety, chrysotile. Frequently mottled green in the massive variety.	**SERPENTINE** p. 305 $Mg_3Si_2O_5(OH)_4$ Monoclinic
Yellow-green, white, blue, gray, brown	3.9 to 4.2	5½	Massive and in disseminated grains. Rarely in hexagonal prisms. Associated with red zincite and black franklinite at Franklin, N. J.	WILLEMITE p. 335 Zn_2SiO_4 Rhombohedral
White, gray, blue, green	2.15 to 2.3	5½–6	Massive or in imbedded grains; rarely in crystals. A feldspathoid associated with nepheline, never with quartz. Dodecahedral cleavage poor.	SODALITE p. 294 $Na_4Al_3Si_3O_{12}Cl$ Isometric
Deep azure-blue, greenish blue	2.4 to 2.45	5–5½	Usually massive. Associated with feldspathoids and pyrite. Poor dodecahedral cleavage.	Lazurite p. 295 $Na_{4-5}Al_3Si_3O_{12}S$ Isometric

D. Hardness: $> 5\frac{1}{2}$, < 7. (Cannot be scratched by knife; can be scratched by quartz.)

1. Cleavage prominent

Cleavage		Color	G.	H.	Remarks	Name, Composition, Crystal System
One cleavage direction	{010}	White, gray, pale lavender, yellowish, greenish	3.35 to 3.45	$6\frac{1}{2}$–7	In thin tabular crystals. Luster pearly on cleavage face. Associated with emery, margarite, chlorite.	Diaspore p. 205 $AlO(OH)$ Orthorhombic
	{010} perfect	Hair-brown, grayish green	3.23	6–7	Commonly in long, slender, prismatic crystals. May be in parallel groups — columnar or fibrous. Found in schistose rocks.	SILLIMANITE p. 349 Al_2SiO_5 Orthorhombic
	{001}	Yellowish to blackish green	3.35 to 3.45	6–7	In prismatic crystals striated parallel to length. Found in metamorphic rocks and crystalline limestones.	**EPIDOTE** p. 342 $Ca_2(Al,Fe)_3(SiO_4)_3(OH)$ Monoclinic
	{100}	Blue, usually darker at center of crystal. May be gray or green	3.56 to 3.66	5–7	In bladed aggregates with cleavage parallel to length. Can be scratched by knife parallel to length of crystal but not in a direction at right angles to this.	**KYANITE** p. 350 Al_2SiO_5 Triclinic
Two cleavage directions	{001} good {100} poor	White, pale green, or blue	3.0 to 3.1	6	Usually cleavable, resembling feldspar. Found in pegmatites associated with other lithium minerals.	AMBLYGONITE p. 249 $LiAlFPO_4$ Triclinic
	{001} good {100}	Colorless, white, gray	2.8 to 2.9	5–$5\frac{1}{2}$	Usually cleavable massive to fibrous. Also compact. Associated with crystalline limestone.	WOLLASTONITE p. 326 $CaSiO_3$ Triclinic
	{001} {100}	Grayish white, green, pink	3.25 to 3.37	6–$6\frac{1}{2}$	In prismatic crystals deeply striated. Also massive, columnar, compact. Luster pearly on cleavage, elsewhere vitreous.	Clinozoisite p. 343 $Ca_2Al_3(SiO_4)_3(OH)$ Monoclinic
	{110}	Colorless, white	2.25	5–$5\frac{1}{2}$	In slender prismatic crystals, prism faces vertically striated. Often in radiating groups. A zeolite, found lining cavities in igneous rocks.	**NATROLITE** p. 299 $Na_2Al_2Si_3O_{10} \cdot 2H_2O$ Monoclinic

LUSTER: NONMETALLIC

II. Streak colorless

D. Hardness: > 5½, < 7. (Cannot be scratched by knife; can be scratched by quartz.)

1. Cleavage prominent. (*Continued*)

Cleavage		Color	G.	H.	Remarks	Name, Composition, Crystal System
Two cleavage directions at or nearly 90° angles	{001} {010}	Colorless, white, gray, cream, red, green	2.54 to 2.56	6	In cleavable masses or in irregular grains as rock constituents. May be in crystals in pegmatite. Distinguished with certainty only with the microscope. Green amazonstone is microcline.	**ORTHOCLASE** (Monoclinic) p. 282 **MICROCLINE** (Triclinic) p. 285 $KAlSi_3O_8$
	{001} {010}	Colorless, white, gray, bluish. Often shows a beautiful play of colors	2.62 (albite) to 2.76 (anorthite)	6	In cleavable masses or in irregular grains as a rock constituent. On the better cleavage can be seen a series of fine parallel striations due to albite twinning; these distinguish it from orthoclase.	**PLAGIOCLASE** p. 286 Various combinations of albite, $NaAlSi_3O_8$ and anorthite, $CaAl_2Si_2O_8$ Triclinic
	{110}	White, gray, pink, green	3.15 to 3.20	6½–7	In flattened prismatic crystals, vertically striated. Also massive cleavable. Pink variety, kunzite; green, hiddenite. Found in pegmatites. Frequently shows good {100} parting.	SPODUMENE p. 324 $LiAlSi_2O_6$ Monoclinic
	{110}	White, green, black	3.1 to 3.5	5–6	In stout prisms with rectangular cross section. Often in granular crystalline masses. Diopside (colorless, white, green), aegirite (brown, green), augite (dark green to black) are rock-forming minerals. Characterized by rectangular cross section and cleavage.	**PYROXENE GROUP** p. 319 Essentially calcium magnesium silicates Monoclinic
	{110}	Gray-brown, green, bronze-brown, black	3.2 to 3.5	5½	Crystals usually prismatic but rare. Commonly massive, fibrous, lamellar. Fe may replace Mg and mineral is darker.	ENSTATITE p. 319 $MgSiO_3$ Orthorhombic

Cleavage			Color	G.	H.	Remarks	Name, Composition, Crystal System
Two cleavage directions	at or nearly 90° angles	{110}	Rose-red, pink, brown	3.58 to 3.70	5½–6	Color diagnostic. Usually massive; cleavable to compact; in imbedded grains; in large rough crystals with rounded edges.	RHODONITE p. 325 $MnSiO_3$ Triclinic
	at 55° and 125° angles	{110}	White, green, black	3.0 to 3.3	5–6	Crystals usually slender fibrous asbestiform. Tremolite (white, gray, violet) and actinolite (green) are common in metamorphic rocks. Hornblende and arfvedsonite (dark green to black) are common in igneous rocks. The group is characterized by its broad cleavage angle.	**AMPHIBOLE GROUP** p. 315 Essentially calcium magnesium silicates Monoclinic
		{110}	Gray, clove-brown, green	2.85 to 3.2	5½–6	An amphibole. Distinct crystals rare. Commonly in aggregates and fibrous massive.	Anthophyllite p. 316 $(Mg,Fe)_7Si_8O_{22}(OH)$ Orthorhombic
Six cleavage directions, dodecahedral		{110}	Blue, gray, white, green	2.15 to 2.3	5½–6	Massive or in imbedded grains; rarely in crystals. A feldspathoid associated with nepheline, never with quartz.	SODALITE p. 294 $Na_4Al_3Si_3O_{12}Cl$ Isometric

2. Cleavage not prominent

Color	G.	H.	Remarks	Name, Composition, Crystal System
Colorless	2.26	7	Occurs as small crystals in cavities in volcanic rocks. Difficult to determine without optical aid.	Tridymite p. 280 SiO_2 Pseudohexagonal
Colorless or white	2.27	5–5½	Usually in trapezohedrons with vitreous luster. A zeolite, found lining cavities in igneous rocks.	ANALCIME p. 300 $NaAlSi_2O_6 \cdot H_2O$ Isometric
	2.32	7	Occurs in spherical aggregations in volcanic rocks. Difficult to determine without optical aid.	Cristobalite p. 280 SiO_2 Pseudoisometric

LUSTER: NONMETALLIC

II. Streak colorless

D. Hardness: $> 5\frac{1}{2}$, < 7. (Cannot be scratched by knife; can be scratched by quartz.)

2. Cleavage not prominent. *(Continued)*

Color	G.	H.	Remarks	Name, Composition, Crystal System
Colorless, yellow, red, brown, green, gray, blue	1.9 to 2.2	5–6	Conchoidal fracture. Precious opal shows internal play of colors. Gravity and hardness less than fine-grained quartz.	**OPAL** p. 281 $SiO_2 \cdot nH_2O$ Amorphous
Gray, white, colorless	2.45 to 2.50	$5\frac{1}{2}$–6	In trapezohedral crystals embedded in dark igneous rock. Does not line cavities as analcime does.	**LEUCITE** p. 291 $KAlSi_2O_6$ Pseudoisometric
Colorless, pale green, yellow	2.8 to 3.0	5–$5\frac{1}{2}$	Usually in crystals with many brilliant faces. Occurs with zeolites lining cavities in igneous rocks.	DATOLITE p. 346 $CaBSiO_4(OH)$ Monoclinic
Colorless, white, pale yellow	2.97 to 3.02	7	In prismatic crystals resembling topaz but distinguished by lack of cleavage. Also in irregular masses and indistinct crystals. A rare mineral.	Danburite p. 333 $CaB_2Si_2O_8$ Orthorhombic
White, gray, light to dark green, brown	2.65 to 2.74	5–6	In prismatic crystals, granular or massive. Commonly altered. Prismatic cleavage obscure.	SCAPOLITE p. 295 Essentially sodium-calcium aluminum silicate Tetragonal
Colorless, white, smoky, amethyst. Variously colored when impure	2.65	7	Crystals usually show horizontally striated prism with pyramid.	**QUARTZ** p. 273 SiO_2 Rhombohedral
Colorless, gray, greenish, reddish	2.55 to 2.65	$5\frac{1}{2}$–6	Greasy luster. A rock constituent, usually massive; rarely in hexagonal prisms. Poor prismatic cleavage. A feldspathoid.	NEPHELINE p. 293 $(Na,K)(Al,Si)_2O_4$ Hexagonal
White, gray, yellow, green	2.9 to 3.0	7	Commonly in small isolated cubic crystals, less often in groups.	Boracite p. 238 $Mg_7Cl_2B_{16}O_{30}$ Pseudoisometric

Color	G.	H.	Remarks	Name, Composition, Crystal System
Light yellow, brown, orange	3.1 to 3.2	6–6½	Occurs in disseminated crystals and grains. Commonly in crystalline limestones.	Chondrodite p. 336 $Mg_5(SiO_4)_2(F,OH)_2$ Monoclinic
Light brown, yellow, red, green	2.65	7	Luster waxy to dull. Commonly colloform. May be banded or lining cavities.	**CHALCEDONY** p. 277 SiO_2 Cryptocrystalline quartz
Blue, bluish green, green	2.6 to 2.8	6	Usually appears amorphous in reniform and stalactitic masses.	TURQUOIS p. 252 $Al_2(OH)_3PO_4{\cdot}H_2O + xCu$ Triclinic
Apple-green, gray, white	2.8 to 2.95	6–6½	Reniform and stalactitic with crystalline surface. In subparallel groups of tabular crystals.	**PREHNITE** p. 310 $Ca_2Al_2Si_3O_{10}(OH)_2$ Orthorhombic
Yellow-green, white, blue, gray, brown	3.9 to 4.2	5½	Massive and in disseminated grains. Rarely in hexagonal prisms. Associated with red zincite and black franklinite at Franklin, N. J.	WILLEMITE p. 335 Zn_2SiO_4 Rhombohedral
Blue, violet, pink	3.26 to 3.36	7	Occurs in aggregates of fibrous and felted masses. Imperfect cleavage parallel to length of fibers. Resembles tourmaline. Poor {100} cleavage.	Dumortierite p. 353 $Al_8BSi_3O_{19}(OH)$ Orthorhombic
Olive to grayish green, brown	3.27 to 3.37	6½–7	Usually in disseminated grains in basic igneous rocks. May be massive granular.	**OLIVINE** p. 334 $(Mg,Fe)_2SiO_4$ Orthorhombic
Black, green, brown, blue, red, pink, white	3.0 to 3.25	7–7½	In slender prismatic crystals with triangular cross section. Crystals may be in radiating groups. Found usually in pegmatites. Black most common, other colors associated with lithium minerals.	**TOURMALINE** p. 328 $WX_3B_3Al_3(AlSiO_9)_3(O,OH,F)_4$ W = Na,Ca X = Al,Fe,Li,Mg Rhombohedral
Green, brown, yellow, blue, red	3.35 to 4.45	6½	In square prismatic crystals vertically striated. Often columnar and granular massive. Found in crystalline limestones.	IDOCRASE p. 341 (Vesuvianite) $Ca_{10}Al_4(Mg,Fe)_2Si_9O_{34}(OH)_4$ Tetragonal

LUSTER: NONMETALLIC

II. Streak colorless

D. Hardness: > 5½, < 7. (Cannot be scratched by knife; can be scratched by quartz.)

2. Cleavage not prominent. (*Continued*)

Color	G.	H.	Remarks	Name, Composition, Crystal System
Clove-brown, gray, green, yellow	3.27 to 3.35	6½–7	In wedge-shaped crystals with sharp edges. Also lamellar.	AXINITE p. 348 $H(Ca,Mn,Fe)_3Al_2B(SiO_4)_4$ Triclinic
Red-brown to brownish black	3.65 to 3.75	7–7½	In prismatic crystals; commonly in cruciform penetration twins. Frequently altered on the surface and then soft. Found in schists.	STAUROLITE p. 351 $Fe''Al_5Si_2O_{12}(OH)$ Orthorhombic
Reddish brown, flesh-red, olive-green	3.16 to 3.20	7½	Prismatic crystals with nearly square cross section. Cross section may show black cross (chiastolite). May be altered to mica and then soft. Found in schists.	**ANDALUSITE** p. 348 Al_2SiO_5 Orthorhombic
Brown, gray, green, yellow	3.4 to 3.55	5–5½	Luster adamantine to resinous. In thin wedge-shaped crystals with sharp edges. Prismatic cleavage seldom seen.	**SPHENE** p. 352 (Titanite) $CaTiSiO_5$ Monoclinic
Yellowish to reddish brown	5.0 to 5.3	5–5½	In isolated crystals, granular. Commonly found in pegmatites.	Monazite p. 243 $(Ce,La,Di)PO_4$ Monoclinic
Brown to black	6.8 to 7.1	6–7	Rarely in prismatic crystals, twinned. Fibrous, giving reniform surface. Rolled grains. Usually gives light brown streak.	**CASSITERITE** p. 199 SnO_2 Tetragonal
Reddish brown to black	4.18 to 4.25	6–6½	In prismatic crystals vertically striated; often slender acicular. Crystals frequently twinned. A constituent of black sands.	**RUTILE** p. 200 TiO_2 Tetragonal
Brown to pitch-black	3.5 to 4.2	5½–6	Crystals often tabular. Massive and in imbedded grains. An accessory mineral in igneous rocks.	Allanite p. 344 $R_2''R_3'''(SiO_4)_3(OH)$ R'' = Ca,Ce,La,Na R''' = Al,Fe,Mn,Be,Mg Monoclinic

Color	G.	H.	Remarks	Name, Composition, Crystal System
Blue, rarely colorless	2.60 to 2.66	7–7½	In imbedded grains and massive, resembling quartz. Commonly altered and foliated; then softer than a knife.	Cordierite p. 301 $Mg_2Al_4Si_5O_{18}$ Orthorhombic (Pseudohexagonal)
Deep azure-blue, greenish blue	2.4 to 2.45	5–5½	Usually massive. Associated with feldspathoids and pyrite. Poor dodecahedral cleavage.	LAZURITE p. 295 $Na_{4-5}Al_3Si_3O_{12}\cdot S$ Isometric
Azure-blue	3.0 to 3.1	5–5½	Usually in pyramidal crystals, which distinguishes it from massive lazurite. A rare mineral.	LAZULITE p. 250 $MgAl_2(OH)_2(PO_4)_2$ Monoclinic
Blue, green, white, gray	2.15 to 2.3	5½–6	Massive or in imbedded grains; rarely in crystals. A feldspathoid associated with nepheline, never with quartz. Poor dodecahedral cleavage.	SODALITE p. 294 $Na_4Al_3Si_3O_{12}\cdot Cl$ Isometric

E. Hardness: > 7. (Cannot be scratched by quartz.)

1. Cleavage prominent

Cleavage		Color	G.	H.	Remarks	Name, Composition, Crystal System
One cleavage direction	{001}	Colorless, yellow, pink, bluish, greenish	3.4 to 3.6	8	Usually in crystals, also coarse to fine granular. Found in pegmatites.	**TOPAZ** p. 347 $(AlF)_2SiO_4(OH,F)$ Orthorhombic
	{010}	Brown, gray, greenish gray	3.23	6–7	Commonly in long slender prismatic crystals. May be in parallel groups, columnar or fibrous. Found in schistose rocks.	SILLIMANITE p. 349 Al_2SiO_5 Orthorhombic
Two cleavage directions	{110}	White, gray, pink, green	3.15 to 3.20	6½–7	In flattened prismatic crystals, vertically striated. Also massive cleavable. Pink variety, kunzite; green, hiddenite. Found in pegmatites. Frequently shows good {100} parting.	SPODUMENE p. 324 $(Li,Na)Al(SiO_3)_2$ Monoclinic

LUSTER: NONMETALLIC

II. Streak colorless

E. Hardness: > 7. (Cannot be scratched by quartz.)

1. Cleavage prominent. (*Continued*)

Cleavage		Color	G.	H.	Remarks	Name, Composition, Crystal System
Four cleavage directions	{111}	Colorless, yellow, red, blue, black	3.5	10	Adamantine luster. In octahedral crystals, frequently twinned. Faces may be curved.	Diamond p. 144 C Isometric
No cleavage. Rhombohedral and basal parting.		Colorless, gray, blue, red, yellow, brown, green	3.95 to 4.1	9	Luster adamantine to vitreous. Parting fragments may appear nearly cubic. In rude barrel-shaped crystals.	**CORUNDUM** p. 188 Al_2O_3 Rhombohedral

2. Cleavage not prominent

Color	G.	H.	Remarks	Name, Composition, Crystal System
Colorless, white, smoky, amethyst. Variously colored when impure	2.65	7	Crystals usually show horizontally striated prism with pyramid.	**QUARTZ** p. 273 SiO_2 Rhombohedral
Colorless, white, pale yellow	2.97 to 3.02	7	In prismatic crystals resembling topaz but distinguished by lack of cleavage. Also in irregular masses and indistinct crystals. A rare mineral.	Danburite p. 333 $CaB_2Si_2O_8$ Orthorhombic
White, colorless	2.97 to 3.0	7½–8	In small rhombohedral crystals. A rare mineral.	Phenacite p. 335 Be_2SiO_4 Rhombohedral
White and almost any color	3.95 to 4.1	9	Luster adamantine to vitreous. Parting fragments may appear nearly cubic. In rude barrel-shaped crystals.	**CORUNDUM** p. 188 Al_2O_3 Rhombohedral

Color	G.	H.	Remarks	Name, Composition, Crystal System
Red, black, lavender, blue, green, brown	3.6 to 4.0	8	In octahedrons; twinning common. Associated with crystalline limestones.	**SPINEL** p. 193 $MgAl_2O_4$ Isometric
Bluish green, green, yellow, pink, colorless	2.75 to 2.8	7½–8	Commonly in hexagonal prisms terminated by the base; pyramid faces are rare. Crystals large in places. Poor basal cleavage.	**BERYL** p. 331 $Be_3Al_2Si_6O_{18}$ Hexagonal
Yellowish to emerald-green	3.65 to 3.8	8½	In tabular crystals frequently in pseudohexagonal twins. Found in pegmatites.	CHRYSOBERYL p. 198 $BeAl_2O_4$ Orthorhombic
Green, brown, blue, red, pink, white, black	3.0 to 3.25	7–7½	In slender prismatic crystals with triangular cross section. Crystals may be in radiating groups. Found usually in pegmatites. Black most common, other colors associated with lithium minerals.	**TOURMALINE** p. 328 $WX_3B_3Al_3(AlSi_2O_9)_3(O,OH,F)_4$ Rhombohedral
Green, gray, white	3.3 to 3.5	6½–7	Massive, closely compact. Poor prismatic cleavage at nearly 90° angles. A pyroxene.	Jadeite p. 323 $NaAlSi_2O_6$ Monoclinic
Olive to grayish green, brown	3.27 to 3.37	6½–7	Usually in disseminated grains in basic igneous rocks. May be massive granular.	**OLIVINE** p. 334 $(Mg,Fe)_2SiO_4$ Orthorhombic
Green, brown, yellow, blue, red	3.35 to 3.45	6½	In square prismatic crystals vertically striated. Often columnar and granular massive. Found in crystalline limestones.	IDOCRASE p. 341 (Vesuvianite) $Ca_{10}Al_4(Mg,Fe)_2Si_9O_{34}(OH)_4$ Tetragonal
Dark green	4.55	7½–8	Usually in octahedrons characteristically striated. A zinc spinel.	Gahnite p. 195 $ZnAl_2O_4$ Isometric
Reddish brown to black	6.8 to 7.1	6–7	Rarely in prismatic crystals twinned. Fibrous, giving reniform surface. Rolled grains. Usually gives light brown streak.	**CASSITERITE** p. 199 SnO_2 Tetragonal

LUSTER: NONMETALLIC

II. Streak colorless

E. Hardness: > 7. (Cannot be scratched by quartz.)

2. Cleavage not prominent. (*Continued*)

Color	G.	H.	Remarks	Name, Composition, Crystal System
Reddish brown, flesh-red, olive-green	3.16 to 3.20	7½	Prismatic crystals with nearly square cross section. Cross section may show black cross (chiastolite). May be altered to mica and then soft. Found in schists.	ANDALUSITE p. 348 Al_2SiO_5 Orthorhombic
Clove-brown, green, yellow, gray	3.27 to 3.35	6½–7	In wedge-shaped crystals with sharp edges. Also lamellar.	AXINITE p. 348 $H(Ca,Mn,Fe)_3Al_2B(SiO_4)_4$ Triclinic
Red-brown to brownish black	3.65 to 3.75	7–7½	In prismatic crystals; commonly in cruciform penetration twins. Frequently altered on the surface and then soft. Found in schists.	STAUROLITE p. 351 $Fe''Al_5Si_2O_{12}(OH)$ Orthorhombic
Brown, red, gray, green, colorless	4.68	7½	Usually in small prisms truncated by the pyramid. An accessory mineral in igneous rocks. Found as rolled grains in sand.	**ZIRCON** p. 344 $ZrSiO_4$ Tetragonal
Usually brown to red. Also yellow, green, pink	3.5 to 4.3	6½–7½	Usually in dodecahedrons or trapezohedrons or in combinations of the two. An accessory mineral in igneous rocks and pegmatites. Commonly in metamorphic rocks. As sand.	**GARNET** p. 337 $R_3''R_2'''(SiO_4)_3$ $R'' = Ca,Mg,Fe,Mn$ $R''' = Al,Fe,Ti,Cr$ Isometric

MINERALS ARRANGED ACCORDING TO INCREASING SPECIFIC GRAVITY

G.	Name	p.	Composition	H.	Crystal System
0.917	Ice	186	H_2O	1½	Hex.
1.6	Carnallite	219	$KMgCl_3\cdot 6H_2O$	1	Orth.
1.65	**Ulexite**	241	$NaCaB_5O_9\cdot 8H_2O$	1	Tric.
1.7	**Borax**	239	$Na_2B_4O_7\cdot 10H_2O$	2–2½	Mon.
1.75	Epsomite	263	$MgSO_4\cdot 7H_2O$	2–2½	Orth.
1.95	**Kernite**	240	$Na_2B_4O_7\cdot 4H_2O$	3	Mon.
1.99	**Sylvite**	214	KCl	2	Iso.
2.0–2.19					
2.0–2.55	**Bauxite**	209		1–3	Mixture
2.0–2.4	**Chrysocolla**	327	$CuSiO_3\cdot 2H_2O$	2–4	?
2.0	Sepiolite	304	$Mg_2Si_3O_8\cdot 2H_2O$	2–2½	Mon?
2.05–2.09	**Sulfur**	143	S	1½–2½	Orth.
2.05–2.15	**Chabazite**	298	$(Ca,Na,K)_7Al_{12}(Al,Si)_2Si_{26}O_{80}\cdot 40H_2O$	4–5	Rhomb.
1.9–2.2	**Opal**	281	$SiO_2\cdot nH_2O$	5–6	Amorph.
2.09–2.14	Niter	238	KNO_3	2	Orth.
2.1–2.2	**Stilbite**	297	$(Ca,Na,K)_3Al_5(Al,Si)Si_{14}O_{40}\cdot 15H_2O$	3½–4	Mon.
2.16	**Halite**	212	$NaCl$	2½	Iso.
2.12–2.30	Chalcanthite	264	$CuSO_4\cdot 5H_2O$	2½	Tric.
2.18–2.20	**Heulandite**	297	$(Ca,Na,K)_6Al_{10}(Al,Si)Si_{29}O_{80}\cdot 25H_2O$	3½–4	Mon.
2.2–2.39					
2.12–2.30	Chalcanthite	264	$CuSO_4\cdot 5H_2O$	2½	Tric.
2.0–2.4	**Chrysocolla**	327	$CuSiO_3\cdot 2H_2O$	2–4	?
2.2	**Serpentine**	305	$Mg_3Si_2O_5(OH)_4$	2–5	Mon.
2.25	**Natrolite**	299	$Na_2Al_2Si_3O_{10}\cdot 2H_2O$	5–5½	Mon.
2.26	Tridymite	280	SiO_2	7	Pseudohex.
2.27	**Analcime**	300	$NaAlSi_2O_6\cdot H_2O$	5–5½	Iso.
2.29	Soda niter	237	$NaNO_3$	1–2	Rhomb.
2.30	Cristobalite	280	SiO_2	7	Pseudoiso.
2.30	**Sodalite**	294	$Na_4Al_3Si_3O_{12}Cl$	5½–6	Iso.
2.3	**Graphite**	148	C	1–2	Hex.
2.32	**Gypsum**	262	$CaSO_4\cdot 2H_2O$	2	Mon.
2.33	Wavellite	251	$Al_3(OH)_3(PO_4)_2\cdot 5H_2O$	3½–4	Orth.
2.3–2.4	**Apophyllite**	307	$Ca_4K(Si_4O_{10})_2F\cdot 8H_2O$	4½–5	Tetrag.
2.39	**Brucite**	210	$Mg(OH)_2$	2½	Rhomb.
2.4–2.59					
2.0–2.55	**Bauxite**	209		1–3	Amorph.
2.42	**Colemanite**	241	$Ca_2B_6O_{11}\cdot 5H_2O$	4–4½	Mon.
2.4–2.45	**Lazurite**	295	$Na_{4-5}Al_3Si_3O_{12}S$	5–5½	Iso.
2.45–2.50	**Leucite**	291	$KAlSi_2O_6$	5½–6	Pseudoiso.
2.2–2.8	**Garnierite**	307	$(Ni,Mg)SiO_3\cdot nH_2O$	2–3	Amorph.
2.54–2.57	**Microcline**	285	$KAlSi_3O_8$	6	Tric.
2.57	**Orthoclase**	282	$KAlSi_3O_8$	6	Mon.

MINERALS ARRANGED ACCORDING TO INCREASING SPECIFIC GRAVITY

G.	Name	p.	Composition	H.	Crystal System
2.6–2.79					
2.55–2.65	**Nepheline**	293	$(Na,K)(Al,Si)_2O_4$	5½–6	Hex.
2.6–2.63	**Kaolinite**	302	$Al_2Si_2O_5(OH)_4$	2–2½	Mon.
2.62	**Albite**	287	$NaAlSi_3O_8$	6	Tric.
2.60–2.66	Cordierite	301	$Mg_2Al_4Si_5O_{18}$	7–7½	Orth.
2.58–2.68	Vivianite	252	$Fe_3(PO_4)_2\cdot 8H_2O$	1½–2	Mon.
2.65	**Oligoclase**	290	$Ab_{90}An_{10}$ to $Ab_{70}An_{30}$	6	Tric.
2.65	**Quartz**	273	SiO_2	7	Rhomb.
2.69	**Andesine**	290	$Ab_{70}An_{30}$ to $Ab_{50}An_{50}$	6	Tric.
2.6–2.8	Alunite	265	$KAl_3(OH)_6(SO_4)_2$	4	Rhomb.
2.6–2.8	Turquois	252	$Al_2(OH)_3PO_4\cdot H_2O + x$Cu	6	Tric.
2.71	**Labradorite**	290	$Ab_{50}An_{50}$ to $Ab_{30}An_{70}$	6	Tric.
2.65–2.74	**Scapolite**	295	Various	5–6	Tetrag.
2.72	**Calcite**	221	$CaCO_3$	3	Rhomb.
2.6–2.9	**Chlorite**	309	$(Mg,Fe)_5(Al,Fe''')_2$-$Si_3O_{10}(OH)_8$	2–2½	Mon.
2.62–2.76	**Plagioclase**	286	$NaAlSi_3O_8+CaAl_2Si_2O_8$	6	Tric.
2.6–2.9	**Collophanite**	248	$Ca_3(PO_4)_2\cdot H_2O$	3–5	Amorph.
2.74	**Bytownite**	290	$Ab_{30}An_{70}$ to $Ab_{10}An_{90}$	6	Tric.
2.7–2.8	Pectolite	326	$Ca_2NaSi_3O_8(OH)$	5	Tric.
2.7–2.8	**Talc**	303	$Mg_3Si_4O_{10}(OH)_2$	1	Mon.
2.70–2.85	Glauberite	254	$Na_2Ca(SO_4)_2$	2½–3	Mon.
2.76	**Anorthite**	287	$CaAl_2Si_2O_8$	6	Tric.
2.75–2.8	**Beryl**	331	$Be_3Al_2Si_6O_{18}$	7½–8	Hex.
2.78	Polyhalite	261	$K_2Ca_2Mg(SO_4)_4\cdot 2H_2O$	2½–3	Tric.
2.8–2.99					
2.6–2.9	**Collophanite**	248	$Ca_3(PO_4)_2\cdot H_2O$	3–5	Amorph.
2.8–2.9	Pyrophyllite	302	$Al_2Si_4O_{10}(OH)_2$	1–2	Mon.
2.8–2.9	**Wollastonite**	326	$CaSiO_3$	5–5½	Tric.
2.85	**Dolomite**	226	$CaMg(CO_3)_2$	3½–4	Rhomb.
2.86	Phlogopite	314	$KMg_2Al_2Si_3O_{10}(OH)_2$	2½–3	Mon.
2.76–3.1	**Muscovite**	311	$KAl_3Si_3O_{10}(OH)_2$	2–2½	Mon.
2.8–2.95	**Prehnite**	310	$Ca_2Al_2Si_3O_{10}(OH)_2$	6–6½	Orth.
2.8–3.0	**Datolite**	346	$CaBSiO_4(OH)$	5–5½	Mon.
2.8–3.0	**Lepidolite**	314	$K_2Li_3Al_4Si_7O_{21}(OH,F)_3$	2½–4	Mon.
2.89–2.98	**Anhydrite**	258	$CaSO_4$	3–3½	Orth.
2.9–3.0	Boracite	238	$Mg_7Cl_2B_{16}O_{30}$	7	Pseudoiso.
2.95	**Aragonite**	231	$CaCO_3$	3½–4	Orth.
2.95	Erythrite	253	$Co_3(AsO_4)_2\cdot 8H_2O$	1½–2½	Mon.
2.8–3.2	**Biotite**	313	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	2½–3	Mon.
2.95–3.0	**Cryolite**	216	Na_3AlF_6	2½	Mon.
2.97–3.00	Phenacite	335	Be_2SiO_4	7½–8	Rhomb.
3.0–3.19					
2.97–3.02	Danburite	333	$CaB_2Si_2O_8$	7	Orth.

G.	Name	p.	Composition	H.	Crystal System
2.85–3.2	Anthophyllite	316	$(Mg,Fe)_7Si_8O_{22}(OH)_2$	5½–6	Orth.
3.0–3.1	**Amblygonite**	249	$LiAlFPO_4$	6	Tric.
3.0–3.1	**Lazulite**	250	$MgAl_2(OH)_2(PO_4)_2$	5–5½	Mon.
3.0–3.2	**Magnesite**	227	$MgCO_3$	3½–5	Rhomb.
3.0–3.1	Margarite	309	$CaAl_4Si_2O_{10}(OH)_2$	3½–5	Mon.
3.0–3.25	**Tourmaline**	328	$WX_3B_3Al_3(AlSi_2O_9)_3$-$(O,OH,F)_4$	7–7½	Rhomb.
3.0–3.3	**Tremolite**	316	$Ca_2Mg_5Si_8O_{22}(OH)_2$	5–6	Mon.
3.1–3.2	Chondrodite	336	$Mg_5(SiO_4)_2(OH,F)_2$	6–6½	Mon.
3.15–3.20	**Apatite**	245	$Ca_5(F,Cl)(PO_4)_3$	5	Hex.
3.15–3.20	**Spodumene**	324	$LiAlSi_2O_6$	6½–7	Mon.
3.16–3.20	**Andalusite**	348	Al_2SiO_5	7½	Orth.
3.18	**Fluorite**	216	CaF_2	4	Iso.
3.2–3.39					
3.1–3.3	Scorodite	250	$FeAsO_4 \cdot 2H_2O$	3½–4	Orth.
3.2	**Hornblende**	318	$Ca_2Na(Mg,Fe'')_4(Al,$-$Fe''',Ti)_3Si_6O_{22}(O,OH)_2$	5–6	Mon.
3.23	**Sillimanite**	349	Al_2SiO_5	6–7	Orth.
3.2–3.3	**Diopside**	320	$CaMgSi_2O_6$	5–6	Mon.
3.2–3.4	**Augite**	321	$Ca(Mg,Fe,Al)(Al,Si)_2O_6$	5–6	Mon.
3.25–3.37	Clinozoisite	343	$Ca_2Al_3(SiO_4)_3(OH)$	6–6½	Mon.
3.26–3.36	Dumortierite	353	$Al_8BSi_3O_{19}(OH)$	7	Orth.
3.27–3.35	Axinite	348	$H(Ca,Mn,Fe)_3$-$Al_2B(SiO_4)_4$	6½–7	Tric.
3.27–3.37	**Olivine**	334	$(Mg,Fe)_2SiO_4$	6½–7	Orth.
3.2–3.5	**Enstatite**	319	$MgSiO_3$	5½	Orth.
3.4–3.59					
3.3–3.5	Jadeite	323	$NaAlSi_2O_6$	6½–7	Mon.
3.35–3.45	**Diaspore**	205	$AlO(OH)$	6½–7	Orth.
3.35–3.45	**Epidote**	342	$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$	6–7	Mon.
3.35–3.45	**Idocrase**	341	$Ca_{10}Al_4(Mg,Fe)_2Si_9O_{34}$-$(OH)_4$	6½	Tetrag.
3.4–3.5	**Hemimorphite**	332	$Zn_4Si_2O_7(OH)_2 \cdot H_2O$	4½–5	Orth.
3.45	Arfvedsonite	318	$Na_3Mg_4AlSi_8O_{22}(OH,F)_2$	6	Mon.
3.40–3.55	Aegirite	322	$NaFe'''Si_2O_6$	6–6½	Mon.
3.4–3.55	**Sphene**	352	$CaTiSiO_5$	5–5½	Mon.
3.48	**Realgar**	164	AsS	1½–2	Mon.
3.42–3.56	Triphylite	244	$LiFePO_4$	4½–5	Orth.
3.49	**Orpiment**	165	As_2S_3	1½–2	Mon.
3.4–3.6	**Topaz**	347	$Al_2SiO_4(F,OH)_2$	8	Orth.
3.5	**Diamond**	144	C	10	Iso.
3.45–3.60	**Rhodochrosite**	229	$MnCO_3$	3½–4½	Rhomb.
3.6–3.79					
3.5–4.2	Allanite	344	$R_2''R_3'''(SiO_4)_3(OH)$	5½–6	Mon.
3.5–4.3	**Garnet**	337	$R_3''R_2'''(SiO_4)_3$	6½–7½	Iso.
3.6–4.0	**Spinel.**	193	$MgAl_2O_4$	8	Iso.
3.56–3.66	**Kyanite**	350	Al_2SiO_5	5–7	Tric.

MINERALS ARRANGED ACCORDING TO INCREASING SPECIFIC GRAVITY

G.	Name	p.	Composition	H.	Crystal System
3.58–3.70	**Rhodonite**	325	$MnSiO_3$	5½–6	Tric.
3.65–3.75	**Staurolite**	351	$Fe''Al_5Si_2O_{12}(OH)$	7–7½	Orth.
3.7	**Strontianite**	234	$SrCO_3$	3½–4	Orth.
3.65–3.8	**Chrysoberyl**	198	$BeAl_2O_4$	8½	Orth.
3.75–3.77	Atacamite	219	$Cu_2Cl(OH)_3$	3–3½	Orth.
3.77	**Azurite**	237	$Cu_3(CO_3)_2(OH)_2$	3½–4	Mon.
3.8–3.99					
3.7–4.7	**Psilomelane**	210	$H_4R_2Mn_8O_{20}$	5–6	Orth.
3.6–4.0	**Spinel**	193	$MgAl_2O_4$	8	Iso.
3.6–4.0	Limonite	208		5–5½	Amorph.
3.83–3.88	**Siderite**	228	$FeCO_3$	3½–4	Rhomb.
3.5–4.2	Allanite	344	$R_2''R_3'''(SiO_4)_3(OH)$	5½–6	Mon.
3.5–4.3	**Garnet**	337	$R_3''R_2'''(SiO_4)_3$	6½–7½	Iso.
3.9	Antlerite	260	$Cu_3(SO_4)(OH)_4$	3½–4	Orth.
3.9–4.03	**Malachite**	236	$Cu_2CO_3(OH)_2$	3½–4	Mon.
3.95–3.97	**Celestite**	257	$SrSO_4$	3–3½	Orth.
4.0–4.19					
3.9–4.1	**Sphalerite**	155	ZnS	3½–4	Iso.
4.02	**Corundum**	188	Al_2O_3	9	Rhomb.
3.9–4.2	**Willemite**	335	Zn_2SiO_4	5½	Rhomb.
4.2–4.39					
4.1–4.3	**Chalcopyrite**	157	$CuFeS_2$	3½–4	Tetrag.
3.7–4.7	**Psilomelane**	210	$H_4R_2Mn_8O_{20}$	5–6	Orth.
4.18–4.25	**Rutile**	200	TiO_2	6–6½	Tetrag.
4.3	**Manganite**	207	$MnO(OH)$	4	Orth.
4.3	**Witherite**	233	$BaCO_3$	3½	Orth.
4.37	**Goethite**	205	$FeO(OH)$	5–5½	Orth.
4.35–4.40	**Smithsonite**	230	$ZnCO_3$	5	Rhomb.
4.4–4.59					
4.4	Stannite	159	Cu_2FeSnS_4	4	Tetrag.
4.43–4.45	**Enargite**	182	Cu_3AsS_4	3	Orth.
4.5	**Barite**	255	$BaSO_4$	3–3½	Orth.
4.55	Gahnite	195	$ZnAl_2O_4$	7½–8	Iso.
4.52–4.62	**Stibnite**	166	Sb_2S_3	2	Orth.
4.6–4.79					
3.7–4.7	**Psilomelane**	210	$H_4R_2Mn_8O_{20}$	5–6	Orth.
4.6	**Chromite**	197	$FeCr_2O_4$	5½	Iso.
4.58–4.65	**Pyrrhotite**	160	$Fe_{(1-x)}S$	4	Hex.
4.7	**Ilmenite**	192	$FeTiO_3$	5½–6	Rhomb.
4.75	**Pyrolusite**	202	MnO_2	1–2	Tetrag.

G.	Name	p.	Composition	H.	Crystal System
4.6–4.76	Covellite	163	CuS	1½–2	Hex.
4.62–4.73	**Molybdenite**	174	MoS_2	1–1½	Hex.
4.68	**Zircon**	344	$ZrSiO_4$	7½	Tetrag.
4.8–4.99					
4.6–5.0	Pentlandite	162	$(Fe,Ni)S$	3½–4	Iso.
4.6–5.1	**Tetrahedrite-Tennantite**	181	$(Cu,Fe,Zn,Ag)_{12}(Sb,As)_4S_{13}$·	3–4½	Iso.
4.89	**Marcasite**	171	FeS_2	6–6½	Orth.
4.9	Greenockite	159	CdS	3–3½	Hex.
5.0–5.19					
5.02	**Pyrite**	169	FeS_2	6–6½	Iso.
4.8–5.3	**Hematite**	191	Fe_2O_3	5½–6½	Rhomb.
5.06–5.08	**Bornite**	152	Cu_5FeS_4	3	Iso.
5.15	**Franklinite**	196	$(Fe,Zn,Mn)(Fe,Mn)_2O_4$	6	Iso.
5.0–5.3	Monazite	243	$(Ce,La,Di)PO_4$	5–5½	Mon.
5.18	**Magnetite**	195	Fe_3O_4	6	Iso.
5.2–5.39					
5.4–5.59					
5.5	Millerite	161	NiS	3–3½	Rhomb.
5.5±	**Cerargyrite**	215	$AgCl$	2–3	Iso.
5.55	**Proustite**	180	Ag_3AsS_3	2–2½	Rhomb.
5.6–5.79					
5.5–5.8	**Chalcocite**	151	Cu_2S	2½–3	Pseudoiso.
5.68	**Zincite**	188	ZnO	4–4½	Hex.
5.7	Arsenic	141	As	3½	Rhomb.
5.5–6.0	Jamesonite	183	$Pb_4FeSb_6S_{14}$	2–3	Mon.
5.3–7.3	Columbite	203	$(Fe,Mn)(Cb,Ta)_2O_6$	6	Orth.
5.8–5.99					
5.8–5.9.	Bournonite	184	$PbCuSbS_3$	2½–3	Orth.
5.85	**Pyrargyrite**	180	Ag_3SbS_3	2½	Rhomb.
6.0–6.49					
5.9–6.1	Crocoite	259	$PbCrO_4$	2½–3	Mon.
5.9–6.1	**Scheelite**	267	$CaWO_4$	4½–5	Tetrag.
6.0	**Cuprite**	187	Cu_2O	3½–4	Iso.
6.07	**Arsenopyrite**	173	$FeAsS$	5½–6	Mon.
6.0–6.2	Polybasite	178	$Ag_{16}Sb_2S_{11}$	2–3	Mon.
6.2–6.3	Stephanite	179	Ag_5SbS_4	2–2½	Orth.
6.2–6.4	**Anglesite**	257	$PbSO_4$	3	Orth.
5.3–7.3	Columbite	203	$(Fe,Mn)(Cb,Ta)_2O_6$	6	Orth.
6.33	**Cobaltite**	171	$CoAsS$	5½	Iso.

MINERALS ARRANGED ACCORDING TO INCREASING SPECIFIC GRAVITY

G.	Name	p.	Composition	H.	Crystal System
6.5–6.99					
6.5	**Smaltite**	176	$CoAs_2$	5½–6	Iso.
6.55	**Cerussite**	234	$PbCO_3$	3–3½	Orth.
6.78	Bismuthinite	168	Bi_2S_3	2	Orth.
6.5–7.1	Pyromorphite	246	$Pb_5Cl(PO_4)_3$	3½–4	Hex.
6.8	**Wulfenite**	268	$PbMoO_4$	3	Tetrag.
6.7–7.1	Vanadinite	247	$Pb_5Cl(VO_4)_3$	3	Hex.
6.8–7.1	**Cassiterite**	199	SnO_2	6–7	Tetrag.
7.0–7.49					
7.0–7.2	Mimetite	247	$Pb_5Cl(AsO_4)_3$	3½	Hex.
7.0–7.5	**Wolframite**	266	$(Fe,Mn)WO_4$	5–5½	Mon.
7.3	**Argentite**	150	Ag_2S	2–2½	Iso.
7.5–7.99					
7.4–7.6	**Galena**	153	PbS	2½	Iso.
7.3–7.9	Iron	141	Fe	4½	Iso.
7.78	**Niccolite**	161	$NiAs$	5–5½	Hex.
>8.0					
8.0–8.2	Sylvanite	175	$(Au,Ag)Te_2$	1½–2	Mon.
8.10	**Cinnabar**	163	HgS	2½	Rhomb.
8.9	**Copper**	137	Cu	2½–3	Iso.
9.0–9.7	Uraninite	268		5½	Iso.
9.35	Calaverite	175	$AuTe_2$	2½	Mon.
9.8	Bismuth	142	Bi	2–2½	Rhomb.
10.5	**Silver**	136	Ag	2½–3	Iso.
15.0–19.3	**Gold**	133	Au	2½–3	Iso.
14–19	**Platinum**	139	Pt	4–4½	Iso.

SUBJECT INDEX

MINERAL INDEX

Name	p.	Composition	Xl. Sys.	G.	H.	Remarks
Acadialite	299					See chabazite
Acmite	323	$NaFe'''Si_2O_6$	Mon	3.5	6–6½	A pyroxene
Actinolite	317	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	Mon	3.0–3.2	5–6	An amphibole
Adularia	283					See orthoclase
Aegirite	322	$NaFe'''Si_2O_6$	Mon	3.40–3.55	6–6½	A pyroxene
Aenigmatite	353	$(Na,Ca)_4(Fe'',Fe''',Mn,Ti,Al)_{13}(Si_2O_7)_6$	Tric	3.75	5½	Cl {110}
Agate	277					See quartz
Alabandite	203	MnS	Iso	4.0	3½–4	Black
Alabaster	262					See gypsum
Albite	287	$NaAlSi_3O_8$—$Ab_{90}An_{10}$	Tric	2.62	6	A feldspar
Alexandrite	198					Gem chrysoberyl
Allanite	344	$R_2''R_3'''(SiO_4)_3(OH)$	Mon	3.5–4.2	5½–6	Brown-black
Almandite	339	$Fe_3Al_2(SiO_4)_3$	Iso	4.25	7	A garnet
Altaite	175	$PbTe$	Iso	8.16	3	Tin-white
Alumstone	265					See alunite
Alunite	265	$KAl_3(OH)_6(SO_4)_2$	Rho	2.6–2.8	4	Usually massive
Amalgam	136					See silver
Amazonstone	286					Green microcline
Amblygonite	249	$LiAlFPO_4$	Tric	3.0–3.1	6	Fusible at 2
Amethyst	275					Purple quartz
Amphibole	315					A mineral group
Analcime	300	$NaAlSi_2O_6\cdot H_2O$	Iso	2.27	5–5½	A feldspathoid
Anatase	201	TiO_2	Tet	3.9	5½–6	Adamantine luster
Andalusite	348	Al_2SiO_5	Orth	3.16–3.20	7½	Infusible
Andesine	290	$Ab_{70}An_{30}$—$Ab_{50}An_{50}$	Tric	2.69	6	Plagioclase feldspar
Andradite	339	$Ca_3Fe_2(SiO_4)_3$	Iso	3.75	7	A garnet
Anglesite	257	$PbSO_4$	Orth	6.2–6.4	3	Cl {001} {110}
Anhydrite	258	$CaSO_4$	Orth	2.89–2.98	3–3½	Cl{100} {010} {001}
Ankerite	227	$CaCO_3\cdot(Mg,Fe,Mn)CO_3$	Rho	2.95–3	3½	Cl{$10\bar{1}1$}
Annabergite	253	$Ni_3As_2O_8\cdot 8H_2O$	Mon	3.0	2½–3	Nickel bloom. Green
Anorthite	287	$Ab_{10}An_{90}$—$CaAl_2Si_2O_8$	Tric	2.76	6	Plagioclase feldspar
Anorthoclase	286	$KAlSi_3O_8$—$NaAlSi_3O_8$	Tric	2.58	6	A feldspar
Anthophyllite	316	$(Mg,Fe)_7Si_8O_{22}(OH)_2$	Orth	2.85–3.2	5½–6	An amphibole
Antigorite	305					See serpentine
Antimony	132	Sb	Rho	6.7	3	Cl {0001}
Antlerite	260	$Cu_3(OH)_4SO_4$	Orth	3.9±	3½–4	Green
Apatite	245	$Ca_5(F,Cl)(PO_4)_3$	Hex	3.15–3.20	5	Cl {0001} poor
Apophyllite	307	$Ca_4K(Si_4O_{10})_2F\cdot 8H_2O$	Tet	2.3–2.4	4½–5	Cl {001}
Aquamarine	331					See beryl
Aragonite	231	$CaCO_3$	Orth	2.95	3½–4	Cl {010} {110}
Arfvedsonite	318	$Na_3Mg_4AlSi_8O_{22}(OH,F)_2$	Mon	3.45	6	An amphibole
Argentite	150	Ag_2S	Iso	7.3	2–2½	Sectile
Arsenic	141	As	Rho	5.7	3½	Cl {0001}
Arsenopyrite	173	$FeAsS$	Mon	6.07±0.15	5½–6	Pseudo-orth.
Asbestos	306					See amphibole and serpentine

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Name	p.	Composition	Xl. Sys.	G.	H.	Remarks
Astrophyllite	353	$(Na,Ca)_5(Fe'',Al,Ti)_{15}(Si_2O_7)_6(F,OH)_8$	Orth	3.35	3	Micaceous cl.
Atacamite	219	$Cu_2Cl(OH)_3$	Orth	3.75–3.77	3–3½	Cl {010}
Augite	321	$Ca(Mg,Fe,Al)(Al,Si)_2O_6$	Mon	3.2–3.4	5–6	A pyroxene
Aurichalcite	237	$2(Zn,Cu)CO_3 \cdot 3(Zn,Cu)(OH)_2$	Mon	3.64	2	Green to blue
Aventurine	276					See oligoclase
Axinite	348	$H(Ca,Mn,Fe)_3Al_2B(SiO_4)_4$	Tric	3.27–3.35	6½–7	Crystal angles acute
Azurite	237	$Cu_3(CO_3)_2(OH)_2$	Mon	3.77	3½–4	Always blue
Balas ruby	194					Red gem spinel
Barite	255	$BaSO_4$	Orth	4.5	3–3½	Cl {001} {110}
Barytes	255					See barite
Bauxite	209	A mixture of aluminum hydroxides	Amor	2.0–2.55	1–3	An earthy rock
Beidellite	303	$Al_8(Si_4O_{10})_3(OH)_{12} \cdot 12H_2O$	Orth?	2.6	1½	See kaolinite
Benitoite	353	$CaTiSi_3O_9$	Hex	3.6	6½	Blue
Beryl	331	$Be_3Al_2Si_6O_{18}$	Hex	2.75–2.8	7½–8	Usually green
Biotite	313	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	Mon	2.8–3.2	2½–3	Black mica
Bismuth	142	Bi	Rho	9.8	2–2½	Cl {0001}
Bismuthinite	168	Bi_2S_3	Orth	6.78±0.03	2	Cl {010}
Black-band ore	229					See siderite
Black jack	155					See sphalerite
Black lead	148					See graphite
Bloodstone	277					Green and red chalcedony.
Blue copper carbonate	237					See azurite
Blue vitriol	264					See chalcanthite
Bog-iron ore	208					See limonite
Boracite	238	$Mg_7Cl_2B_{16}O_{30}$	Orth	2.9–3.0	7	Pseudo-iso
Borax	239	$Na_2B_4O_7 \cdot 10H_2O$	Mon	1.7±	2–2½	Cl {100}
Bornite	152	Cu_5FeS_4	Iso	5.06–5.08	3	Purple-blue tarnish
Boulangerite	184	$Pb_5Sb_4S_{11}$	Orth	6.0±	2½–3	Cl {001} {010}
Bournonite	184	$PbCuSbS_3$	Orth	5.8–5.9	2½–3	Fusible at 1
Brazilian emerald	329					See tourmaline
Brittle mica	310					See margarite
Brochantite	261	$Cu_4(OH)_6SO_4$	Mon	3.9	3½–4	Cl {010}. Green
Bromyrite	215	$AgBr$	Iso	5.9	1–1½	Sectile
Bronzite	319	$(Mg,Fe)SiO_3$	Orth	3.3±	5½	See enstatite
Brookite	201	TiO_2	Orth	3.9–4.1	5½–6	Adamantine luster
Brucite	210	$Mg(OH)_2$	Rho	2.39	2½	Cl {0001}
Bytownite	290	$Ab_{30}An_{70}$ — $Ab_{10}An_{90}$	Tric	2.74	6	Plag. feldspar
Cairngorm stone	276					See quartz

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Name	p.	Composition	XI Sys.	G.	H.	Remarks
Calamine	332					See hemimorphite
Calaverite	175	$AuTe_2$	Mon	9.35	2½	Fusible at 1
Calcite	221	$CaCO_3$	Rho	2.72	3	Cl $\{10\bar{1}1\}$
Californite	342					See idocrase
Cancrinite	294	$(Na,K)_{6-8}Al_6Si_6O_{24}\cdot(CO_3)_{1-2}\cdot 2\text{–}3H_2O$	Hex	2.45	5–6	A feldspathoid
Capillary pyrites	161					See millerite
Carnallite	219	$KMgCl_3\cdot 6H_2O$	Orth	1.6	1	Deliquescent
Carnelian	277					Red chalcedony
Carnotite	248	$K_2(UO_2)_2(VO_4)_2\cdot 8H_2O$	Orth	4.1	Soft	Yellow
Cassiterite	199	SnO_2	Tet	6.8–7.1	6–7	Luster adamantine
Cat's-eye	276					See chrysoberyl or quartz
Celestite	257	$SrSO_4$	Orth	3.95–3.97	3–3½	Cl $\{001\}\{110\}$
Celsian	285	$BaAl_2Si_2O_8$	Mon	3.37	6	A feldspar
Cerargyrite	215	$AgCl$	Iso	5.5±	2–3	Perfectly sectile
Cerussite	234	$PbCO_3$	Orth	6.55	3–3½	Effer. in HNO_3
Chabazite	298	$(Ca,Na,K)_7Al_{12}(Al,Si)_2Si_{26}O_{80}\cdot 40H_2O$	Rho	2.05–2.15	4–5	Cubelike crystals
Chalcanthite	264	$CuSO_4\cdot 5H_2O$	Tric	2.12–2.30	2½	Soluble in water
Chalcedony	277					Cryptocryst. quartz
Chalcocite	151	Cu_2S	Orth	5.5–5.8	2½–3	Imperfectly sectile
Chalcopyrite	157	$CuFeS_2$	Tet	4.1–4.3	3½–4	Brittle. Yellow
Chalcotrichite	187					Fibrous cuprite
Chalk	224					See calcite
Chalybite	228					See siderite
Chert	277	SiO_2		2.65	7	Cryptocryst. quartz
Chessylite	237					See azurite
Chiastolite	348					See andalusite
Chloanthite	176	$NiAs_2$	Iso	6.5±	5½–6	See smaltite
Chlorite	309	$(Mg,Fe)_5(Al,Fe''')_2Si_3O_{10}(OH)_8$	Mon	2.6–2.9	2–2½	Cl $\{001\}$
Chloritoid	310	$(Fe,Mg)_2Al_4Si_2O_{10}(OH)_4$	Mon	3.5	6–7	Brittle mica
Chondrodite	336	$Mg_5(SiO_4)_2(F,OH)_2$	Mon	3.1–3.2	6–6½	Yellow-red
Chromite	197	$FeCr_2O_4$	Iso	4.6	5½	Luster submetallic
Chrysoberyl	198	$BeAl_2O_4$	Orth	3.65–3.8	8½	Crystals tabular
Chrysocolla	327	$CuSiO_3\cdot 2H_2O$	?	2.0–2.4	2–4	Bluish green
Chrysolite	334					See olivine
Chrysoprase	277					Green chalcedony
Chrysotile	305					Serpentine asbestos
Cinnabar	163	HgS	Rho	8.10	2½	Red
Cinnamon stone	339					See grossularite
Citrine	276					See quartz
Clay ironstone	229					See siderite
Cleavelandite	290					A white, platy albite feldspar
Cliachite	209	$Al(OH)_3$	Amor	2.5±	1–3	See bauxite

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Name	p.	Composition	Xl. Sys.	G.	H.	Remarks
Clinochlore	308					See chlorite
Clinoenstatite	320	$MgSiO_3$	Mon′	3.19	6	Prismatic cl.
Clinohumite	336	$Mg_9(SiO_4)_4(F,OH)_2$	Mon	3.1–3.2	6	See chondrodite
Clinozoisite	343	$Ca_2Al_3(SiO_4)_3(OH)$	Mon	3.25–3.37	6–6½	Crystals striated
Cobaltite	171	CoAsS	Iso	6.33	5½	In pyritohedrons
Cog-wheel ore	184					See bournonite
Colemanite	241	$Ca_2B_6O_{11}\cdot 5H_2O$	Mon	2.42	4–4½	Cl {010} perfect
Collophanite	248	$Ca_3(PO_4)_2\cdot H_2O$	Amor	2.6–2.9	3–5	Massive, oölitic
Columbite	203	$(Fe,Mn)(Cb,Ta)_2O_6$	Orth	5.3–7.3	6	Luster submetallic
Common mica	311					See muscovite
Common salt	212					See halite
Copper	137	Cu	Iso	8.9	2½–3	Malleable
Copper glance	151					See chalcocite
Copper nickel	161					See niccolite
Copper pyrites	157					See chalcopyrite
Cordierite	301	$Mg_2Al_4Si_5O_{18}$	Orth	2.60–2.66	7–7½	Blue
Corundum	188	Al_2O_3	Rho	4.02	9	Rhomb. parting
Cotton-balls	241					See ulexite
Covellite	163	CuS	Hex	4.6–4.76	1½–2	Blue
Cristobalite	280	SiO_2	Tet?	2.30	7	In volcanic rocks
Crocoite	259	$PbCrO_4$	Mon	5.9–6.1	2½–3	Orange-red
Cryolite	216	Na_3AlF_6	Mon	2.95–3.0	2½	White
Cummingtonite	316	$(Mg,Fe)_7Si_8O_{22}(OH)_2$	Mon	2.85–3.2	6	An amphibole
Cuprite	187	Cu_2O	Iso	6.0	3½–4	In red crystals
Cyanite	350					See kyanite
Cymophane	198					See chrysoberyl
Danaite	173	$(Fe,Co)AsS$	Mon	5.9–6.2	5½–6	See arsenopyrite
Danburite	333	$CaB_2Si_2O_8$	Orth	2.97–3.02	7	In crystals
Datolite	346	$CaBSiO_4(OH)$	Mon	2.8–3.0	5–5½	Usually in crystals
Demantoid	339					Green andradite garnet
Diallage	320					See diopside
Diamond	144	C	Iso	3.5	10	Adamantine luster
Diaspore	205	$AlO(OH)$	Orth	3.35–3.45	6½–7	Cl {010} perfect
Diatomaceous earth	281					See opal
Diatomite	281					See opal
Dichroite	301					See cordierite
Dickite	305	$Al_4(Si_4O_{10})_3(OH)_{12}\cdot 3H_2O$	Mon	2.6	2–2½	See kaolinite
Diopside	320	$CaMgSi_2O_6$	Mon	3.2–3.3	5–6	A pyroxene
Dioptase	328	H_2CuSiO_4	Rho	3.3	5	Green
Dolomite	226	$CaMg(CO_3)_2$	Rho	2.85	3½–4	Cl $\{10\bar{1}1\}$
Dry-bone ore	230					See smithsonite
Dumortierite	353	$Al_8BSi_3O_{19}(OH)$	Orth	3.26–3.36	7	Radiating
Edenite	318	$Ca_2NaMg_5AlSi_7O_{22}(OH,F)_2$	Mon	3.0	6	See hornblende
Electrum	134					See gold

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Name	p.	Composition	XI Sys.	G.	H.	Remarks
Eleolite	293					See nepheline
Embolite	215	$Ag(Cl,Br)$	Iso	5.3–5.4	$1–1\frac{1}{2}$	Sectile
Emerald	331					See beryl
Emery	189					Corundum with magnetite
Enargite	182	Cu_3AsS_4	Orth	4.43–4.45	3	Cl {110}
Endlichite	248					See vanadinite
Enstatite	319	$MgSiO_3$	Orth	3.2–3.5	$5\frac{1}{2}$	A pyroxene
Epidote	342	$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$	Mon	3.35–3.45	6–7	Cl {001}
Epsomite	263	$MgSO_4 \cdot 7H_2O$	Orth	1.75	$2–2\frac{1}{2}$	Bitter taste
Epsom salt	263					See epsomite
Erythrite	253	$Co_3(AsO_4)_2 \cdot 8H_2O$	Mon	2.95	$1\frac{1}{2}–2\frac{1}{2}$	Pink. Cobalt bloom
Essonite	339					See grossularite
Euclase	332	$B_2Al_2(SiO_4)_2(OH)_2$	Mon	3.1	$7\frac{1}{2}$	Cl {010}
Eucryptite	324	$Li(Al,Si)_2O_4$	Hex	2.67		Spodumene alter.
Fahlore	181					See tetrahedrite
Fayalite	334	Fe_2SiO_4	Orth	4.14	$6\frac{1}{2}$	See olivine
Feather ore	183					See jamesonite
Feldspar	282					A mineral group
Feldspathoid	291					A mineral group
Ferberite	266	$FeWO_4$	Mon	7.0–7.5	5	See wolframite
Fergusonite	204	$R'''(Cb,Ta)O_4$	Tet	5.8	$5\frac{1}{2}–6$	Brown-black
Fersmannite	353	$Ca_4Na_2Ti_4Si_3O_{18}F_2$	Mon	3.44	$5\frac{1}{2}$	Brown
Fibrolite	349					See sillimanite
Flint	277	SiO_2		2.65	7	Cryptocryst. qtz.
Flos ferri	233					See aragonite
Fluorite	216	CaF_2	Iso	3.18	4	Cl octahedral
Forsterite	334	Mg_2SiO_4	Orth	3.2	$6\frac{1}{2}$	See olivine
Fowlerite	325					Zinc-bearing rhodonite
Franklinite	196	$(Fe,Zn,Mn)(Fe,Mn)_2O_4$	Iso	5.15	6	At Franklin, N. J.
Freibergite	181					Argentiferous tetrahedrite
Gadolinite	332	$Y_2Fe''Be_2(SiO_4)_2O_2$	Mon	4.0–4.5	$6\frac{1}{2}–7$	Black
Gahnite	195	$ZnAl_2O_4$	Iso	4.55	$7\frac{1}{2}–8$	In green octahedrons
Galena	153	PbS	Iso	7.4–7.6	$2\frac{1}{2}$	Cl cubic
Galenite	153					See galena
Garnet	337	$R_3''R_2'''(SiO_4)_3$	Iso	3.5–4.3	$6\frac{1}{2}–7\frac{1}{2}$	In crystals
Garnierite	307	$(Ni,Mg)SiO_3 \cdot nH_2O$	Amor	2.2–2.8	2–3	Green
Gay-Lussite	237	$CaCO_3 \cdot Na_2CO_3 \cdot 5H_2O$	Mon	1.94	2–3	Fusible at 1
Gedrite	316					See anthophyllite
Geocronite	184	$Pb_5(Sb,As)_2S_8$	Orth	6.4±	$2\frac{1}{2}$	
Gersdorffite	171	$NiAsS$	Iso	5.9	$5\frac{1}{2}$	See cobaltite
Geyserite	281					See opal
Gibbsite	209	$Al(OH)_3$	Mon	2.3–2.4	$2\frac{1}{2}–3\frac{1}{2}$	Basal cl.

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Name	p.	Composition	Xl. Sys.	G.	H.	Remarks
Glauberite	254	$Na_2Ca(SO_4)_2$	Mon	2.70–2.85	2½–3	Cl {001}
Glauconite	314	$K_2(Mg,Fe)_2Al_6(Si_4O_{10})_3$-$(OH)_{12}$	Mon	2.3±	2	In green sands
Glaucophane	319	$Na_2Mg_3Al_2Si_8O_{22}$-$(OH,F)_2$	Mon	3.0–3.2	6–6½	An amphibole
Gmelinite	299	$(Na,Ca)_6Al_6(Al,Si)$-$Si_{13}O_{40}\cdot 20H_2O$	Rho	2.1±	4½	A zeolite
Goethite	205	$FeO(OH)$	Orth	4.37	5–5½	Cl {010}
Gold	133	Au	Iso	15.0–19.3	2½–3	Yellow. Soft
Graphite	148	C	Hex	2.3	1–2	Black. Platy
Gray copper	181					See tetrahedrite
Green copper carbonate	236					See malachite
Greenockite	159	CdS	Hex	4.9	3–3½	Yellow-orange
Grossularite	339	$Ca_3Al_2(SiO_4)_3$	Iso	3.53	6½	A garnet
Gypsum	262	$CaSO_4\cdot 2H_2O$	Mon	2.32	2	Cl{010}{100}{$\bar{1}$11}
Halite	212	NaCl	Iso	2.16	2½	Cleavage cubic. Salty
Halloysite	303	$Al_2Si_2O_5(OH)_4\cdot H_2O$	Amor	2.0–2.2	1–2	A clay mineral
Harmotome	298	$Ba_5(NaK)Al_{11}Si_{29}O_{80}\cdot$-$25H_2O$	Mon	2.45	4½	A zeolite
Hastingsite	318	$Ca_2NaMg_4Al_3Si_6O_{22}$-$(OH,F)_2$	Mon	3.2	6	See hornblende
Hauynite	294	$(Na,Ca)_{6-8}Al_6Si_6O_{24}\cdot$-$(SO_4)_{1-2}$	Iso	2.4–2.5	5½–6	A feldspathoid
Heavy spar	255					See barite
Hedenbergite	321	$CaFeSi_2O_6$	Mon	3.55	5–6	A pyroxene
Heliotrope	277					Green and red chalcedony
Hematite	191	Fe_2O_3	Rho	5.26	5½–6½	Red streak
Hemimorphite	332	$Zn_4Si_2O_7(OH)_2\cdot H_2O$	Orth	3.4–3.5	4½–5	Cl {110}
Hessite	175	Ag_2Te	Iso	8.4	2½–3	
Heulandite	297	$(Ca,Na,K)_6Al_{10}(Al,Si)$-$Si_{29}O_{80}\cdot 25H_2O$	Mon	2.18–2.20	3½–4	Cl {010} perfect
Hiddenite	324					Green spodumene
Holmquistite	319					Lithium-bearing glaucophane
Hornblende	318	$Ca_2Na(Mg,Fe'')_4$-$(Al,Fe''',Ti)_3Si_6O_{22}$-$(O,OH)_2$	Mon	3.2	5–6	An amphibole
Horn silver	215					See cerargyrite
Huebnerite	266	$MnWO_4$	Mon	7.0	5	See wolframite
Humite	336	$Mg_7(SiO_4)_3(F,OH)_2$	Orth	3.1–3.2	6	See chondrodite
Hyacinth	345					See zircon
Hyalite	281					Globular, colorless opal
Hyalophane	283	$(K,Ba)(Al,Si_1)_2Si_2O_8$	Mon	2.8	6	See orthoclase
Hydrozincite	231	$2ZnCO_3\cdot 3Zn(OH)_2$	Mon	3.6–3.8	2–2½	Secondary mineral
Hypersthene	320	$(Mg,Fe)_2Si_2O_6$	Orth	3.4–3.5	5–6	A pyroxene

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Name	p.	Composition	Xl. Sys.	G.	H.	Remarks
Ice	186	H_2O	Hex	0.917	1½	....
Iceland Spar	223	....	.....	....	.....	See calcite
Iddingsite	334	$H_8M_9Fe_2Si_3O_{14}$ (?)	Orth	3.5–3.8	3	After olivine
Idocrase	341	$Ca_{10}Al_4(Mg,Fe)_2Si_9O_{34}(OH)_4$	Tet	3.35–3.45	6½	Prismatic crystals
Ilmenite	192	$FeTiO_3$	Rho	4.7	5½–6	Slightly magnetic
Ilvaite	344	$Ca(Fe,Mn)_2Fe'''(SiO_4)_2(OH)$	Orth	4.0	5½–6	Black
Indicolite	329	....	.....	....	.....	See tourmaline
Iodobromite	215	$Ag(Cl,Br,I)$	Iso	5.71	1–1½	Sectile
Iodyrite	215	AgI	Hex	5.5–5.7	1–1½	Sectile
Iolite	301	....	.....	....	.....	See cordierite
Iridium	141	Ir	Iso	22.7	6–7	A platinum metal
Iridosmine	141	Ir,Os	Rho	19.3–21.1	6–7	See platinum
Iron	141	Fe	Iso	7.3–7.9	4½	Very rare
Iron pyrites	169	....	.....	....	.....	See pyrite
Jacinth	345	....	.....	....	.....	See zircon
Jade	316	....	.....	....	.....	See nephrite and jadeite
Jadeite	323	$NaAlSi_2O_6$	Mon	3.3–3.5	6½–7	Green. Compact
Jamesonite	183	$Pb_4FeSb_6S_{14}$	Mon	5.5–6.0	2–3	Feather ore
Jargon	346	....	.....	....	.....	See zircon
Jarosite	265	$KFe_3(OH)_6(SO_4)_2$	Rho	3.2±	3	Yellow-brown
Jasper	277	....	.....	....	.....	See quartz
Kaersutite	318	$Ca_4Na(Mg,Fe'')_7(Al,Fe''')_5Ti_2Si_{12}O_{46}(OH)_2$	Mon	3.34	5–6	An amphibole
Kainite	215	$MgSO_4\cdot KCl\cdot 3H_2O$	Mon	2.1	3	....
Kaolin	303	....	.....	....	.....	Clay minerals
Kaolinite	302	$Al_2Si_2O_5(OH)_4$	Mon	2.6–2.65	2–2½	Earthy
Kernite	240	$Na_2B_4O_7\cdot 4H_2O$	Mon	1.95	3	Cl {001} {100}
Krennerite	175	$AuTe_2$	Orth	8.62	2–3	Basal cl.
Kunzite	324	....	.....	....	.....	See spodumene
Kyanite	350	Al_2SiO_5	Tric	3.56–3.66	5–7	Blue. Bladed
Labradorite	290	$Ab_{50}An_{50}$ — $Ab_{30}An_{70}$	Tric	2.71	6	Plag. feldspar
Lamprophyllite	353	$CaNa_3Ti_3Si_3O_{14}(OH,F)$	Mon?	3.45	4	Platy
Lapis lazuli	295	....	.....	....	.....	See lazurite
Larsenite	335	$PbZnSiO_4$	Orth	5.9	3	Olivine group
Laumontite	301	$(Ca,Na_7)Al_{12}(Al,Si)_2Si_{26}O_{80}\cdot 25H_2O$	Mon	2.28	4	A zeolite
Lazulite	250	$MgAl_2(OH)_2(PO_4)_2$	Mon	3.0–3.1	5–5½	Blue
Lazurite	295	$Na_{4-5}Al_3Si_3O_{12}S$	Iso	2.4–2.45	5–5½	Pyrite associated
Lechatelierite	280	SiO_2	Amor	2.2	6–7	Fused silica
Lepidolite	314	$K_2Li_3Al_4Si_7O_{21}(OH,F)_3$	Mon	2.8–3.0	2½–4	A mica
Leucite	291	$KAlSi_2O_6$	.....	2.45–2.50	5½–6	In trapezohedrons
Limonite	208	$FeO(OH)\cdot nH_2O + Fe_2O_3\cdot nH_2O$	Amor	3.6–4.0	5–5½	Streak yellow-brown

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Name	p.	Composition	Xl. Sys.	G.	H.	Remarks
Neptunite	353	$(Na,K)(Fe'',Mn,Ti)Si_2O_6$	Mon	3.23	5–6	Black
Niccolite	161	$NiAs$	Hex	7.78	5–5½	Copper-red
Nickel bloom	253	....	.....	....	.....	See annabergite
Nickel iron	141	Ni,Fe	Iso	7.8–8.2	5	In meteorites
Niter	238	KNO_3	Orth	2.09–2.14	2	Saltpeter
Norbergite	336	$Mg_3(SiO_4)(F,OH)_2$	Orth	3.1–3.2	6	See chondrodite
Noselite	294	$Na_4Al_3Si_3O_{12}SO_4$	Iso	2.3±	6	A feldspathoid
Octahedrite	201	....	.....	....	.....	See anatase
Oligoclase	290	$Ab_{90}An_{10}$ to $Ab_{70}An_{30}$	Tric	2.65	6	Plag. feldspar
Olivine	334	$(Mg,Fe)_2SiO_4$	Orth	3.27–3.37	6½–7	Green rock mineral
Onyx	277	....	.....	....	.....	Layered chalcedony
Opal	281	$SiO_2\cdot nH_2O$	Amor	1.9–2.2	5–6	Conchoidal fracture
Orpiment	165	As_2S_3	Mon	3.49	1½–2	Cl {010}. Yellow
Orthite	344	....	.....	....	.....	See allanite
Orthoclase	282	$KAlSi_3O_8$	Mon	2.57	6	A feldspar
Ottrelite	310	$(Fe'',Mn)(Al,Fe''')_2Si_3O_{10}\cdot H_2O$	Mon	3.5	6–7	Brittle mica
Palladium	141	Pd	Iso	11.9	4½–5	See platinum
Parawollastonite	326	....	.....	....	.....	See wollastonite
Pargasite	318	$Ca_4Na_2Mg_9Al_4Si_{13}O_{44}(OH,F)_4$	Mon	3–3.5	5½	See hornblende
Patronite	248	....	.....	....	.....	An ore of vanadium
Peacock ore	152	....	.....	....	.....	See bornite
Pectolite	326	$Ca_2NaSi_3O_8(OH)$	Tric	2.7–2.8	5	Crystals acicular
Penninite	308	....	.....	....	.....	See chlorite
Pentlandite	162	$(Fe,Ni)S$	Iso	4.6–5.0	3½–4	In pyrrhotite
Peridot	334	....	.....	....	.....	Gem olivine
Perovskite	201	$CaTiO_3$	Iso	4.03	5½	Yellow
Perthite	286	....	.....	....	.....	Microcline and albite
Petzite	175	$(Ag,Au)_2Te$	Iso?	8.7–9.0	2½–3	....
Phenacite	335	Be_2SiO_4	Rho	2.97–3.00	7½–8	In pegmatites
Phillipsite	298	$(Ca,Ba,K,Na)_6Al_8(Al,Si)_2Si_{10}O_{40}\cdot 15–20H_2O$	Mon	2.2	4½–5	A zeolite
Phlogopite	314	$KMg_2Al_2Si_3O_{10}(OH)_2$	Mon	2.86	2½–3	Brown mica
Phosgenite	236	$Pb_2Cl_2CO_3$	Tet	6.0–6.3	3	Fusible at 1
Phosphorite	249	....	.....	....	.....	Phosphate rock
Picotite	194	....	.....	....	.....	See spinel
Pinite	212	....	.....	....	.....	See muscovite
Pitchblende	268	....	.....	....	.....	See uraninite
Plagioclase	286	$Ab_{100}An_0 \rightarrow Ab_0An_{100}$	Tric	2.62–2.76	6	A feldspar series
Plagionite	184	$Pb_5Sb_8S_{17}$	Mon	5.56	2½	....
Platinum	139	Pt	Iso	14–19	4–4½	As grains in placers

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Name	p.	Composition	Xl. Sys.	G.	H.	Remarks
Pleonaste	194					See spinel
Plumbago	148					See graphite
Polianite	202	MnO_2	Tet	5.0	6–6½	Steel-gray
Pollucite	293	$Cs_4Al_4Si_9O_{26}\cdot H_2O$	Iso	2.9	6½	Colorless
Polybasite	178	$Ag_{16}Sb_2S_{11}$	Mon	6.0–6.2	2–3	Pseudorhombohedral
Polyhalite	261	$K_2Ca_2Mg(SO_4)_4\cdot 2H_2O$	Tric	2.78	2½–3	Bitter taste
Potash feldspar	283					See orthoclase
Potash mica	311					See muscovite
Prase	277					See quartz
Prehnite	310	$Ca_2Al_2Si_3O_{10}(OH)_2$	Orth	2.8–2.95	6–6½	Tabular crystals
Prochlorite	308					See chlorite
Proustite	180	Ag_3AsS_3	Rho	5.55	2–2½	Light ruby silver
Pseudoleucite	291					See leucite
Pseudowollastonite	326					See wollastonite
Psilomelane	210	$H_4R_2Mn_8O_{20}$	Orth	3.7–4.7	5–6	Botryoidal
Purple copper ore	152					See bornite
Pyrargyrite	180	Ag_3SbS_3	Rho	5.85	2½	Dark ruby silver
Pyrite	169	FeS_2	Iso	5.02	6–6½	Crystals striated
Pyrochlore	204	$(Na,Ca)_2(Cb,Ti)$-$(O,F)_7$?	Iso	4.3±	5	Infusible
Pyrolusite	202	MnO_2	Tet	4.75	1–2	Sooty
Pyromorphite	246	$Pb_5Cl(PO_4)_3$	Hex	6.5–7.1	3½–4	Adamantine luster
Pyrope	339	$Mg_3Al_2(SiO_4)_3$	Iso	3.51	7	A garnet
Pyrophyllite	302	$Al_2Si_4O_{10}(OH)_2$	Mon	2.8–2.9	1–2	Smooth feel
Pyroxene	319					A mineral group
Pyrrhotite	160	$Fe_{1-x}S$	Hex	4.58–4.65	4	Magnetic
Quartz	273	SiO_2	Rho	2.65	7	No cleavage
Ramsayite	353	$Na_2Ti_2Si_2O_9$	Orth	3.43	6	From Kola
Rasorite	240					See kernite
Realgar	164	AsS	Mon	3.48	1½–2	Cl $\{010\}$. Red
Red copper ore	187					See cuprite
Red ocher	191					See hematite
Rhodochrosite	229	$MnCO_3$	Rho	3.45–3.6	3½–4½	Cl $\{10\bar{1}1\}$. Pink
Rhodolite	339	$3(Mg,Fe)O\cdot Al_2O_3\cdot 3SiO_2$	Iso	3.84	7	See garnet
Rhodonite	325	$MnSiO_3$	Tric	3.58–3.70	5½–6	Pink
Riebeckite	319	$Na_3Fe_3''Fe_2'''Si_8O_{23}$-$(OH)$	Mon	3.44	4	An amphibole
Rock crystal	275					See quartz
Rock salt	212					See halite
Roscoelite	248	$K_2V_4Al_2Si_6O_{20}(OH)_4$	Mon	2.97	2½	Vanadium mica
Rubellite	329					See tourmaline
Ruby	189					Red gem corundum
Ruby copper	187					See cuprite
Ruby silver	180					See pyrargyrite and proustite

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Name	p.	Composition	Xl. Sys.	G.	H.	Remarks
Rutile	200	TiO_2	Tet	4.18–4.25	6–6½	Adamantine luster
Saltpeter	238	…	…	…	…	See niter
Sanidine	283	…	…	…	…	See orthoclase
Sapphire	189	…	…	…	…	Blue gem corundum
Satin spar	262	…	…	…	…	Fibrous gypsum
Scapolite	295	Various	Tet	2.65–2.74	5–6	Cl {010} {110}
Scheelite	267	$CaWO_4$	Tet	5.9–6.1	4½–5	Cl {011}
Schorlite	328	…	…	…	…	See tourmaline
Scolecite	300	$CaAl_2Si_3O_{10}\cdot 3H_2O$	Mon	2.2±	5–5½	A zeolite
Scorodite	250	$FeAsO_4\cdot 2H_2O$	Orth	3.1–3.3	3½–4	Green to brown
Selenite	262	…	…	…	…	See gypsum
Semseyite	184	$Pb_9Sb_8S_4$	Mon	5.8	2½	…
Sepiolite	304	$Mg_2Si_3O_8\cdot 2H_2O$	Mon?	2.0	2–2½	Meerschaum
Sericite	312	…	…	…	…	Fine-grained muscovite
Serpentine	305	$Mg_3Si_2O_5(OH)_4$	Mon	2.2	2–5	Green to yellow
Siderite	228	$FeCO_3$	Rho	3.83–3.88	3½–4	Cl $\{10\bar{1}1\}$
Sillimanite	349	Al_2SiO_5	Orth	3.23	6–7	Cl {010} perfect
Silver	136	Ag	Iso	10.5	2½–3	White, malleable
Silver glance	150	…	…	…	…	See argentite
Smaltite	176	$CoAs_2$	Iso	6.5±0.4	5½–6	Tin-white
Smithsonite	230	$ZnCO_3$	Rho	4.35–4.40	5	Reniform
Soapstone	303	…	…	…	…	See talc
Sodalite	294	$Na_4Al_3Si_3O_{12}Cl$	Iso	2.15–2.3	5½–6	Usually blue
Soda-microcline	286	…	…	…	…	See microcline
Soda niter	237	$NaNO_3$	Rho	2.29	1–2	Cooling taste
Spathic iron	228	…	…	…	…	See siderite
Specular iron	191	…	…	…	…	See hematite
Sperrylite	140	$PtAs_2$	Iso	10.50	6–7	See platinum
Spessartite	339	$Mn_3Al_2(SiO_4)_3$	Iso	4.18	7	A garnet
Sphalerite	155	ZnS	Iso	3.9–4.1	3½–4	Cl {110} 6 directions
Sphene	352	$CaTiSiO_5$	Mon	3.40–3.55	5–5½	Wedge-shaped xls
Spinel	193	$MgAl_2O_4$	Iso	3.6–4.0	8	In octahedrons
Spodumene	324	$LiAlSi_2O_6$	Mon	3.15–3.20	6½–7	Cl {110} Part {100}
Stannite	159	Cu_2FeSnS_4	Tet	4.4	4	Easily fusible
Staurolite	351	$Fe''Al_5Si_2O_{12}(OH)$	Orth	3.65–3.75	7–7½	In cruciform twins
Steatite	303	…	…	…	…	See talc
Stephanite	179	Ag_5SbS_4	Orth	6.2–6.3	2–2½	Pseudohexagonal
Stibnite	166	Sb_2S_3	Orth	4.52–4.62	2	Cl {010} perfect
Stilbite	297	$(Ca,Na,K)_3Al_5(Al,Si)$-$Si_{14}O_{40}\cdot 15H_2O$	Mon	2.1–2.2	3½–4	Sheaflike aggregates
Stromeyerite	152	$(Ag,Cu)_2S$	Orth	6.2–6.3	2½–3	…
Strontianite	234	$SrCO_3$	Orth	3.7	3½–4	Efferv. in HCl
Sulfur	143	S	Orth	2.05–2.09	1½–2½	Burns with blue flame
Sunstone	290	…	…	…	…	See oligoclase
Sylvanite	175	$(Au,Ag)Te_2$	Mon	8.0–8.2	1½–2	Cl {010} perfect

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Name	p.	Composition	Xl Sys.	G.	H.	Remarks
Sylvite	214	KCl	Iso	1.99	2	Cl cubic perfect
Talc	303	$Mg_3Si_4O_{10}(OH)_2$	Mon	2.7–2.8	1	Greasy feel
Tantalite	204	$(Fe,Mn)Ta_2O_6$	Orth	6.5±	6	See columbite
Tennantite	181	$(Cu,Fe,Zn,Ag)_{12}As_4S_{13}$	Iso	4.6–5.1	3–4½	In tetrahedrons
Tenorite	188	CuO	Tric	6.5	3–4	Black
Tephroite	335	Mn_2SiO_4	Orth	4.1	6	See olivine
Tetrahedrite	181	$(Cu,Fe,Zn,Ag)_{12}Sb_4S_{13}$	Iso	4.6–5.1	3–4½	In tetrahedrons
Thenardite	254	Na_2SO_4	Orth	2.68	2½	In saline lakes
Thomsonite	301	$(Ca,Na)_6Al_8(Al,Si)_2Si_{10}O_{40}\cdot 12H_2O$	Orth	2.3	5	A zeolite
Thorite	346	$ThSiO_4$	Tet	5.3	5	Usually hydrated
Thulite	343	....	.....	....	.....	Rose-red zoisite
Tiger's-eye	276	....	.....	....	.....	See quartz
Tin	132	Sn	Tet	7.3	2	Very rare
Tin stone	199	....	.....	....	.....	See cassiterite
Titanic iron ore	192	....	.....	....	.....	See ilmenite
Titanite	352	....	.....	....	.....	See sphene
Topaz	347	$Al_2SiO_4(F,OH)_2$	Orth	3.4–3.6	8	Cl {001} perfect
Tourmaline	328	$WX_3B_3Al_3(AlSi_2O_9)_3(O,OH,F)_4$	Rho	3.0–3.25	7–7½	Trigonal section
Travertine	225	....	.....	....	.....	See calcite
Tremolite	316	$Ca_2Mg_5Si_8O_{22}(OH)_2$	Mon	3.0–3.3	5–6	Cl {110} perfect
Tridymite	280	SiO_2	Orth	2.26	7	In volcanic rocks
Triphylite	244	$LiFePO_4$	Orth	3.42–3.56	4½–5	Cl {001} {010}
Troilite	160	....	.....	....	.....	See pyrrhotite
Trona	237	$3Na_2O\cdot 4CO_3\cdot 5H_2O$	Mon	2.13	3	Alkaline taste
Troostite	335	....	.....	....	.....	Manganiferous willemite
Tufa	225	....	.....	....	.....	See calcite
Turgite	207	$2Fe_2O_3\cdot H_2O$	.....	4.2–4.6	6½	Red streak
Turquois	252	$Al_2(OH)_3PO_4\cdot H_2O + x\mathrm{Cu}$	Tric	2.6–2.8	6	Blue-green
Ulexite	241	$NaCaB_5O_9\cdot 8H_2O$	Tric	1.96	1	" Cotton-balls "
Uralian emerald	340	....	.....	....	.....	See andradite
Uralite	318	....	.....	....	.....	See hornblende
Uraninite	268	Complex	Iso	9.0–9.7	5½	Pitchy luster
Uvarovite	339	$Ca_3Cr_2(SiO_4)_3$	Iso	3.45	7½	Green garnet
Vanadinite	247	$Pb_5Cl(VO_4)_3$	Hex	6.7–7.1	3	Luster resinous
Verde antique	307	....	.....	....	.....	See serpentine
Vesuvianite	341	....	.....	....	.....	See idocrase
Vivianite	252	$Fe_3(PO_4)_2\cdot 8H_2O$	Mon	2.58–2.68	1½–2	Cl {010} perfect
Wad	203	....	.....	....	.....	Manganese ore
Wavellite	251	$Al_3(OH)_3(PO_4)_2\cdot 5H_2O$	Orth	2.33	3½–4	Radiating aggregates
Wernerite	295	....	.....	....	.....	See scapolite

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