# MINERALOGY

F. H. HATCH.

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# MINERALOGY

BY

## F. H. HATCH

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## DESCRIPTIVE MINERALOGY

# PREFACE TO THE FOURTH EDITION

THE first edition of this introduction to the study of Mineralogy was published in 1892. Since then the book has been reprinted three times, but till now without revision. Starting with the idea of a simple revision, I have found it necessary to rewrite and to enlarge it; but in doing this, I have been careful to retain the essential features of its original arrangement.

As before, there are two parts, the first of which deals with the properties of minerals, and the second with the description of the more important species that either make up rocks, or occur as ores, as salts, or as gems. This subdivision, which is identical with the one originally adopted, has been found convenient by students; but, as in all attempts at the classification of natural products, it is not free from inconsistencies and overlaps. Thus, for example, *calcite*, which, it cannot be denied, is a rock-forming mineral, has been relegated to the Salts in company with the other carbonate of lime and those of magnesia, strontia, and baryta—namely, *aragonite*, *dolomite*, *magnesite*, *strontianite*, and *witherite.* Similarly *apatite*, which is an accessory constituent of many rocks, is placed in the phosphate division of the Salts; and *tourmaline*, *zircon*, and *garnet*, which are also frequent accessory constituents of rocks, appear among the Gems. Again, pyrites, which is almost ubiquitous enough to be regarded as a rock-forming mineral, is placed with the Ores; and even there it is difficult to find its best position, for, although it is chiefly mined for its sulphur content, its natural position is with the ores of iron.

Such classificatory inconsistencies need not, however, occasion any real difficulty to the reader, since the description of any given mineral can be found by reference to the index, where the number of the page, containing its descriptive paragraph, is distinguished by heavy type.

In selecting mineral types for description, I have endeavoured to include only those that either play an important rôle in the economy of Nature, or are sought after by man for industrial purposes. Rare minerals, which have found no industrial application, although they may be of the greatest interest to the Crystallographer or to the Chemist, are, from the standpoint of the present work, mere *lusus naturæ*, and as such have been rigorously excluded.

In the choice of a name, where there are several synonyms for a mineral, I have been guided by the British Museum Index. For physical constants I have chiefly relied on Hintze's "Handbuch der Mineralogie," but have also consulted Rosenbusch and Wülfing's "Mikroskopische Physiographie," Weinschenk's "Gesteinsbildenden Mineralien," Brush and Penfield's "Determinative Mineralogy," and Miers' "Mineralogy." The compilation of the paragraphs dealing with the distribution of the ores and other useful minerals has involved some research in the publications of the various mining institutions, in order to carry out the principle, adopted by me, of restricting the list to localities of industrial importance.

For kindly consenting to read the proofs I have to thank my friends W. Campbell Smith, of the British Museum, and R. H. Rastall, Fellow of Christ's College, Cambridge.

F. H. H.

SEDGWICK MUSEUM,
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1911.

# MINERALOGY

## PART I

## THE PROPERTIES OF MINERALS

## INTRODUCTION

THE geological study of the visible portion of the earth's solid crust has established the fact that it is chiefly made up of material which is either of igneous origin, having consolidated from a molten state, or consists of sediments that have accumulated at the bottom of former seas, and now lie piled up one above the other in strata many thousands of feet thick. These rock masses, whether igneous or sedimentary, are made up of the homogeneous inorganic substances known as **Minerals.** Besides those of which rocks are composed, there is a great variety of other minerals, filling chinks and fissures in the earth's crust, and comprising, *inter alia*, the valuable ore deposits which are the source of our metals.

It is the business of the mineralogist to study the form, characters, and physical and chemical properties of these different kinds of mineral matter; and the facts thus elicited afford a means by which the different species of minerals may be classified and distinguished.

In accordance with this principle, Part I. of this book is divided into three chapters, of which the first deals with the morphological characters of minerals, the second with their physical properties, and the third with their chemical composition.

# CHAPTER I

## MORPHOLOGICAL CHARACTERS

In studying the properties of minerals, one of the first things that strikes the observer is their frequent occurrence in geometrical forms bounded by plane surfaces. In these bodies, which are termed **crystals**, the component particles of matter are arranged in accordance with certain fixed laws of symmetry; and that this is so, is evidenced by the fact that the physical properties of a crystal are found to bear a definite relation to its external geometrical boundaries.

Mineral matter is said to be *crystalline* when it exists as part of a crystal or as an aggregation of crystals. In some minerals, however, the aggregation of the molecules is subservient to no law of symmetry; and in these there is consequently no interdependence between physical structure and external form. This is known as the *amorphous* state of matter.

It must be borne in mind, however, that a crystalline mineral need not always present a definite geometrical form. The environment of the crystal during its formation may have militated against the assumption of geometrical contours; but the crystalline or non-crystalline nature of a mineral will nevertheless be always indicated by its physical structure.

The form or **habit** of crystallized minerals is determined by the extent to which certain of the bounding planes (*faces*) of the crystals are developed at the expense of others. Such habits are the following:

*Tabular* (*or platy, etc.*) : barytes.
*Prismatic* (*or columnar*) : stibnite, epidote.
*Acicular* (*or needle-shaped*) : cerussite.
*Capillary* (*or hair-like*) : millerite.

When the mineral is amorphous or minutely crystalline, it assumes an external shape which is bounded by other than plane surfaces. Such shapes are designated by the following terms:

*Nodular :* blende, malachite.
*Globular :* blende, calcite, marcasite.
*Botryoidal* (*like a bunch of grapes*) : dolomite, chalcedony.
*Mammillated :* psilomelane.
*Reniform* (*or kidney-shaped*) : hæmatite.
*Stalactitic* (*pendent*) : calcite, aragonite, limonite.
*Dendritic* (*branched*) : copper.
*Wiry :* silver.
*Mossy :* copper.
*Leafy :* gold.

The internal structure of minerals having the external forms enumerated above is designated by the following terms:

*Granular.*—When composed of grains or small irregularly-shaped crystals in close juxtaposition: calcite (in marble), magnetite.

*Massive* or *Compact.*—When the outlines of the constituent grains are invisible: hæmatite.

In addition, some minerals show an internal *fibrous* or *concentric laminated* arrangement; thus, a mammillated or globular external form may be associated with an internal fibrous structure, as in wavellite, pyrites, and hæmatite, or with a concentric laminated structure, as in malachite and hæmatite.

The faces of crystals may be smooth, drusy, striated, or curved. When *smooth* they reflect clear images of distant objects, a property which is utilized in the measurement, by the reflecting goniometer, of the angle formed by two faces of a crystal.* *Drusy* faces are those which are roughened by the presence of minute projecting crystals. *Striated* faces are marked by a series of parallel lines which may be due to repeated (*polysynthetic*) twinning, as in albite (see p. 92), or to a rapid alternation (*oscillation*) of two sets of faces, as in pyrites. *Curved* faces are produced by rapid succession of small, so-called *vicinal* faces, the angle between each pair being a little less than 180°. Diamond, dolomite, and gypsum, are minerals which frequently have curved faces.

**Symmetry of Crystals.**—If a sufficiently large number of crystals be examined, it will be found that they

---

* Note that the angles measured by means of the reflecting goniometer, and quoted in most books of mineralogy, are not the face-angles, but their supplements.

show differences in the symmetrical arrangement of their faces. It will also be found that they exhibit various degrees of symmetry. Thus, a crystal may possess what is termed *centrosymmetry*—*i.e.*, it has a centre of symmetry, through which every line will meet the crystal at similar points at its two ends.* It may also possess one or more planes of symmetry. A *plane of symmetry* is a plane dividing a body into two parts, each of which is the exact but inverse counterpart of the other; that is to say, the two parts bear to one another the same relation that an image bears to its object, the mirror being equivalent to the plane of symmetry (see Fig. 1).

FIG. 1.—A PLANE OF SYMMETRY.

Every face of a crystal possessing centrosymmetry must have a corresponding face parallel to it on the opposite side of the centre of symmetry, and there must also be faces corresponding to these on the opposite sides of planes of symmetry, and making equal angles with them respectively. A group of faces which are thus mutually connected by symmetry is technically described as a *form*.

Crystals possess other kinds of symmetry besides those depending on centrosymmetry and planes of symmetry. Thus, the faces of a crystal may be symmetrically distributed about an *axis of symmetry*—*i.e.*, each of its faces can be brought into the position of another similar face by rotation about such an axis.

---

* All crystals except certain *hemihedral* and *hemimorphic* forms see p. 29) possess centrosymmetry.

According as the angle through which the crystal is rotated, to produce this result, is $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, or $\frac{1}{6}$, of the total rotation to the original position, so the axis of symmetry is said to be *binary*, *ternary*, *quaternary*, or *senary* (or, according to some authors, *digonal*, *trigonal*, *tetragonal*, *hexagonal*). A plane of symmetry is always parallel to a possible face of the crystal; an axis of symmetry is always parallel to a possible edge.

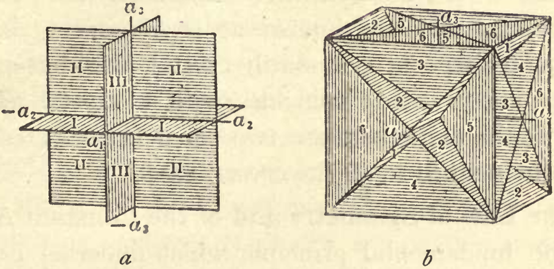

FIG. 2.—FORM WITH NINE PLANES OF SYMMETRY.
Three are shown in *a*, and six in *b*.

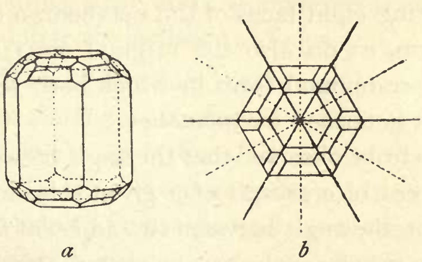

FIG. 3.—HEXAGONAL FORM, WITH SEVEN PLANES OF SYMMETRY. VIEW (*a*) AND PLAN (*b*).
Six are shown in *b*, and the seventh is the plane of projection.

For convenience in mathematical treatment, crystal forms are referred to fixed lines which are chosen, when possible, from the intersections of their planes of symmetry, and are known as *crystal axes*. Axes of symmetry are not necessarily crystal axes, but an axis of symmetry either coincides with a crystal axis, or bisects the angle between two equal crystal axes, or is equally inclined to all the crystal axes.

**The Law of Symmetry and of the Constant Angle.**—The fundamental principle which underlies crystallography may be formulated as follows: Every crystal is enclosed by plane faces, and is subservient to the *law of symmetry*, which requires that similar parts of a crystal shall be similarly modified. For example, if one corner of a cube is replaced by a face, the law of symmetry requires that all eight corners shall be so replaced. The resulting eight faces of the octahedron comprise a simple form, as do also the original six faces of the cube; the compound form in which both sets of faces are present is termed a *combination*.

It is also to be observed that the angle between similar pairs of faces of a crystal of a given substance is constant. Thus, the angle between two adjacent faces of the octahedron measures always 109° 28′ 16″; while the corresponding angle between two adjacent rhombic pyramid faces $(111 : 1\bar{1}1)$ of sulphur, for instance, measures always 106° 26′.* This is *the law of the constant angle*.

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* See footnote on p. 5. The angle $(111 : 1\bar{1}1)$ for sulphur, as quoted in the textbooks, is 73° 34′. The face-angle is the supplement of this—viz., $180° - 73° 34' = 106° 26'$.

**Zones.**—However complicated a crystal may appear to be, it will be found that the combination may generally be reduced to a few sets of faces, which, if produced, would intersect in edges parallel to the same straight line. A set of faces, therefore, which are parallel to the same line (the *zone-axis*) is termed a *zone*. The zone-axis is supposed to be drawn through the centre of the crystal at the intersection of the crystal axes. In the measurement of crystals by the reflecting goniometer, zones are of the greatest service. Once the crystal is set up so that a zone-axis is parallel with the axis of the instrument, the angles between all the faces belonging to that zone can be measured during a single rotation of the graduated circle. The reading of the scale is noted when the reflected image (the "signal") from each face is successively in adjustment, and the angle between any two faces is the difference in their readings.

**Classification of Crystals.**—By considering crystals in the light of the three elements of symmetry described above, it is found that there are thirty-two possible cases, to which thirty-two classes of crystals correspond. They may, however, be conveniently grouped, by means of their planes of symmetry, into six systems.

The greatest number of planes of symmetry possible in a crystal is *nine;* all forms possessing these belong to the REGULAR or CUBIC system.* Three of these planes are perpendicular to one another, and six bisect the angles between each pair of the first (see Fig. 2).

---

* For the less symmetrical forms of the cubic system see p. 29.

The remaining systems are the following: The HEXAGONAL, with *seven* planes of symmetry, six of which intersect in one straight line, and are inclined to one another at an angle of 30°, the seventh being perpendicular to the other six (see Fig. 3).

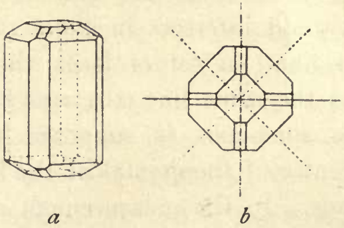

FIG. 4.—TETRAGONAL FORM, WITH FIVE PLANES OF SYMMETRY. VIEW (*a*) AND PLAN (*b*).

Four are shown in *b*, and the fifth is the plane of projection.

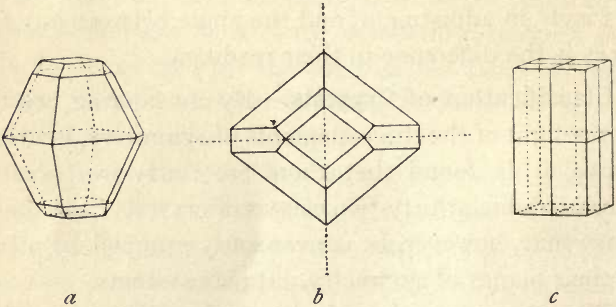

FIG. 5.—RHOMBIC FORMS, WITH THREE PLANES OF SYMMETRY.

*a* and *b* are the view and plan respectively of the same crystal, and *c* is another rhombic combination showing three planes of symmetry.

The TETRAGONAL, with *five* planes, four of which intersect in one straight line, and are inclined to one another at an angle of 45°, the fifth being perpendicular to the other four (see Fig. 4).

The Rhombic, with *three* planes of symmetry perpendicular to one another (see Fig. 5).

The Monoclinic, with *one* plane of symmetry (see Fig. 6).

The Triclinic, Anorthic, or Asymmetric, with no planes of symmetry (see Fig. 7).

The rhombohedral forms are considered by some to constitute a distinct system (the *trigonal* or *rhombohedral system*), with three planes of symmetry, intersecting in one straight line, and inclined to one another at an angle of 60°. They are often treated, however, as hemihedral derivatives of the hexagonal pyramids (see p. 30).

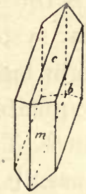

Fig. 6.—Monoclinic Form, with One Plane of Symmetry.

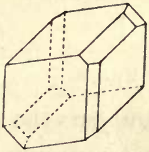

Fig. 7.—Triclinic Crystal with no Plane of Symmetry, but possessing Centrosymmetry.

**The Regular or Cubic System of Crystals.**—This system comprises the following holohedral forms, which may occur alone or in combination: octahedron, cube, rhombic dodecahedron, icosi-tetrahedron, triakis-octahedron, tetrakis-hexahedron, and hexakis-octahedron. (For hemihedral forms see p. 29.)

For the purpose of comparison those forms are referred to three equal crystal axes standing at right angles to one another (and at right angles to the three principal planes of symmetry). Each crystal axis is a quaternary axis of symmetry. There are further four ternary axes of symmetry, equally inclined to them, and six binary axes of symmetry, bisecting the angles between them.

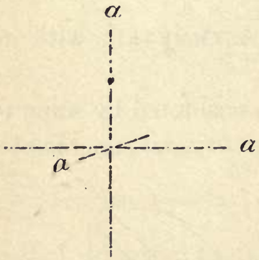

FIG. 8.

The *octahedron* is the simplest form of the regular system. It is composed of eight faces, each of which is an equilateral triangle, and cuts the three axes at unit distance. The face-angle between any two adjacent faces measured across an edge is 109° 28′ 16″ (see Fig. 9).

The *cube* is another simple and very common form of this system. It is contained by six square faces, each of which cuts one axis at right angles, and runs parallel to the other two, thus coinciding in direction with the principal planes of symmetry. The angle between two faces measures 90° (see Fig. 10).

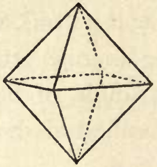

FIG. 9.—OCTAHEDRON.

The *rhombic dodecahedron* is contained by twelve equal rhombs (the diagonals of which bear to one another the ratio of 1 : $\sqrt{2}$). Each face cuts two axes at unit distance, and is parallel to the third. The remaining six planes of symmetry of the regular system coincide in direction with the faces of this form. The angle between two faces which meet in an edge measures 120°.

The *icosi-tetrahedron* is a form contained by twenty-four deltoids (a plane quadrilateral figure bounded by pairs of adjacent equal straight lines). Each face cuts two axes at unit distance, the third at a distance measured by a rational quantity, *m*, less than unity. The series is limited on the one hand by the cube, on the other by the octahedron (see Fig. 12).

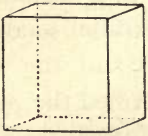

FIG. 10.—CUBE.

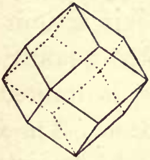

FIG. 11.—DODECAHEDRON.

The *triakis-octahedron*, or *three-faced octahedron*, is a form contained by twenty-four isosceles triangles. Each face cuts two axes at unit distance, the third at a distance equal to a rational quantity, *m*, greater than unity. The series is limited on the one hand by the octahedron, and on the other by the rhombic dodecahe-

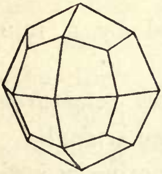

FIG. 12.—ICOSI-TETRAHEDRON.

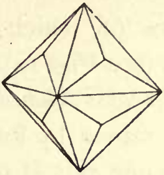

FIG. 13.—TRIAKIS-OCTAHEDRON.

dron. The form is also known as the *pyramidal octahedron;* this designation has reference to the shape, which is that of an octahedron with a three-faced pyramid on each face (see Fig. 13).

The *tetrakis-hexahedron*, or *four-faced cube*, is a form contained by twenty-four isosceles triangles. Each face cuts one axis at unit distance, one at a distance equal to a rational quantity, *m*, and is parallel to the third. The series is limited by the cube and the rhombic dodecahedron. The form is also termed the *pyramidal cube*, from the fact that it can be described as a cube each face of which is surmounted by a four-faced pyramid (see Fig. 14).

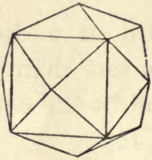

FIG. 14.—TETRAKIS-HEXAHEDRON.

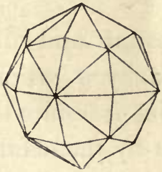

FIG. 15.—HEXAKIS-OCTAHEDRON.

The *hexakis-octahedron*, or *six-faced octahedron*, is a form contained by forty-eight scalene triangles. Each face cuts one axis at unit distance, another at a distance equal to a rational quantity, *m*, and the third at a distance equal to a rational quantity, *n*. By the variation of the values for *m* and *n*,* the hexakis-octahedron

---

* These letters, *m* and *n*, are used to denote the value of the **intercept**, or distance cut off on the axis by the face, reckoning from the point of origin. They represent any rational number, such as 1, 2, 3, or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc.

may be made to approximate successively to all the simpler forms of the system. It is therefore the most general of all the forms of the regular system (see Fig. 15). For examples of the various combinations of simple forms, see Fig. 16.

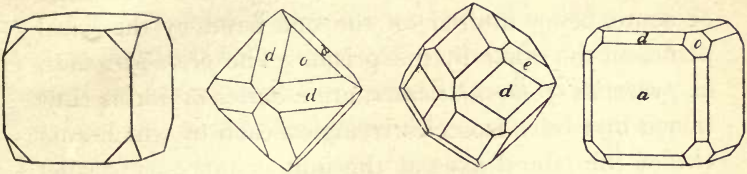

FIG. 16.—COMBINATIONS.

*a*, Cube; *o*, octahedron; *d*, dodecahedron; *e*, icosi-tetrahedron.

**The Hexagonal System.***—The forms belonging to the system are referred to four axes, three of which (*a*) are equal and similar, and cross one another at an angle of 60°; while the fourth (the *principal axis*, *c*) is unequal and dissimilar to the other three, and stands at right angles to the plane formed by them (see Fig. 18). The ratio of *a* to *c* is an irrational number, to be determined for each particular mineral. It represents the relative lengths of the intercepts of the pyramid chosen for the fundamental form. Thus, in quartz the ratio *a* : *c* = 1·0999. The principal axis coincides with

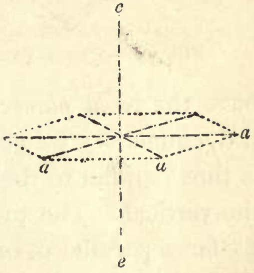

FIG. 17.

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* So called on account of the horizontal section being a hexagon.

a senary axis of symmetry, and there are six binary axes of symmetry perpendicular to it.

The most important forms are the pyramids, the prisms, and the basal plane. The pyramids are obtuse or acute, being limited on the one hand by the basal plane, on the other by the prism. The *proto-pyramids*, or *pyramids of the first order*, are a series of forms contained by twelve isosceles triangles, each of which cuts two of the lateral axes at the unit distance, is parallel to the third, and cuts the vertical axis at a distance equal to $c$ multiplied by a rational quantity, $m$ (see Fig. 18). When $m$ is infinitely small (*i.e.*, equals 0), we have the *basal plane;* when $m$ becomes infinitely large (*i.e.*, equals $\infty$), we get the *proto-prism*. The basal plane is thus parallel to the lateral axes, and at right angles to the vertical. The proto-prism is a form composed of six faces parallel to one lateral axis, and to the vertical. Both forms can only occur in combination, and are often associated with one another (see Fig. 19).

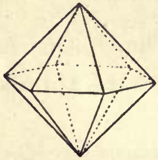

FIG. 18.—PROTO-PYRAMID.

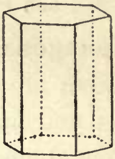

FIG. 19.—PROTO-PRISM.

The *deutero-pyramids*, or *pyramids of the second order*, are a series of forms each of which is contained by twelve isosceles triangles, cutting one of the lateral axes at the unit distance, the remaining two at a distance equal to twice the unit length, and the vertical axis at a distance equal to *c* multiplied by a rational quantity, *m*. This series is also limited by the basal plane and the deutero-prism.

The *dihexagonal pyramids* are a series of pyramids contained by twenty-four scalene triangles. Each face cuts one lateral axis at the unit distance, and another at a distance equal to *a* multiplied by a rational quantity, *n*, which must be less than 2; while the vertical axis is intercepted at a distance represented by *mc*. There is a corresponding *dihexagonal prism*, in which the intercept on the vertical axis is infinitely great—*i.e.*, its faces are parallel to this axis. For examples of the combinations of simple forms, see Fig. 20.

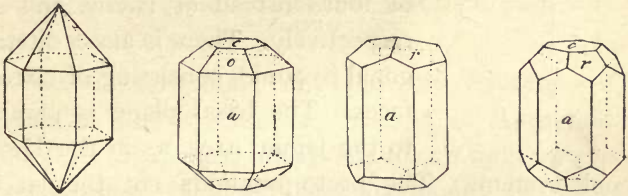

FIG. 20.—COMPOUND FORMS.

*c*, Basal plane; *o*, pyramid; *a*, prism; *r*, rhombohedron (see p. 29).

**The Tetragonal System.*** — The forms of this system are referred to three axes at right angles to one another, two of which (*a*) are equal, the third (the vertical or principal axis, *c*) unequal (see Fig. 21). The principal axis (*c*) coincides with a quaternary

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* So called on account of the horizontal section being a tetragon or square.

axis of symmetry, and the two remaining axes with binary axes of symmetry. Each pair of crystal axes lies in a plane of symmetry. The two remaining planes of symmetry bisect the angle between the two equal crystal axes (*a*). As in the Hexagonal system, we have pyramids and prisms of two orders (a *proto* and a *deutero* series); but in this system the pyramids consist of eight faces, and the prisms of four, instead of twelve and six respectively. There is also a ditetragonal pyramid, consisting of sixteen faces. The basal plane is parallel to the lateral axes, as in the Hexagonal system. The proto-pyramids cut the lateral axes at the unit distance, and the vertical at a distance equal to *mc*. When *m* equals infinity, the form becomes the proto-prism. The deutero-pyramid cuts one lateral axis at unit distance, and is parallel to the other; while the vertical is cut at a distance equal to *mc*: by in-

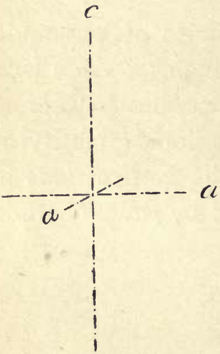

FIG. 21.

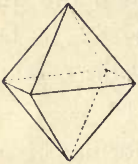

FIG. 22.—PROTO-PYRAMID.

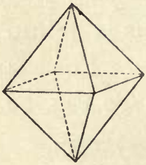

FIG. 23.—DEUTERO-PYRAMID.

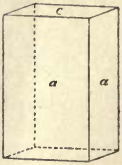

FIG. 24.—DEUTERO-PRISM.

creasing the value of $m$ we approximate to the deutero-prism.

For examples of the combinations of simple forms, see Fig. 25.

FIG. 25.—TETRAGONAL COMBINATIONS.
$s$ and $p$, Proto-pyramids; $e$, deutero-pyramid; $m$, proto-prism; $a$, deutero-prism.

**The Orthorhombic or Rhombic System.** — The forms of this system are referred to three unequal and dissimilar axes, which stand at right angles to one another. One of these ($c$) having been chosen for the vertical, the shorter of the two laterals (the *brachy-axis* or *brachy-diagonal*, $a$) is directed towards the observer, while the larger (the *macro-axis* or *macro-diagonal*, $b$) is then transverse. Each crystal axis coincides with a binary axis of symmetry, and each pair lies in a plane of symmetry.

The forms comprise pyramids, prisms, domes, and pinacoids, of which the last three can only be seen in combination.

Starting from a fundamental pyramid which cuts the three axes at the unit distance, we derive various pyramids, according as we increase or diminish the distance cut off on the vertical, the macro- and the brachy-axes. Thus, besides the fundamental series, we get two series of pyramids, a brachy series and a macro series, each series being limited by the corresponding prism, brachy- or macro-prism, as the case may be.

It must be borne in mind that the unit of measurement is different for *each* axis in the rhombic and succeeding systems. The ratio of the intercepts of the fundamental form, which is chosen for each particular mineral, is $a : b : c$, or, if $b$ be taken as unit, $a : 1 : c$; $a$ and $c$ being irrational. Thus the ratio of the intercepts of the pyramid, chosen as the fundamental form for sulphur, is 0·8130 : 1 : 1·9037; or $a : b : c = 0·8130 : 1 : 1·9037$.

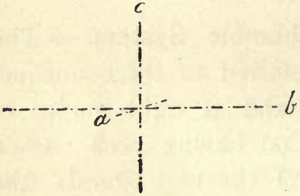

FIG. 26.

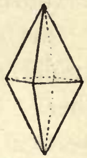

FIG. 27.—A RHOMBIC PYRAMID.

These axial lengths are known as *parameters*, and the form used to determine them is termed the *parametral form*. The intercepts made on the crystal axes by any face of a crystal must be such that they can be expressed as rational multiples of the parameters. This is known as the *law of rational intercepts*.

The *domes*[*] are forms comparable to the prisms, but differing from them in being parallel to a lateral instead of to a vertical axis. Like the prisms, they may be

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[*] So called on account of their giving a roof-like termination to crystals.

regarded as special cases of the pyramids—*i.e.*, as pyramidal faces that cut one of the lateral axes at an infinite distance; they are, in fact, the lateral limiting forms of the brachy and macro series of pyramids respectively, just as the prisms are the limiting forms of the pyramids in a vertical direction. The brachy-dome cuts the macro-axis and the vertical axis, and runs parallel to the brachy-axis; the macro-dome, on the other hand, cuts the brachy-axis and the vertical axis, and runs parallel to the macro-axis.

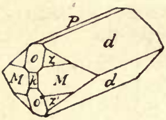

FIG. 28.—COMBINATION.

*P*, basal plane;
*z*, pyramid;
*k*, macro-pinacoid;
*M*, prism;
*d*, brachy-dome;
*o*, macro-dome.

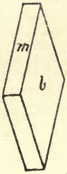

FIG. 29.—COMBINATION.

*m*, macro-dome;
*b*, brachy-pinacoid.

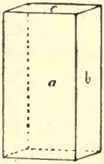

FIG. 30.—COMBINATION.

*c*, basal plane;
*b*, brachy-pinacoid;
*a*, macro-pinacoid.

The *pinacoids* are faces which cut one axis perpendicularly, and are parallel to the other two. In this sense the basal plane may be regarded as a pinacoid. The true pinacoids are two in number—namely, the brachy-pinacoid, parallel to the vertical and the brachy-axis, and the macro-pinacoid, parallel to the vertical and the macro-axis. For compound forms, see Figs. 28, 29, and 30.

**The Monoclinic System.** — The forms of this system are referred to three unequal and dissimilar axes; of these, one is at right angles to the other two, which cut one another obliquely. The crystals are conventionally so placed that the observer looks into the obtuse angle ($\beta$) formed by the inclined axis with the vertical. The inclined axis is termed the *clino-axis* (or *clino-diagonal*, *a*); while the perpendicular axis is known as the *ortho-axis* (or *ortho-diagonal*, *b*).

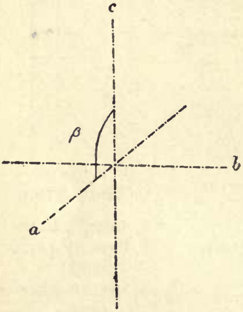

Fig. 31.

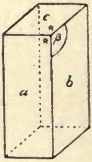

Fig. 32.—Monoclinic Combination of—

*c*, Basal plane; *b*, clino-pinacoid; *a*, ortho-pinacoid; $\beta$ is the angle between the axes *a* and *c*; *R*, *R*, are right angles.

The one plane of symmetry of this system contains the vertical axis and the inclined axis. It is represented as a crystal face by the clino-pinacoid (see Fig. 32). The crystal axis *b* is a binary axis of symmetry. In consequence of there being only one plane of symmetry, a pyramid, or more correctly *hemi-pyramid*, in this system consists of four faces instead of eight: two at the top, front (−) or back (+), and two at the bottom, back (−) or front (+).

As in the rhombic system, the forms comprise pyramids, prisms, domes, and pinacoids. These are classified according to their relation to the axes. Thus, besides the fundamental pyramid with unit values for the lateral axes, and those derived from it by the variation of the intercept on the vertical axis (the lateral axes being in this series cut at unit distance), there is an ortho- and a clino-series of pyramids, an ortho- and a clino-series of prisms and domes, and the two pinacoids—the ortho-pinacoid and the clino-pinacoid.

FIG. 33.—MONOCLINIC COMBINATION OF—

*c*, Pyramid; *m*, prism; *b*, clino-pinacoid.

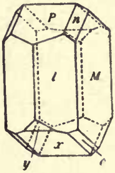

FIG. 34.—COMBINATION OF—

*P*, Basal plane; *n*, clino-dome; *l*, prism; *M*, clino-pinacoid; *x* and *y*, ortho-domes.

The terminal or basal plane is parallel to the two lateral axes (see Fig. 34).

**The Triclinic or Anorthic System.**—The forms of this system are referred to three unequal and dissimilar axes which intersect obliquely. These axes are placed so that one axis is vertical (*c*), and the lateral axes are inclined from back to front (*a*), and from left to right (*c*).

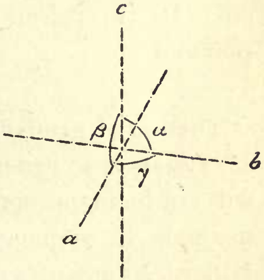

FIG. 35.

There is no plane nor axis of symmetry, and the simple forms consist only of the two parallel faces required by the law of centro-symmetry. Being open forms, they can only occur in combination.

Here again the forms include pyramids, prisms, domes, and pinacoids, constituting macro- and brachy-series, as in the Rhombic system. Fig. 37 represents a combination, consisting of basal plane (*P*), brachy-pinacoid (*M*), two prisms (*T* and *l*), a macro-dome (*x*), and a pyramid (*o*).

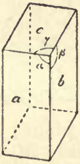

FIG. 36.—TRICLINIC COMBINATION OF—

*c*, Basal plane; *b*, brachy-pinacoid; *a*, macro-pinacoid.

The angles between the common edges of these faces are equal to those between the axes, namely, $\alpha$, $\beta$, and $\gamma$.

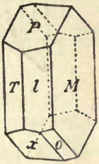

FIG. 37.—TRICLINIC COMBINATION.

*P*, Basal plane; *o*, pyramid; *T* and *l*, prisms; *M*, brachy-pinacoid; *x*, macro-dome.

## SYMBOLS.

The use of symbols to designate the forms and faces of crystals is so general, that a few words on the subject will not be inappropriate here. There are two principal methods in vogue—namely, those of Naumann and Miller. Naumann's system was once popular on account of simplicity; but the Millerian system is better adapted for mathematical treatment, and has been adopted almost universally. In the former system (Naumann's) the fundamental form is designated by an initial letter; thus, O stands for the octahedron of the regular system, and P for the fundamental pyramid of the remaining systems. Other forms are represented by the addition to these letters of coefficients, including the sign for infinity ($\infty$). When placed before the initial letter (*e.g.*, $m\mathrm{P}$), these coefficients indicate what multiple of the intercept of the fundamental form is cut off by the faces of the form in question on the vertical axis; but when they follow the letter, they refer to one of the lateral axes (*e.g.*, $\mathrm{P}m$). The length of the intercept on one of the axes being always reduced to the unit value, it is only necessary to give the intercepts on two axes. Thus, $m\mathrm{P}n$ indicates a form that cuts off intercepts equal to $mc$ on the vertical and $na$ or $nb$ on one lateral, the intercept on the third axis being the unit distance.

In the rhombic system, where it is necessary to distinguish between the long and short lateral axes, the signs $-$ and $\smile$ are used for this purpose by placing them above the initial letter. Thus $\bar{\mathrm{P}}m$ indicates a form that cuts off $mb$ on the macro-axis, the intercepts on the two other axes being unity; while $\breve{\mathrm{P}}m$ is a form with an intercept of $ma$ on the brachy-axis.

In the monoclinic system, again, we have to distinguish between a perpendicular and an inclined axis. This is done by placing a bar straight or obliquely through the initial letter. Thus $\text{Ꝑ}m$ indicates that $m$ refers to the ortho-axis, while in $\cancel{\mathrm{P}}m$ it refers to the clino-axis.

In the Millerian system the symbol is composed of the "indices" of the face. These are obtained by converting the multiples of the three fundamental intercepts (or parameters), for a given face, into fractions, of which the numerator is in each case 1: the denominators of these fractions are then the "indices." Thus, a face of which the ratio for the intercepts is $1a : 2b : 3c$, will have indices represented by the denominators of the fractions $\frac{1}{6}$, $\frac{1}{3}$, and $\frac{1}{2}$; and 632 will be its Millerian symbol. The symbol for the form of which (632) is one face is {632}. Naumann's symbol for this form would be $3\bar{P}2$ in the rhombic system.

The symbols of some of the principal forms, according to both systems, are given in the following table. The first column shows the multiples of the fundamental intercepts on the three axes.

### REGULAR SYSTEM.

| Name of Form. | Multiples of | | | Naumann. | Miller. |
|---|---|---|---|---|---|
| | $a$ | $a$ | $a$ | | |
| Octahedron ... ... | 1 | 1 | 1 | O | (111) |
| Cube ... ... ... | 1 | $\infty$ | $\infty$ | $\infty$ O $\infty$ | (100) |
| Rhombic dodecahedron ... ... | 1 | 1 | $\infty$ | $\infty$ O | (110) |
| Icosi-tetrahedron ... | 1 | $m$ | $m$ | $m$ O $m$ | $(h\,l\,l)$* |
| Hexakis-octahedron | 1 | $n$ | $m$ | $m$ O $n$ | $(h\,k\,l)$ |

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* The letters $h$, $k$, and $l$, are used in the Millerian symbols to represent any whole numbers, just as the coefficients $m$ and $n$ represent any rational numbers in Naumann's system. The relation between $h\,k\,l$ and $m\,n$ may be expressed thus: $m : n = \frac{h}{l} : \frac{h}{k}$.

## HEXAGONAL SYSTEM.

| Name of Form. | Multiples of | | | | Naumann. | Miller.* | Bravais. |
|---|---|---|---|---|---|---|---|
| | *a* | *a* | *a* | *c* | | | |
| Basal plane ... | ∞ | ∞ | ∞ | 1 | 0 P | (111) | (0001) |
| Pyramids ... | 1 | ∞ | $\bar{1}$ | *m* | *m* P | $(hkk, eff)$ | $(p0pq)$ |
| Prism... ... | 1 | ∞ | $\bar{1}$ | ∞ | ∞ P | $(1\bar{2}1)$ | $(10\bar{1}0)$ |
| Rhombohedron | | | | | R | $(hll)$ | |

## TETRAGONAL SYSTEM.

| Name of Form. | Multiples of | | | Naumann. | Miller. |
|---|---|---|---|---|---|
| | *a* | *a* | *c* | | |
| Basal plane ... | ∞ | ∞ | 1 | 0 P | (001) |
| Pyramids ... | 1 | 1 | *m* | *m* P | $(hhl)$ |
| Deutero-pyramids | 1 | ∞ | *m* | *m* P ∞ | $(h0l)$ |
| Prism ... ... | 1 | 1 | ∞ | ∞ P | (110) |
| Deutero-prism ... | 1 | ∞ | ∞ | ∞ P ∞ | (100) |

## RHOMBIC SYSTEM.

| Name of Form. | Multiples of | | | Naumann. | Miller. |
|---|---|---|---|---|---|
| | *a* | *b* | *c* | | |
| Basal plane ... | ∞ | ∞ | 1 | 0 P | (001) |
| Pyramids ... | 1 | 1 | *m* | *m* P | $(hhl)$ |
| Brachy-pyramids | *n* | 1 | *m* | $m\,\breve{P}\,n$ | $(hkl)\ h < k$ |
| Macro-pyramids | 1 | *n* | *m* | $m\,\bar{P}\,n$ | $(hkl)\ h > k$ |
| Prism ... ... | 1 | 1 | ∞ | ∞ P | (110) |
| Brachy-domes ... | ∞ | 1 | *m* | $m\,\breve{P}\,\infty$ | $(0kl)$ |
| Macro-domes ... | 1 | ∞ | *m* | $\mathrm{m}\,\bar{P}\,\infty$ | $(h0l)$ |
| Brachy-pinacoid | ∞ | 1 | ∞ | $\infty\,\breve{P}\,\infty$ | (010) |
| Macro-pinacoid ... | 1 | ∞ | ∞ | $\infty\,\bar{P}\,\infty$ | (100) |

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* In Miller's notation the three edges of a rhombohedron (p. 30) are taken as axes. Bravais' notation refers to four axes, three of which lie in one plane at 120° to each other, and have equal parameters (*a*), the fourth, with parameter *c*, being the vertical axis (see Fig. 17).

## MONOCLINIC SYSTEM.

| Name of Form. | | Multiples of<br>*a* | <br>*b* | <br>*c* | Naumann. | Miller. |
|---|---|---|---|---|---|---|
| Basal plane ... | ... | ∞ | ∞ | 1 | 0 P | (001) |
| Pyramids ... | ... | 1 | 1 | *m* | *m* P | (*h h l*) |
| Clino-pyramids | ... | *n* | 1 | *m* | *m* ₽ *n* | (*h k l*) $h < k$ |
| Ortho-pyramids | .. | 1 | *n* | *m* | *m* Ꝑ *n* | (*h k l*) $h > k$ |
| Prism ... | ... | 1 | 1 | ∞ | ∞ P | (110) |
| Clino-domes... | ... | ∞ | 1 | *m* | *m* ₽ ∞ | (0 *k l*) |
| Ortho-domes | ... | 1 | ∞ | *m* | *m* Ꝑ ∞ | (*h* 0 *l*) |
| Clino-pinacoid | ... | ∞ | 1 | ∞ | ∞ ₽ ∞ | (010) |
| Ortho-pinacoid | ... | 1 | ∞ | ∞ | ∞ Ꝑ ∞ | (100) |

## MODIFICATIONS IN THE SYMMETRY OF CRYSTALS.

The symmetry of the forms of the different systems is subject to certain modifications, resulting in hemihedrism, hemimorphism, and twinning. In the first two cases the degree of symmetry is diminished; in the last it is often increased.

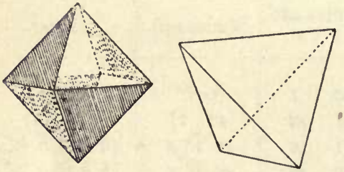

FIG. 38.—OCTAHEDRON AND TETRAHEDRON.

The suppression of the shaded faces in the former gives rise to the latter form.

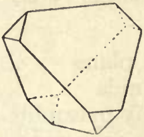

FIG. 39.—TETRAHEDRON.

With its corners truncated by a second tetrahedron.

**Hemihedrism.**—Hemihedral forms are those which possess only half the full number of faces required by the symmetry of the system to which they belong. Such forms can best be understood by reference to the full-faced (*holohedral*) form. The suppression of alternate faces, or groups of faces, in the holohedral form gives rise to a hemihedral derivative of that form. Thus, the hemihedral derivative of the octahedron is the *tetrahedron*, composed of four equilateral triangles, as exemplified in an important silver-copper ore (tetrahedrite). Another example in the regular system is the *pentagonal dodecahedron*, which may be derived from

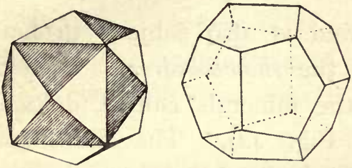

FIG. 40.—PENTAGONAL DODECAHEDRON.

Derived from the tetrakis-hexahedron by the suppression of the shaded faces.

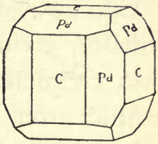

FIG. 41.—PENTAGONAL DODECAHEDRON (*Pd*).

In combination with the cube *c*.

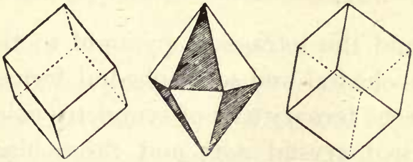

FIG. 42.—TWO KINDS OF RHOMBOHEDRA.

Derived by the suppression of alternate faces of the hexagonal pyramid.

the corresponding tetrakis-hexahedron, or six-faced cube, by the suppression of alternate faces.

Fig. 41 shows a combination of the pentagonal dodecahedron with the cube, often found in iron pyrites.

The hexagonal pyramid is also subject to hemihedrism, giving rise to the *rhombohedron*, a six-faced form characteristic of the minerals calcite, dolomite, spathic iron ore (see Fig. 42). The dihexagonal pyramid gives rise similarly to the *scalenohedron* (see Fig. 43), and the tetragonal pyramid to the sphenoid. The rhombohedral and scalenohedral forms are characterized by the ternary axis of symmetry coincident with the principal crystal axis and three binary axes of symmetry.

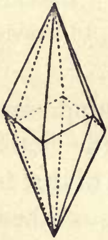

Fig. 43.—Scalenohedron.

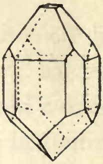

Fig. 44.—Hemimorphite.

**Hemimorphism.** — Hemimorphism is a property possessed by certain crystals of presenting different forms at the opposite ends of an axis of symmetry (generally the vertical axis), instead of being terminated similarly at both ends as in normal crystals. The phenomenon of hemimorphism is closely connected with that of pyro-electricity, since those minerals which are hemimorphic acquire positive and negative electricity at the ends or *poles* of the hemimorphic axis when warmed or cooled—*e.g.*, tourmaline and hemimorphite (silicate of zinc).

**Twinning.**—A *twin* is, as its name implies, a double crystal. The examination of a twin shows that it consists of two individual crystals, or two parts of one and the same individual, united on a common plane, or penetrating one another symmetrically. To explain this phenomenon, it is necessary to refer the two individuals to a plane—the *twinning plane*—with regard to which both are symmetrically disposed.* Now, it is found that the two twinned individuals can be brought into a position of complete parallelism if one of them be rotated through an angle of 180° on an axis (the *twin axis* $t\ t'$ in Fig. 45) perpendicular to the twinning plane. The plane which unites the two individuals (the *plane of*

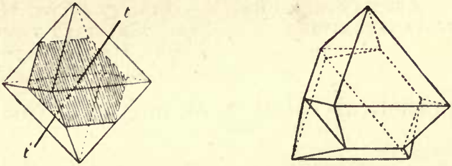

Fig. 45.—Twinned Crystal.

Produced by the rotation of one-half through an angle of 180° round the axis, $t\ t'$.

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* Note that the twinning plane can never be a plane of symmetry of the *individual* crystal *if it is holohedral;* on the other hand, it is always a possible face of the crystal.

*composition*) is often, but not necessarily, coincident with the plane of twinning. In some cases the two individuals completely penetrate one another, as in Figs. 46 and 47. These types can also be explained by a hypothetical rotation of one individual about a twin axis.

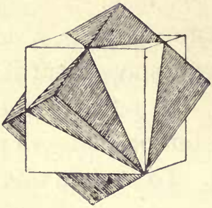
Fig. 46.—Cubes twinned by Interpenetration.

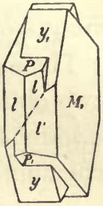

Fig. 47.—Two Monoclinic Crystals twinned by Interpenetration.

One of the most characteristic features of twinned crystals is the presence of re-entrant angles, whereas the angles of simple crystals are always salient. Twinning frequently results in the production of knee-shaped (geniculated), arrow-headed, cross- and heart-shaped forms, as in the minerals tinstone, staurolite,

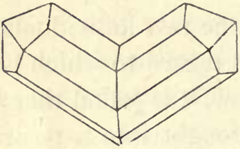
Fig. 48.—Geniculated Twin of Tinstone.

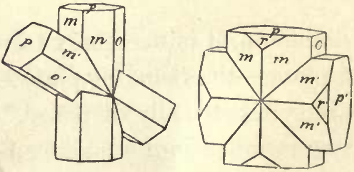

Fig. 49.—Cross-shaped Twins of Staurolite.

and gypsum (Figs. 48, 49, and 50). Sometimes the same type of twinning is repeated in one and the same crystal, producing what is termed *polysynthetic* or lamellar twinning, the lamellæ occasionally being so frequently repeated as to produce the effect of a mere striation, as in plagioclase felspar. In some cases the compound crystal has a higher degree of symmetry than the untwinned crystals; thus, rhombic and monoclinic minerals when twinned occasionally acquire pseudo-hexagonal symmetry—*e.g.*, aragonite and tridymite.

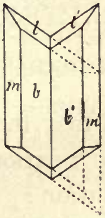

FIG. 50.—ARROW-HEADED TWIN OF GYPSUM.
The dotted part shows the position of the rotated halı in the untwinned crystal.

## CHAPTER II

## THE PHYSICAL PROPERTIES OF MINERALS

On page 2 it was stated that the physical properties of crystals bear a definite relation to their geometrical form. What is this relation? Experiment has shown that the physical properties of crystalline bodies vary in a manner dependent on their *direction in space*, and that these directions are connected with the symmetry of the crystal, or, in other words, with the symmetrical arrangement of its molecules. Thus, while a sphere of glass when warmed remains a sphere, a sphere of sulphur becomes an ellipsoid, the axes of which are related to the axes of the crystal from which the sphere was cut. The optical properties of crystals are similarly related to their symmetry. These physical properties of a crystal are termed *vector* in contradistinction to the *scalar* properties, which are independent of direction. The vector properties are related to an internal structure which may be graphically represented by an ellipsoid. For crystals belonging to the hexagonal and tetragonal systems the ellipsoid is a spheroid—*i.e.*, it is one produced by the rotation of an ellipse about one of its axes. In the regular or cubic system, the spheroid is a sphere, the generating ellipse being in this case a circle. In crystals belonging to the rhombic, monoclinic, and triclinic systems, the ellipsoid has three unequal axes. Such an ellipsoid is produced by the rotation of an ellipse about one of its axes, while the other axis is being lengthened or shortened in such a manner that its ends describe ellipses instead of circles. The triaxial ellipsoid has three planes of symmetry, which in the rhombic system are coincident with the three planes of crystal symmetry. In the monoclinic system only one of these planes is coincident with a plane of crystal symmetry, while in the triclinic system, since there is no plane of crystal symmetry, the ellipsoid is independent of the crystal form.

Amorphous bodies, on the other hand, only possess scalar properties.

In the present chapter the physical properties of minerals are considered under the following heads: MOLECULAR COHESION, AS EXEMPLIFIED BY CLEAVAGE, FRACTURE, TENACITY AND HARDNESS; PHENOMENA RELATING TO LIGHT; CHARACTERS DEPENDING ON THE ACTION OF HEAT, ELECTRICITY, AND MAGNETISM; TASTE AND ODOUR; SURFACE ENERGY; DENSITY.

## MOLECULAR COHESION.

**Cleavage.**—A piece of Iceland spar, when tapped with a light hammer, splits into a number of rhombohedral bodies of variable size but of similar form. A piece of rock-salt, similarly treated, splits into cubes. Mica, on the other hand, splits into thin laminæ. This property of crystals of separating along certain planes, related to the symmetry of the system to which the particular crystal belongs, is termed *cleavage*. It is one of the most striking of the physical properties of crystals, and one that gives important evidence as to the mode of aggregation of the crystal particles: for the separation takes place in the direction of least cohesion—*i.e.*, perpendicularly to that in which the particles exert their greatest attraction.* Planes of minimum cohesion are repeated over planes of symmetry and about axes of symmetry.

Cleavage may be considered with regard to (1) quality or degree; (2) direction.

1. *Quality or Degree.*—According to the character of the surface produced by splitting a crystallized mineral along its cleavage planes, we may distinguish between imperfect and perfect cleavage. A mineral possessing only an imperfect cleavage will, when broken, present a rough surface in which the planes of separation are frequently interrupted by cross-fractures and continued on a different level. The complete parallelism of the separated portions of the cleavage planes can be proved, however, by their being simultaneously illuminated when moved to and fro in a beam of light in such a

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* The cleavage of minerals is not to be confounded with that of rocks, which is a fissile structure due to the arrangement of the minerals constituting the rock, and in no sense a molecular structure.

manner as to reflect the rays towards the eye of the observer. A mineral with perfect cleavage will split along faces which in most cases are more smooth and even than the original faces of the crystal themselves.

2. *Direction.*—The planes of cleavage are always parallel to possible faces of the crystal; and the number of intersecting planes varies with the number of faces which make up the form in question. Thus, a mineral with octahedral cleavage will split in four different directions; with cubical, in three; with prismatic, in two (except in the triclinic system); with pinacoidal, or basal, in one. Some minerals, however, possess cleavages parallel to the faces of more than one form, and these can usually be distinguished by their different quality, or degree of perfection.

The following are examples of cleavage:

*Cubical:* rock-salt, galena.
*Octahedral:* fluorspar, diamond.
*Rhombic dodecahedral:* zinc-blende.
*Pyramidal:* sulphur.
*Prismatic:* hornblende.
*Basal:* mica, topaz.
*Pinacoidal:* gypsum.
*Domatic:* barytes.
*Rhombohedral:* calcite.
*Two cleavages:* felspar, barytes.

In all these cases the cleavage may be regarded as perfect or fairly perfect. Examples of imperfect cleavage may be found in the minerals augite and olivine.

*Planes of parting* are to be distinguished from true cleavage, as they only occur at intervals in the crystal, and are probably due to secondary twinning or incipient alteration. Planes of parting are seen, for instance, in corundum, diallage, and magnetite.

The radiating lines of easy separation known as *percussion figures*, which are obtained when a crystal face is struck with a sharp point, are closely allied to cleavage. They are particularly well exhibited by mica (see page 101).

**Fracture.**—The nature of the surface produced by breaking a mineral is also a valuable diagnostic character. Fracture, as it is termed, must not be confounded with cleavage. The former can only be produced in a direction in which cleavage is not developed; consequently, if the tendency to cleave is strongly developed in a mineral, it will be difficult to produce a true fracture.

The fracture of minerals may be described in the following terms:

*Even:* chalcedony.
*Uneven:* tourmaline.
*Conchoidal:* calcite, flint.
*Subconchoidal:* quartz.
*Splintery:* jade.
*Hackly:* copper.

**Tenacity.**—Tenacity is manifested by the behaviour of a mineral when submitted to pressure, percussion, tension, torsion, or division. According to the results obtained the mineral is said to be *brittle*, *malleable*, *ductile*, *elastic*, or *sectile*. Haidinger found that the ductility of the metals, as shown by the ease with which they could be drawn into wire, decreased in the following order: gold, silver, platinum, iron, copper, zinc, tin, lead; and their malleability, as shown by the ease with which they could be flattened out under the hammer, as follows: gold, silver, copper, tin, platinum, lead, zinc, iron.

A mineral is elastic when, after being bent, it returns to its original shape. Mica is elastic, chlorite and talc inelastic. When a mineral can be cut by a knife it is sectile; horn-silver is a familiar example.

**Hardness.** — The term "hardness" signifies the resistance offered by a body to the separation of its particles. The relative hardness of minerals may be utilized as a means of identification. It is measured by the force required to scratch (*i.e.*, to separate the superficial particles of) the mineral with a steel point, or the sharp-pointed fragment of some mineral harder than the one to be experimented upon. The results obtained from one and the same mineral are found to vary with the crystal face, and with the direction in one and the same face.

This directional variation is a function of the symmetry of the crystal, and if, on any face of a crystal, a *curve of hardness* be constructed by joining up the ends of lines drawn from a central point, whose lengths represent the hardness existing in their direction, it will be found to have the symmetry appropriate to the crystal experimented upon. Thus, the curve of hardness on the face of the cube is intersected by the trace of four planes of symmetry (see Fig. 51), and that on a face of the octahedron by the trace of three planes of symmetry (Fig. 52).

The relative *average* hardness of minerals may be expressed by reference to the following scale, devised by the Freiberg mineralogist Mohs:

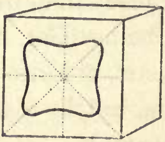

FIG. 51.

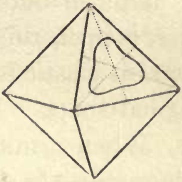

FIG. 52.

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluorspar.
5. Apatite.
6. Felspar (adularia).
7. Quartz.
8. Topaz.
9. Corundum (sapphire).
10. Diamond.

Each of these minerals can be scratched by those that follow it, and will itself scratch those that precede it in the scale.

Minerals having the hardness 1—2 can be scratched by the finger-nail; those lying between 3 and 5 by the point of the knife (with gradually increasing difficulty); 6 can scarcely be marked by the knife, but is touched by a steel file; 7 scratches glass; 8 scratches the steel file; while 9 is only to be scratched by the diamond.

These so-called "degrees of hardness" are only points arbitrarily fixed in a graduated scale. There is no constant ratio between the different numbers. Thus, the degrees of hardness of talc, gypsum, and calcite, lie within much narrower limits than those of topaz, corundum, and the diamond. Experiments made by Rosiwal, by grinding with a standard powder, showed that the relative hardness of the minerals used for the scale may be expressed by the following figures, corundum being taken at 1,000: diamond, 140,000; corundum, 1,000; topaz, 175; quartz, 120; felspar, 37; apatite, 6·5; fluorspar, 5; calcite, 4·5; gypsum, 1·25; talc, 0·33.

## PHENOMENA RELATING TO LIGHT.

**Colour.**—The colour of a mineral is either an intrinsic property—as, for instance, that of gold, copper, cinnabar, ruby-silver—or it is accidental, and due to the inclusion or admixture of a small quantity of some colouring substance, as in rose-quartz, jasper, fluorspar, some varieties of felspar (*e.g.*, the so-called amazon-stone), and most gem-stones. When powdered, most minerals show a different colour to that which characterizes them in the mass. Thus, hæmatite, which may be dark brown or black in the mass, yields powder of a cherry-red colour. This property is utilized as a test—namely, by filing off a little of the mineral, or by drawing it across the rough surface of a piece of unglazed porcelain; the resulting mark is termed the *streak* of the mineral.

The streak of a mineral is therefore the colour of its powder.

**Pellucidity.**—According to the amount of light transmitted by minerals, we may distinguish between their *transparency*, *translucency*, and *opacity*. The pellucidity of a mineral is to a certain degree dependent on its colour; for a dark colour diminishes transparency. It is also influenced by the thickness of the specimen, some minerals which are opaque in thick pieces being translucent in thin plates or splinters. The opacity of minerals is not always an inherent quality, since in some cases it is the result of decomposition, hydration, etc. (*e.g.*, the kaolinization of felspar and the serpentinization of olivine).

**Lustre.**—The lustre of a mineral is due, partly to the *degree* in which light is reflected, and partly to the *nature* of the reflected light. According to the degree or intensity of lustre, a mineral is said to be *splendent* (as blende), *shining* (as calcite), *glistening* (as magnetite), *glimmering* (as galena), or *dull* (as serpentine). According to the nature of the reflected light, the lustre is *metallic* (as in the native metals, pyrites, etc.), *submetallic* (as in pitchblende), *adamantine* (as in diamond and blende), *vitreous* (as in quartz), *greasy* (as in elæolite), *pearly* (as in diallage and bronzite), or *silky* (as in tremolite).

There are a few other phenomena, produced either by peculiarities in the reflecting surface, or by the fact that reflection takes place from surfaces in the interior of the crystal. Such, for example, are the following:

*opalescence* — a peculiar milky or cloudy appearance produced by the diffraction of light by minute fissures in the interior of a crystal (*e.g.*, opal, moonstone); *chatoyancy* — a changeable banded lustre like that of the eye of a cat. Chatoyant stones, like chrysoberyl ("cat's-eye"), when cut suitably, flash out bands of light which shift their position according to the way in which the stone is moved. This phenomenon is the result of a fibrous structure. When two or three systems of striations intersect, a star composed of four or six luminous rays is produced. This phenomenon is termed *asterism*, and is displayed by certain varieties of ruby, sapphire, garnet, and mica. *Schiller* is the name given to certain metallic and pearly lustres produced by the reflection from the surfaces of minute enclosed plates, rods, or particles (as in diallage, bronzite, hypersthene, and avanturine). *Change* or *play of colours* is a phenomenon of diffraction produced at the surface of some minerals by a fine lineation (*e.g.*, labradorite). *Iridescence* and *irisation* refer to the prismatic colours produced by the interference of light in the interior or at the surface of a mineral. In the former case the phenomenon is due to the presence of minute fissures, in the latter to the presence of a thin superficial film.

**Refraction.**—*Isotropic* media are those in which the velocity of transmission of light is independent of the direction in which the ray is transmitted. *Anisotropic* media are those in which the velocity of transmission changes with the direction.

Gaseous, fluid, and amorphous substances and crystals of the regular system are isotropic; substances crystallizing in the tetragonal, hexagonal, rhombic, monoclinic, and triclinic systems are anisotropic.

In one and the same homogeneous isotropic substance light is transmitted without change of direction and without change in the velocity of transmission; but in passing from one isotropic medium to another the velocity of light is changed, and there is consequently a change in direction, except in the particular case when the incident ray is normal to the plane separating the two media. This deflection of a ray of light in passing from one medium to another is termed *refraction.* The law of refraction may be formulated thus: *In passing from an optically rare to an optically dense medium a ray of light is refracted or bent towards the normal to the bounding surface, and the angle of refraction bears a constant relation to the angle of incidence for the same two media.* This constant ratio is the *index of refraction,* and may be expressed thus:

$$n = \frac{\text{sine of angle of incidence}}{\text{sine of angle of refraction}}.$$

As generally used, it refers to the index of refraction of an isotropic substance as compared to air.

Since the velocity of light varies inversely with the density of the medium, the refractive index is inversely proportional to the velocity.

The amount of deflection suffered by the incident ray when refracted depends also on its wave-length.

It is consequently different for rays of different colour. Refraction is therefore accompanied by *dispersion*, by which white light is resolved into the component colours of the spectrum.

Now consider the case of light travelling from a denser to a rarer medium. Since in this case the refracted ray is deflected from the normal to the bounding surface, there must be a certain angle of incidence for which the deflected ray is parallel to the bounding surface. This angle, which varies in different substances, but is constant for one and the same substance, is known as the *critical angle.*

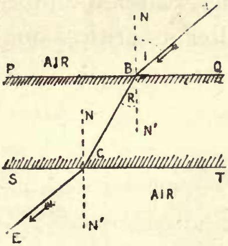

FIG. 53.—DIAGRAM ILLUSTRATING THE PHENOMENON OF REFRACTION.

*PQ* and *ST*, the parallel bounding surfaces of a plate of an isotropic substance in air; *AB*, the incident ray in air; *BC*, the refracted ray in a denser isotropic medium; *CE*, the course of the ray in emerging from the denser medium again into air (*CE* is parallel to *BA*); *NN'*, the normal to the bounding plane between the two media; *i*, angle of incidence; *r*, angle of refraction.

A ray of light, traversing a denser medium, and coming upon the bounding plane with a rarer medium at the critical angle, continues its course on emergence parallel to that plane (see Fig. 54).

If the ray in the denser medium strikes the bounding plane with a rarer medium at an angle greater than the critical angle, it undergoes *total reflection* (see Fig. 55).

Since in the first case

$$n = \frac{\sin 90^\circ}{\text{sine of critical angle}},$$

and $\sin 90^\circ = 1$,

$$n = \frac{1}{\text{sine of critical angle}}.$$

Consequently, the greater the index of refraction of a substance, the smaller its critical angle.

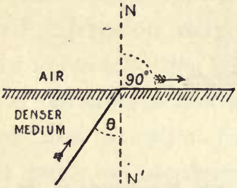

FIG. 54.—DIAGRAM SHOWING THE PATH OF A RAY WHICH MEETS THE BOUNDING SURFACE WITH A RARER MEDIUM AT THE CRITICAL ANGLE ($\theta$).

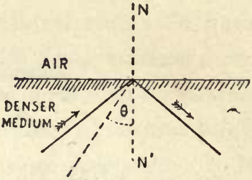

FIG. 55.—DIAGRAM SHOWING THE PATH OF A RAY WHICH MEETS THE BOUNDING SURFACE WITH A RARER MEDIUM AT AN ANGLE OF INCIDENCE GREATER THAN THE CRITICAL ANGLE ($\theta$).

The following are examples of this relation:

| Substance. | Index of Refraction. | Critical Angle. |
|---|---|---|
| Water ... | 1·33 ... | 48° 35′ |
| Glass ... ... | 1·53 ... | 40° 45′ |
| Diamond ... | 2·42 ... | 24° 25′ |

The small critical angle of the diamond explains why so much light is reflected from the interior facets of a brilliant; and the fact that this reflection is accompanied by a large amount of dispersion of the coloured rays, determined by its high refractive index, accounts for the "fire" of this precious stone.

**Double Refraction and Polarization.**—When a ray of light passes from an isotropic medium into an anisotropic medium, the incident ray is separated into two rays, which traverse the anisotropic medium in different directions and at different velocities. Further, each ray is *polarized—i.e.*, its vibrations, instead of being in all azimuths at right angles to the direction in which the light travels, are now confined to one plane; and the planes of polarization or vibration of the two rays are at right angles to one another. This is the phenomenon of *double refraction.* The passage of the two rays through the anisotropic medium is regulated in accordance with the elasticity of the particular medium; and the distribution of the elasticity—or, in other words, the nature of the figure of elasticity—is a function of the symmetry of the system in which the substance crystallizes. We have to distinguish between crystals with a principal axis (tetragonal and hexagonal), and those without a principal axis (rhombic, monoclinic, and triclinic).

**Uniaxial Crystals.**—As explained on page 34, the figure of elasticity for crystals of the tetragonal and hexagonal systems, which have a principal axis, is a spheroid; in other words, sections at right angles to the principal axis are circles, all other sections being ellipses. Both the velocity and the direction of vibration of the two rays produced by double refraction in this class of crystals are represented by the cross-section through the centre of the spheroid of elasticity at right angles to the incident ray. The vibrations of the rays take place respectively parallel to the greatest and least diameters of the section, and the lengths of these express the velocity of the rays. Since the section at right angles to the principal axis is a circle, and all diameters are equal, rays which enter the crystal parallel to this axis traverse it as through an isotropic medium—*i.e.*, without double refraction. This axis is distinguished as the *optic axis*, and crystals of the tetragonal and hexagonal systems are said to be *uniaxial*.

Every other section is an ellipse, which is the more elongated the greater the angle made by the incident ray with the principal axis. In all the ellipses, however, the one diameter remains equal to the diameter of the circular section. The refracted ray which vibrates parallel to this diameter travels with a constant velocity, and has a constant index of refraction (designated by $\omega$). It is called the *ordinary* ray (O).

Since the length of the second diameter* varies with the inclination of the incident ray to the principal axis, the ray vibrating parallel to it travels with a similarly varying velocity, and has, therefore, no constant index of refraction. The latter reaches its maximum or minimum value when the incidence is at right angles to the principal axis. The ray vibrating parallel to the second diameter is known as the *extraordinary ray* (E), and its

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* It will be either the major or the minor axis of the ellipse, according as the spheroid is *prolate* or *oblate*.

maximum or minimum index of refraction is represented by $\epsilon$. As with $n$, both $\omega$ and $\epsilon$ have a different value for differently coloured light. If the principal axis is the axis of greatest elasticity (in the case of a prolate spheroid), the crystal is said to be optically *negative*, and the refractive index of the ordinary ray is greater than that of the extraordinary ray ($\omega > \epsilon$). If, on the contrary, the principal axis is the axis of least elasticity (in the case of an oblate spheroid), the crystal is optically *positive*, and $\epsilon$ is greater than $\omega$.*

**Wave Surface.**—The relation between the ordinary and the extraordinary ray in a uniaxial crystal can be best understood by a consideration of the nature of the wave surfaces produced by the propagation of the two sets of rays.

Suppose a luminiferous wave motion initiated within a uniaxial crystal. Two sets of rays (the ordinary and the extraordinary) will be propagated outward through the crystal in all directions. After a given interval of time, imagine all the points to which the light has travelled in that period of time united by a surface (*wave surface*), one for each set of rays. The wave surface for the ordinary rays will be the surface of a sphere, because these rays travel with equal velocity in all directions. That uniting the extraordinary rays will be the surface of a spheroid, the shape of which will be the inverse of the spheroid of elasticity for the crystal

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* In positive crystals $\epsilon - \omega$ has a positive value; in negative crystals it has a negative value. $\pm(\epsilon - \omega)$ is a measure of the double refraction.

in question;* that is to say, its major axis, which is the maximum distance travelled in the given period of time, will be at right angles to the major axis of the spheroid of elasticity, since the latter represents the direction in which the vibrations take place, and is proportional to the velocity of propagation.

Since in *negative* uniaxial crystals the axis of greatest elasticity coincides with the principal axis, in these crystals the extraordinary ray will be propagated with the greatest velocity in a direction at right angles to the principal axis, while it will travel with its minimum velocity in the direction of this axis, and this minimum velocity will also be the velocity of the ordinary ray. In other words, the wave surfaces of the two sets of rays will be tangential at a point on the principal axis, and the sphere will be enclosed by the spheroid.

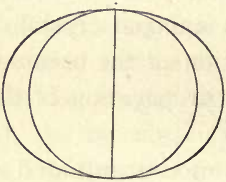

Fig. 56.—Diagram of the Wave Surfaces of the Ordinary and Extraordinary Rays in a Negative Uniaxial Crystal.

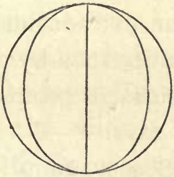

Fig. 57.—Diagram of the Wave Surfaces of the Ordinary and Extraordinary Rays in a Positive Uniaxial Crystal.

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* In other words, the wave surface of the extraordinary rays is a prolate spheroid for crystals, in which the spheroid of elasticity is oblate, and *vice versa*.

On the other hand, in positive uniaxial crystals, in which the axis of least elasticity coincides with the principal axis, the extraordinary ray has its greatest velocity in the direction of this axis, and this greatest velocity is equal to that of the ordinary ray. The two wave surfaces are therefore also tangential at a point on the principal axis, but the spheroid is in this case enclosed by the sphere.

It is useful to note as a *memoria technica* that the shape of Fig. 56 recalls the negative sign, and that of Fig. 57 the positive sign.

**Biaxial Crystals.**—In crystals of the rhombic, monoclinic, and triclinic systems, which have no principal axis, the elasticity is represented by an ellipsoid with three unequal axes (Fresnel's ellipsoid). The three axes of elasticity are at right angles to one another, and are known respectively as the axis of greatest elasticity (𝔞), the axis of mean elasticity (𝔟), and the axis of least elasticity (𝔠).

There are two directions in crystals belonging to these systems in which there is no double refraction; from analogy with uniaxial crystals these directions are called *optic axes*, and the crystals which possess them *biaxial crystals.* In biaxial crystals the optic axes do not coincide with axes of elasticity, but they are in the plane of, and are symmetrical to, the axes of greatest and of least elasticity. The axis of mean elasticity is therefore the normal to the *plane of the optic axes.* When the axis of greatest elasticity is the acute bisectrix of the angle between the optic axes, the crystal is said to be *negative;*

when the axis of least elasticity is the acute bisectrix, it is *positive.* The smaller the optic axial angle, the nearer does the *optic character* of a biaxial crystal approximate to that of a uniaxial crystal. The angle between the optic axes is designated by $2V$.* It varies slightly with the wave-length, and consequently with the colour of the light. Thus, for diopside $2V = 58^\circ 52'$ for red (Li) light, $58^\circ 43'$ for yellow (Na) light, and $58^\circ 30'$ for green (Tl) light. This phenomenon is known as the *dispersion of the optic axes.*

Every ray which enters a biaxial crystal in any direction other than an optic axis is separated into two rays, which are polarized in planes at right angles to one another, and travel with different velocities, and in different directions. The direction of vibration and the velocity of transmission are represented by the axes of the elliptical section of the ellipsoid of elasticity taken through the centre, and at right angles to the incident ray. Each of the refracted rays has a velocity of transmission which varies with the angle of incidence; there is therefore no constant index of refraction. Three principal indices of refraction are, however, distinguished —namely: $\alpha$, the index of refraction for rays vibrating parallel to the axis of greatest elasticity ($\mathfrak{a}$); $\beta$, the index of refraction for rays vibrating parallel to the axis of mean elasticity ($\mathfrak{b}$); and $\gamma$, the index of refraction for rays

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* As observed in air, the optic axes appear to include a larger angle on account of the refraction of the light travelling along on emergence into air. This *apparent axial angle* in air is denoted by $2E$.

vibrating parallel to the axis of least elasticity ($\mathfrak{c}$); and since the velocity of transmission in these directions is represented by the lengths of the axes $\mathfrak{a}$, $\mathfrak{b}$, and $\mathfrak{c}$, $\mathfrak{a}=\frac{1}{\alpha}$, $\mathfrak{b}=\frac{1}{\beta}$, and $\mathfrak{c}=\frac{1}{\gamma}$. $\beta$ is usually taken as the measure of refraction of a biaxial mineral,* but some authors give $\frac{\alpha+\beta+\gamma}{3}$. $\gamma-\alpha$ is a measure of the double refraction.

Crystals of the rhombic, monoclinic, and triclinic systems can be distinguished from one another by the orientation of the ellipsoid of elasticity with regard to the crystal axes.

In the rhombic system each of the three axes of elasticity ($\mathfrak{a}$, $\mathfrak{b}$, and $\mathfrak{c}$) coincides with a crystal axis, and the plane of the optic axes lies in one of the pinacoids.

In the monoclinic system only one of the crystal axes—namely, the ortho-axis (*b*), which is normal to the one plane of symmetry—coincides with an axis of elasticity. The two remaining axes of elasticity lie in the clino-pinacoid (the plane of symmetry). If the ortho-axis (*b*) coincides with the axis of mean elasticity,

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* The index of refraction may be determined by measuring with a goniometer the angle of least deviation of light traversing a prism of the substance, or, for substances whose refractive index is not too high, by measuring the angle of total reflection when the substance is immersed in a denser liquid or placed against a glass prism. It may also be determined by immersion of the substance in a liquid of known refractive index, one with a refractive index approximating to that of the substance under examination being selected by experiment. The behaviour of the light band at the contact of the two media, when tested by Becke's method, determines whether the substance has a higher or a lower refractive index than the liquid in which it is immersed.

the optic axial plane lies in the clino-pinacoid. If the ortho-axis (*b*) coincides with the axis of greatest, or of least, elasticity, the plane of the optic axes lies normal to the clino-pinacoid.

In the triclinic system none of the axes of elasticity coincides with a crystal axis, for the reason that the crystal axes are chosen arbitrarily, there being no plane or axis of symmetry to dictate a choice.

**Absorption of Light—Pleochroism.**—It is found as the result of experiment that light in passing through a crystal becomes partly absorbed, and, further, that the absorption varies with the direction of vibration within the crystal, or, in other words, that light of a given colour is more absorbed when polarized in one plane than in another. Since the plane of polarization varies with the direction of transmission, crystals which possess the power of absorption in a marked degree will, if white light be used, transmit light of a different colour in different directions. Thus, a crystal of cordierite will, when viewed in transmitted light, appear blue in one direction, and yellow in another. This phenomenon is known as *pleochroism.* If light vibrating in one plane (*i.e.*, polarized light) be transmitted through a pleochroic biaxial mineral, parallel to each axis of elasticity in turn, three distinct colours are obtained, and these are known as the axial colours. In the case of cordierite they are—

Yellow for rays vibrating parallel to $\mathfrak{a}$.
Light blue „ „ „ $\mathfrak{b}$.
Dark blue „ „ „ $\mathfrak{c}$.

Uniaxial crystals are *dichroic* only.

## THERMAL, ELECTRIC, AND MAGNETIC PROPERTIES.

**Thermal Properties.**—The *conductivity for heat* of minerals is related to the symmetry of the system in which they crystallize. That it varies with the direction can be shown by the following experiment: if a cleavage surface of stibnite (a rhombic mineral with brachypinacoidal cleavage) be coated with a thin film of wax and touched with the point of a heated wire, the melted portion of the wax will be found to have the shape of an ellipse, the major axis of which coincides with the vertical axis of the crystal, and the minor axis with the brachydiagonal—a phenomenon consistent with the symmetry of a rhombic crystal. *Specific heat,* although a valuable constant of minerals, is not much used in determinative mineralogy, by reason of the extreme care required for its determination. It is defined as the ratio of the quantity of heat required to raise the temperature of the mineral one degree to the quantity of heat required to raise the temperature of an equal mass of water one degree. Of more service, because readily observed, is the *degree of fusibility,* or the ease with which substances fuse when submitted to the action of heat. A splinter of the mineral is held with the platinum forceps in the flame of a Bunsen burner or of a blowpipe. Its fusibility is determined by comparison with the following substances (Von Kobell's scale *):

1. *Stibnite.*—A rather large fragment fuses easily in the gas flame.

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* As modified by Penfield.

2. *Chalcopyrite.*—A fragment of the standard size (diameter 1·5 millimetres) fuses rather slowly in the gas flame.

3. *Almandine Garnet.*—A fragment of the standard size fuses readily to a globule before the blowpipe.

4. *Actinolite.* — The edges of a fragment of the standard size are readily rounded before the blowpipe.

5. *Orthoclase.* — The edges of a fragment of the standard size are rounded with difficulty before the blowpipe.

6. *Bronzite.* — Only the finest points are rounded before the blowpipe.

**Electrical Properties.**—The electrical conductivity of minerals is a very variable factor. The best conductors are the metals, and, among compounds, those which possess metallic lustre, like pyrites, chalcopyrite, galena, hæmatite, etc. On the other hand, minerals like quartz, felspar, calcite, barytes, fluorspar, garnet, are poor conductors. A process for the separation of metallic minerals from their gangue is founded on these differences in conductivity. In the *electrostatic separation* process the dry mixture of metallic mineral particles and gangue mineral grains, such as quartz, while in a neutral electrical state, are brought into contact with a surface highly charged with electricity; the metallic particles, because they conduct electricity readily, become charged to the same condition as the surface, and fly from it; the quartz particles, on the other hand, require a longer time to receive the charge, and therefore cling to the surface until they have acquired the same electrical condition.

This difference in the behaviour of the two classes of material permits a separation to be made by a suitable arrangement of machinery.

Some minerals, and especially those which are hemimorphic, become electrified when heated or cooled. This phenomenon is known as *pyro-electricity.* It is manifested by the presence of statical changes at opposite ends of the crystal—positive at one, and negative at the other.

**Magnetic Properties.** — The property of being attracted by a magnet is possessed in greater or less degree by all minerals which contain iron, and this property can be made use of in the separation of powdered mixtures of minerals. The process of magnetic separation by means of the electro-magnet has been successfully applied to ore-dressing operations, and the method is advantageously used in laboratory investigations of sands and rocks to effect the isolation of minerals for chemical analysis. For laboratory work the sands are sifted to a uniform size, and the rock crushed to grains not exceeding 0·25 millimetre, the powder being removed by washing. Minerals having a high magnetic permeability, such as magnetite, pyrrhotite, and hæmatite, are first removed by a weak permanent magnet (an operation which is facilitated by covering the poles with a movable paper cap). The minerals of which iron is a constituent can then be removed from the non-ferriferous minerals, and also separated from one another, by regulating the intensity of the field of an electro-magnet by the suitable adjustment of movable pole-pieces.*

In this way, for example, the pyroxene, olivine, hornblende, and biotite, can be separated from the plagioclase felspar with which they are associated in an olivine gabbro, or monazite can be separated from zircon and quartz in a " monazite sand."

## TASTE AND ODOUR.

Only those minerals which are to some extent soluble in water have a **taste**. Examples of such minerals are salt, soda, Epsom salt, alum, nitre.

**Odour** is emitted from some minerals when they are rubbed, struck with a hammer, or heated. Sulphur compounds are characterized by the familiar fœtid odour of sulphuretted hydrogen or by the choking smell of sulphurous acid. Arsenic compounds (like mispickel) have a smell of garlic. There are also characteristic clayey and bituminous odours that are emitted by argillaceous and bituminous minerals.

## THE SURFACE ENERGY OF MINERALS.

The condition of molecular equilibrium established at the free surface of a substance is known as its **surface energy**. It is a function of internal cohesion, and, consequently, is generally greater in solids than in

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* For details of the process, see T. Crook, *Science Progress*, 1907, p. 18.

liquids. In solids it is responsible for the phenomenon known as the *surface condensation of gases;* in liquids it manifests itself as *surface tension.* The surface tension of liquids tends to make them occupy the least space possible in proportion to their mass, and to this is due the inclination of liquids towards the globular form, which reaches its maximum development in mercury. The surface tension of mercury is, of course, exceptionally high among liquids. After mercury comes water; oils have a low surface tension relatively to water. Among solids, the surface energy is greatest in elements, such as the metals, graphite, etc.; and it is manifested in these by the power of condensing gases at the surface, as exemplified by spongy platinum, finely divided carbon, etc. Next to the elements, the sulphides of the heavy metals have the highest surface energy; while the compounds of the non-metals and of the light metals (such as quartz, felspar, calcite, etc.) are deficient in that respect.

When a solid substance is in contact with a liquid, whether it will draw up or depress the liquid in its immediate neighbourhood depends on the ratio between the surface energies of the two substances. The angle of contact made by the liquid with the solid is therefore a measure of the ratio between the surface energies of the solid and the liquid. Since the phenomenon of wetting is brought about by the strong surface energy of the solid overcoming the relatively weak surface tension of the liquid and its internal cohesion, the degree of wetting is also measured by the contact angle (or "wetting angle"). When into water in which a small quantity of oil is present a mixture of solids is introduced, there is a selective wetting by the oil of the solid substances that have a high surface energy. On this principle is based the separation of metals and metallic sulphides from their gangue minerals by the so-called "oil-concentration processes." The separation is assisted by agitation, by means of which air or other gaseous bubbles are induced to form on the oily mineral particles, and they are thus enabled to float on the water in which the gangue minerals, free from oil, are sunk by gravity.

The oil process can be most advantageously used for separating minerals whose difference in density is insufficient to permit of the application of the usual concentration by gravitation methods. Thus chalcopyrite may be separated from magnetite, galena and blende from barytes, sulphides of copper from oxide of tin, etc.

Similarly, when a diamantiferous "deposit" is washed over a grease-coated surface, the diamonds are retained, while the accompanying minerals are carried away by the water.

## DENSITY.

**Density** is the mass of a unit volume. On the centimetre-gramme-second system it is expressed as grammes per cubic centimetre. The *specific gravity* of a substance is the ratio of its density to that of water at 4° C. The mass of a cubic centimetre of pure water at 4° C. and under normal pressure being 0·999973 gramme, "specific gravity" is for all practical purposes identical with "density." It is usually determined by weighing the body first in air and then in water: the difference is the weight of a mass of water equal in bulk to the body; and this difference divided into the weight in air is the specific gravity. Another method, which is very serviceable in cases where the density is not above 3·3, is to make use of one of the so-called "heavy liquids." The concentrated solution is diluted, by the gradual addition of water, until a fragment of the mineral under examination remains just suspended. Its specific gravity is then determined either by weighing a measured volume or by the Westphal balance. By an adroit adjustment of the strength of such a solution, it may be used as a means of separating a mixture of minerals of different density, such as are found associated in rocks.

The best known heavy liquids are the following: Sonstadt's aqueous solution of iodide of potassium and mercury (maximum density 3·18); Klein's aqueous solution of borotungstate of cadmium (maximum density 3·28); Braun's solution—methylene iodide (maximum density 3·32); Retger's solution — thallium-mercuronitrate (liquid at 76° C. with a density of 5·0). A useful liquid for a preliminary removal of the light minerals is bromoform (maximum density 2·9). It has the advantage of being cheap, and it is cleaner and less sticky than some of the above-mentioned liquids.

If minerals be arranged according to their density, it will be found that the native metals rank as the heaviest. Gold is 19 (sinking to 15 in proportion as it is alloyed with copper and silver); platinum, 17; mercury, 13·6; lead, 11·37; silver, 10·6; copper, 8·84. Next come the metallic ores—*e.g.*, cinnabar, 8·1; galena, 7·5; cassiterite or tinstone, 6·9; mispickel, 6·05; cuprite, 6·0; chalcocite, 5·75; bornite, 5·2; magnetite, 5·17; pyrites, 5·03; ilmenite, 4·84; chalcopyrite, 4·2; blende, 4·06; chalybite, 3·86; limonite, 3·8.

Among minerals that are not compounds of the heavy metals, barytes takes the first place, with a density of 4·48; apatite is 3·2; fluorspar, 3·18; calcite, 2·72; gypsum, 2·32; rock-salt, 2·14; sulphur, 2·07; graphite, 2·16.

The common rock-forming minerals have a density between 3·5 and 2·5: thus the pyroxenes range from 3·5 to 3·27; olivine is 3·4; the amphiboles vary from 3·4 to 2·9; the micas from 3·2 to 2·7; the felspars from 2·76 to 2·56; while quartz is 2·65.

The gems vary from 4·6 to 2·2: thus zircon is 4·69; the garnets range from 4·3 to 3·15; corundum (sapphire and ruby) is 4·0; topaz, 3·53; diamond, 3·52; turquoise, 2·75; emerald, 2·7; opal, 2·2.

Thus it will be seen that the metallic ores betray themselves, even to the casual observer, by their great relative weight, a fact which is naturally of inestimable value.

Most of the ore-dressing processes are based on the relatively high density of the valuable metallic ores as compared with their associated gangue minerals. The principle of "gravity concentration" is made use of in a variety of ways—in dollies, jigs, pulsators, percussion and shaking tables, and in the hydraulic sluicing of alluvial gold and tin-ore; while the prospector applies it daily in the simple process of washing gold or other ores in the pan, the batea, or on the vanning shovel.

Among precious stones density is also of great importance, since it enables the jeweller to determine with certainty whether a given stone is really what its colour and general appearance may indicate.

# CHAPTER III

## CHEMICAL COMPOSITION

MINERALS are either simple *elementary* substances such as gold, sulphur, and diamond, or they consist of *compounds* in which the elements are in certain fixed proportions.

The elements are divided by chemists into *metals*, of which the most important are gold, platinum, silver, tin, copper, lead, mercury, iron, nickel, cobalt, zinc, manganese, aluminium, barium, calcium, magnesium, potassium, and sodium; and *non-metals*, such as oxygen, sulphur, nitrogen, phosphorus, chlorine, fluorine, carbon, silicon. Of the metals, only gold, platinum, silver, lead, copper, mercury, and iron (rare), occur native.

With regard to the *compound* substances occurring in Nature, these are either compounds of the metals with simple non-metallic elements, such as oxygen, sulphur, arsenic, and the halogens (chlorine, fluorine, etc.), or they are oxy-salts (and sulpho-salts). The compounds with the simple non-metals are known as oxides, sulphides (and sulphur salts), arsenides, chlorides, fluorides, etc.; while the oxy-salts (and sulpho-salts) are supposed to be derived from the corresponding oxy-acids (and sulph-acids) by the replacement of their hydrogen by metals. Thus—

*Nitrates* are formed from hydrogen nitrate or nitric acid—$HNO_3$.

*Carbonates* are formed from hydrogen carbonate or carbonic acid—$H_2CO_3$.

*Sulphates* are formed from hydrogen sulphate or sulphuric acid—$H_2SO_4$.

*Metaborates* are formed from hydrogen metaborate or metaboric acid—$HBO_2$.

*Phosphates* are formed from hydrogen phosphate or phosphoric acid—$H_3PO_4$.

*Orthosilicates* are formed from hydrogen orthosilicate or orthosilicic acid, $H_4SiO_4$.

*Metasilicates* are formed from hydrogen metasilicate or metasilicic acid—$H_2SiO_3$.

Hydrogen, in combination with oxygen, also enters into the combination of a great number of minerals (hydrates) as "water of constitution" and "water of crystallization."

The compound which plays by far the largest part in the constitution of the earth's crust is silicon dioxide or silica (*i.e.*, a compound of silicon with oxygen, $SiO_2$), which either in the free state as colloidal silica or as quartz, or in combination with metallic bases as silicates, forms more than half the solid crust, and enters into the composition of nearly all its component rocks. Next in importance is alumina, which is an oxide of aluminium. In union with silica, it constitutes the basis of an important series of silicates (felspar, mica, clay, etc.), which are the chief ingredients of a great number of rocks. Carbon dioxide often appears in combination with lime or magnesia, forming immense deposits of limestone and dolomite.

Lime (oxide of calcium), besides being present as a carbonate in limestone, occurs, in combination with sulphuric acid, in anhydrite and gypsum. Other compounds which largely enter into the composition of the rock-forming minerals are magnesia and the alkalies—potash and soda.

Iron and manganese play a part of great importance in many rocks. The oxides and salts of iron may be said to constitute Nature's colour-box; for the rich shades of yellow, red, and brown, which are so effective in coast scenery, and are seen wherever bare rock is exposed, are chiefly due to iron. The deep chocolate colour of some soils, and the varied colours of sands, are to be ascribed to the same cause. Manganese is widely distributed in marine sediments, as has been demonstrated by the *Challenger* researches of Murray and Renard; and like iron, its oxides are a common surface deposit.

**Polymorphism.** — There are several instances of minerals that differ in crystalline form and physical properties, but are identical in chemical composition. The property by which one and the same chemical substance has the power of appearing in two or more different states of molecular aggregation is termed *polymorphism.* Calcite and aragonite (both carbonate of lime), and rutile, anatase, brookite (all titanic acid), are familiar instances. The former is a case of *dimorphism*, the latter of *trimorphism*.

**Isomorphism.** — Isomorphous minerals are those which, having a similar chemical composition, crystallize in identical or closely related forms, and are capable of forming homogeneous *mixed crystals—e.g.*, barytes (sulphate of barium), celestite (sulphate of strontium), and anglesite (sulphate of lead), all of which crystallize in allied rhombic forms. The phenomenon of isomorphism points to a close connection between the atomic constitution of the molecule and the arrangement of the latter in the structure of the crystal.

**Pseudomorphism.**—In the mineral kingdom there are certain substances which exhibit the form of one mineral while possessing the chemical composition and molecular structure of another. These remarkable bodies are termed *pseudomorphs*. Although arising from various causes, they are all due to some secondary process which acts on the original mineral in such a way as to remove or decompose its substance, while retaining its crystal form. Pseudomorphs are classified according to their mode of origin. Quartz is sometimes found in crystal forms characteristic of the mineral calcite ; and tinstone, in the form of felspar: these are pseudomorphs produced by *replacement*, molecule by molecule. Galena, which is sulphide of lead crystallizing in the regular system, is occasionally found presenting the crystal form of pyromorphite (phosphate of lead crystallizing in the hexagonal system): this is a case of pseudomorphism produced by *chemical change.* Other pseudomorphs are produced by *incrustation—i.e.*, the deposition of one mineral in regular layers on the faces of already existing crystals of another (for instance, quartz on chalybite). These are termed *epimorphs.* In the special case, where a change in molecular structure takes place without a corresponding change in chemical composition, such as brookite (titanium dioxide) to rutile (also titanium dioxide), the pseudomorphs are termed *paramorphs.*

**Classification by Chemical Composition.**—In the following list the more important mineral species are classified according to their chemical composition. Those that occur most commonly are distinguished by being printed in heavy type.

## I. THE NATIVE ELEMENTS.

### A. NATIVE METALS AND ALLOYS.

**Gold,** Au.
**Silver,** Ag.
Electrum—gold-silver alloy, Au,Ag.
**Copper,** Cu.
Iron, Fe.
Lead, Pb.
Platinum, Pt.
Iridosmine—iridium-osmium alloy, Ir,Os.
Mercury, or Quicksilver, Hg.

Amalgam—silver-mercury alloy, Ag,Hg.
Arsenic, As.
Antimony, Sb.
Allemontite—antimony-arsenic alloy, Sb,As.
Bismuth, Bi.

### B. NON-METALS.

**Sulphur**, S.
**Diamond**, C (regular).
**Graphite**, C (pseudo-hexagonal).

## II. THE COMPOUNDS OF METALS WITH ELEMENTS OF THE ARSENIC AND SULPHUR GROUPS.

### A. ARSENIDE GROUP.

Niccolite—arsenide of nickel, NiAs.
Smaltite—diarsenide of cobalt, $CoAs_2$.
Chloanthite—diarsenide of nickel, $NiAs_2$.
Sperrylite—diarsenide of platinum, $PtAs_2$.

### B. MONOSULPHIDE GROUP.

Argentite—monosulphide of silver, $Ag_2S$.
**Blende**—monosulphide of zinc, ZnS.
**Galena**—monosulphide of lead, PbS.
**Chalcocite**, or Copper Glance—monosulphide of copper, $Cu_2S$.
Stromeyerite—monosulphide of copper and silver $(Cu,Ag)_2S$.
**Cinnabar**—monosulphide of mercury, HgS (hexagonal).
Metacinnabarite—monosulphide of mercury, HgS (regular).

Millerite—monosulphide of nickel, $NiS$.

Alabandite—monosulphide of manganese, $MnS$.

**Pyrrhotite**, or Magnetic Pyrites—monosulphide of iron, $FeS$.

**Realgar**—monosulphide of arsenic, $AsS$.

### C. DISULPHIDE GROUP.

Hauerite—disulphide of manganese, $MnS_2$.

**Pyrites**—disulphide of iron, $FeS_2$ (cubic).

**Marcasite**—disulphide of iron, $FeS_2$ (rhombic).

**Molybdenite**—disulphide of molybdenum, $MoS_2$.

Sylvanite—telluride of gold and silver $(Au,Ag)Te_2$.*

### D. SESQUISULPHIDE GROUP.

**Stibnite**, or Antimonite—sesquisulphide of antimony, $Sb_2S_3$.

Bismuthinite, or Bismuth Glance—sesquisulphide of bismuth, $Bi_2S_3$.

**Orpiment**—sesquisulphide of arsenic, $As_2S_3$.

### E. ARSENOSULPHIDE GROUP.

Cobaltite, or Cobalt Glance, $CoAs_2.CoS_2$.

Gersdorffite, or Nickel Glance, $NiAs_2.NiS_2$.

**Mispickel**, or Arsenopyrite, $FeAs_2.FeS_2$.

### F. SULPHUR SALTS.

**Bornite**, or Erubescite—sulphoferrite of copper, $3Cu_2S.Fe_2S_3$.

**Chalcopyrite**, or Copper Pyrites—sulphoferrite of copper, $Cu_2S.Fe_2S_3$.

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* Included here on account of the close relationship of tellurium to sulphur.

Polybasite—sulphantimonite of silver and copper, $9(Ag,Cu)_2S.Sb_2S_3$.

Pearceite—sulpharsenite of silver and copper, $9(Ag,Cu)_2S.As_2S_3$.

Stephanite—sulphantimonite of silver, $5Ag_2S.Sb_2S_3$.

**Tetrahedrite**, or Grey Copper — sulphantimonite of copper, $3Cu_2S.Sb_2S_3$.

Tennantite—sulpharsenite of copper, $3Cu_2S.As_2S_3$.

Bournonite—sulphantimonite of lead and copper, $2PbS.Cu_2S.Sb_2S_3$.

Pyrargyrite—sulphantimonite of silver, $3Ag_2S.Sb_2S_3$.

Proustite—sulpharsenite of silver, $3Ag_2S.As_2S_3$.

Enargite—sulpharseniate of copper, $3Cu_2S.As_2S_5$.

Freieslebenite — sulphantimonite of lead and silver, $5(Pb, Ag_2)S.2Sb_2S_3$.

## III. THE COMPOUNDS OF METALS WITH ELEMENTS OF THE CHLORINE GROUP.

### A. Simple Chlorides, etc.

**Rock-salt**—chloride of sodium, $NaCl$.

**Sylvite**—chloride of potassium, $KCl$.

Sal Ammoniac—chloride of ammonium, $(NH_4)Cl$.

Kerargyrite, or Horn Silver—chloride of silver, $AgCl$.

Embolite—bromochloride of silver, $Ag(Br,Cl)$.

**Fluorspar**, or Fluorite—fluoride of calcium, $CaF_2$.

### B. Compound Chlorides, etc.

**Cryolite**—double fluoride of aluminium and sodium, $3NaF.AlF_3$.

Carnallite—hydrated double chloride of potassium and magnesium, $KCl.MgCl_2 + 6H_2O$.

### C. OXYCHLORIDES, ETC.

Matlockite—oxychloride of lead, $PbCl_2.PbO$.
Mendipite—oxychloride of lead, $PbCl_2.2PbO$.
Atacamite—hydrated oxychloride of copper, $CuCl_2.3Cu(OH)_2$.

## IV. THE COMPOUNDS OF METALS WITH OXYGEN.

### A. MONOXIDE GROUP.

**Cuprite**, or Ruby Copper—monoxide of copper, $Cu_2O$.
**Zincite**, or Spartalite—monoxide of zinc, $ZnO$.
**Melaconite**, or Tenorite—monoxide of copper, $CuO$.
Periclase—monoxide of magnesium, $MgO$.
**Brucite**—magnesium hydrate, $Mg(OH)_2$.

### B. EPITRITOXIDE GROUP.

**Spinel**—double oxide of magnesium and aluminium, $MgO.Al_2O_3$.
Hercynite—double oxide of iron and aluminium, $FeO.Al_2O_3$.
Gahnite, or Zinc-spinel — double oxide of zinc and aluminium, $ZnO.Al_2O_3$.
**Magnetite**—double oxide of iron, $FeO.Fe_2O_3$.
**Franklinite**—double oxide of iron, zinc, and manganese, $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$.
**Chromite**—double oxide of iron and chromium, $FeO.Cr_2O_3$.
Hausmannite—double oxide of manganese, $MnO.Mn_2O_3$.
Chrysoberyl, or Alexandrite—double oxide of beryllium and aluminium, $BeO.Al_2O_3$.

## C. SESQUIOXIDE GROUP.

Braunite—sesquioxide of manganese, $Mn_2O_3$.
**Corundum**—sesquioxide of aluminium, $Al_2O_3$.
**Hæmatite**—sesquioxide of iron, $Fe_2O_3$.
**Ilmenite**—sesquioxide of iron and titanium, $(Fe,Ti)_2O_3$.
**Goethite**—hydrated sesquioxide of iron, $Fe_2O_3.H_2O$.
Turgite—hydrated sesquioxide of iron, $2Fe_2O_3.H_2O$.
**Limonite**—hydrated sesquioxide of iron, $2Fe_2O_3.3H_2O$.
**Manganite**—hydrated sesquioxide of manganese, $Mn_2O_3.H_2O$.
Diaspore—hydrated sesquioxide of aluminium, $Al_2O_3.H_2O$.
**Bauxite**—hydrated sesquioxide of aluminium, $Al_2O_3.2H_2O$.
Gibbsite—hydrated sesquioxide of aluminium, $Al_2O_3.3H_2O$.
**Psilomelane**—hydrated sesquioxide of manganese and barium, $(Mn, Ba)O.MnO_2.H_2O$.

## D. DIOXIDE GROUP.

**Pyrolusite**—dioxide of manganese, $MnO_2$.
**Rutile**—dioxide of titanium, $TiO_2$.
Anatase—dioxide of titanium, $TiO_2$.
Brookite—dioxide of titanium, $TiO_2$.
**Cassiterite**, or Tinstone—dioxide of tin, $SnO_2$.
**Zircon**—double oxide of zirconium and silicon, $ZrO_2.SiO_2$.
Tridymite—dioxide of silicon, $SiO_2$ (rhombic).
**Quartz**—dioxide of silicon, $SiO_2$ (hexagonal).
**Chalcedony**—dioxide of silicon, $SiO_2$.
**Opal**—hydrated dioxide of silicon, $SiO_2 + nH_2O$.

## V. OXYGEN SALTS OF THE METALS.

### A. CARBONATES.

**Witherite**—carbonate of barium, $BaCO_3$.
**Strontianite**—carbonate of strontium, $SrCO_3$.
**Cerussite**—carbonate of lead, $PbCO_3$.
**Aragonite**—carbonate of calcium, $CaCO_3$.
**Calcite**—carbonate of calcium, $CaCO_3$.
**Magnesite**—carbonate of magnesium, $MgCO_3$.
**Dolomite**—double carbonate of magnesium and calcium, $MgCa(CO_3)_2$.
Ankerite—carbonate of magnesium, calcium and iron, $(Mg,Ca,Fe)CO_3$.
Barytocalcite—double carbonate of barium and calcium, $BaCa(CO_3)_2$.
**Chalybite**, or Siderite—carbonate of iron, $FeCO_3$.
**Rhodochrosite**—carbonate of manganese, $MnCO_3$.
**Calamine**—carbonate of zinc, $ZnCO_3$.

### B. HYDRATED CARBONATES.

**Chessylite**, or Azurite—hydrated basic carbonate of copper, $2CuCO_3.Cu(OH)_2$.
**Malachite**—hydrated basic carbonate of copper, $CuCO_3.Cu(OH)_2$.
**Natron**—hydrated carbonate of sodium, $Na_2CO_3.10H_2O$.
Trona—hydrated carbonate of sodium, $Na_2CO_3.HNaCO_3.2H_2O$.

### C. CHROMATES AND SULPHATES.

Crocoite—chromate of lead, $PbCrO_4$.
**Anhydrite**—sulphate of calcium, $CaSO_4$.
**Celestite**—sulphate of strontium, $SrSO_4$.

**Barytes**—sulphate of barium, $BaSO_4$.
**Anglesite**—sulphate of lead, $PbSO_4$.
Thenardite—sulphate of sodium, $Na_2SO_4$.

### D. HYDRATED SULPHATES.

**Gypsum**, or Selenite—hydrated sulphate of calcium, $CaSO_4.2H_2O$.
Kieserite—hydrated sulphate of magnesium, $MgSO_4.H_2O$.
Epsomite, or Epsom Salt—hydrated sulphate of magnesium, $MgSO_4.7H_2O$.
Mirabilite, or Glauber's Salt—hydrated sulphate of sodium, $Na_2SO_4.10H_2O$.
Melanterite—hydrated sulphate of iron, $FeSO_4.7H_2O$.
Chalcanthite—hydrated sulphate of copper, $CuSO_4.5H_2O$.
Brochantite—hydrated basic sulphate of copper, $CuSO_4.3Cu(OH)_2$.
Kalinite, or Potash alum—hydrated sulphate of potassium and aluminium, $K_2SO_4.Al_2(SO_4)_3+24H_2O$.
**Alunite**, or Alumstone—hydrated basic sulphate of potassium and aluminium, $K_2SO_4Al_2(SO_4)_3.2Al_2(OH)_6$.

### E. PHOSPHATES, ARSENATES, AND VANADATES.

**Monazite**—phosphate of cerium, lanthanum, and didymium, $(Ce,La,Di)PO_4$.
Xenotime—phosphate of yttrium, $YPO_4$.
Vivianite—hydrated phosphate of iron, $Fe_3(PO_4)_2.8H_2O$.
Erythrite, or Cobalt Bloom—hydrated arsenate of cobalt, $Co_3(AsO_4)_2.8H_2O$.
Annabergite, or Nickel Bloom—hydrated arsenate of nickel, $Ni_3(AsO_4)_2.8H_2O$.
Libethenite—hydrated basic phosphate of copper, $Cu(CuOH)PO_4$.

Olivenite—hydrated basic arsenate of copper, $Cu(CuOH)AsO_4$.

Clinoclase—hydrated basic arsenate of copper, $(CuOH)_3AsO_4$.

Scorodite—hydrated arsenate of iron, $FeAsO_4.2H_2O$.

Torbernite—hydrated phosphate of uranium and copper, $Cu(UO_2)_2(PO_4)_2.8H_2O$.

Autunite—hydrated phosphate of uranium and calcium, $Ca(UO_2)_2(PO_4)_2.8H_2O$.

Wavellite—hydrated phosphate of aluminium, $2(AlOH)_3(PO_4)_2.9H_2O$.

Lazulite—hydrated phosphate of iron and magnesium, $(MgFe)(AlOH)_2(PO_4)_2$.

Turquoise—hydrated phosphate of aluminium, with small quantity of phosphate of copper, $2Al_2O_3.P_2O_5.5H_2O$.

**Pyromorphite**—chloro-phosphate of lead, $3Pb_3(PO_4)_2.PbCl_2$.

Mimetite—chloro-arsenate of lead, $3Pb_3(AsO_4)_2.PbCl_2$.

Vanadinite—chloro-vanadate of lead, $3Pb_3(VO_4)_2.PbCl_2$.

**Apatite** (*a*) chlor-apatite—chloro-phosphate of calcium, $3Ca_3(PO_4)_2.CaCl_2$; (*b*) fluor-apatite—fluoro-phosphate of calcium, $3Ca_3(PO_4)_2.CaF_2$.

## F. NITRATES.

**Nitre**, or Saltpetre—nitrate of potassium, $KNO_3$.

Nitratine, or Soda nitre—nitrate of sodium, $NaNO_3$.

## G. BORATES.

**Borax**—hydrated borate of sodium, $Na_2O.2B_2O_3.10H_2O$.

Boracite—chloro-borate of magnesium, $6MgO.8B_2O_3.MgCl_2$.

### H. TUNGSTATES AND MOLYBDATES.

**Wolfram**—tungstate of iron and manganese, $(Fe,Mn)WO_4$.

Scheelite—tungstate of lime, $CaWO_4$.

Stolzite—tungstate of lead, $PbWO_4$.

Wulfenite—molybdate of lead, $PbMoO_4$.

### I. NIOBO-TANTALATE.

**Columbite**—niobo-tantalate of iron and manganese, $(Fe,Mn)O.(Nb,Ta)_2O_5$.

### J. TITANATE AND TITANO-SILICATE.

Perovskite—titanate of calcium, $CaO.TiO_2$.

**Sphene**, or Titanite—titano-silicate of calcium, $CaO.TiO_2.SiO_2$.

### K. SILICATES.

#### (*a*) *Orthosilicates.*

Forsterite—orthosilicate of magnesium, $SiO_2.2MgO$.

Fayalite—orthosilicate of iron, $SiO_2.2FeO$.

**Olivine**—orthosilicate of iron and magnesium, $SiO_2.2(Fe,Mg)O$.

Tephroite—orthosilicate of manganese, $SiO_2.2MnO$.

Monticellite—orthosilicate of calcium and magnesium, $SiO_2.CaO.MgO$.

Phenacite—orthosilicate of beryllium, $SiO_2.2BeO$.

**Willemite**—orthosilicate of zinc, $SiO_2.2ZnO$.

**Andalusite**—orthosilicate of aluminium, $SiO_2.Al_2O_3$.

**Kyanite**—orthosilicate of aluminium, $SiO_2.Al_2O_3$.

**Topaz**—fluoro-orthosilicate of aluminium, $SiO_2.Al_2(O,F_2)O_2$.

**Nepheline**—orthosilicate of sodium, potassium, and aluminium, $2SiO_2.Al_2O_3.(Na,K)_2O$.

**Anorthite**—orthosilicate of calcium and aluminium, $2SiO_2.Al_2O_3.CaO$.

**Meionite**—orthosilicate of calcium and aluminium, $6SiO_2.3Al_2O_3.4CaO$.

**Grossular-garnet**—orthosilicate of calcium and aluminium, $3SiO_2.Al_2O_3.3CaO$.

**Pyrope**—orthosilicate of magnesium and aluminium, $3SiO_2.Al_2O_3.3MgO$.

**Almandine**—orthosilicate of iron and aluminium, $3SiO_2.Al_2O_3.3FeO$.

Spessartite—orthosilicate of manganese and aluminium, $3SiO_2.Al_2O_3.3MnO$.

Uvarovite—orthosilicate of calcium and chromium, $3SiO_2.Cr_2O_3.3CaO$.

**Melanite**—orthosilicate of calcium and iron, $3SiO_2.Fe_2O_3.3CaO$.

**Sodalite***—chloro-orthosilicate of sodium and aluminium, $3SiO_2.Al_2O_3.(AlCl)O.2Na_2O$.

Haüyne—sulpho-orthosilicate of sodium, calcium, and aluminium, $3SiO_2.Al_2O_3.(AlNaSO_4)O.Na_2O.CaO$.

Nosean—sulpho-orthosilicate of sodium and aluminium, $3SiO_2.Al_2O_3.(AlNaSO_4)O.2Na_2O$.

### (*b*) *Metasilicates.*

Rhodonite—metasilicate of manganese, $SiO_2.MnO$.

**Wollastonite**—metasilicate of calcium, $SiO_2.CaO$.

**Enstatite**—metasilicate of magnesium, $SiO_2.MgO$.

**Hypersthene**—metasilicate of iron and magnesium, $SiO_2.(Fe,Mg)O$.

Hedenbergite—metasilicate of iron and calcium, $2SiO_2.FeO.CaO$.

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* For a discussion of the constitution of the sodalite group see Brögger and Backström, *Zeits. für Min.*, vol. xviii., p. 209.

**Diopside**—metasilicate of magnesium and calcium, $2SiO_2.MgO.CaO$.

**Tremolite**—metasilicate of magnesium and calcium, $4SiO_2.3MgO.CaO$.

Anthophyllite—metasilicate of magnesium and iron, $2SiO_2.(Fe,Mg)O$.

**Actinolite**—metasilicate of magnesium, iron, and calcium, $4SiO_2.3(Mg,Fe)O.CaO$.

Acmite, or Aegirine—metasilicate of sodium and iron, $4SiO_2.Fe_2O_3.Na_2O$.

Riebeckite—metasilicate of sodium and iron, $4SiO_2.Fe_2O_3.Na_2O + 2(FeO.SiO_2)$.

**Augite**—metasilicate of calcium, iron, and aluminium, $2SiO_2.CaO.(Mg,Fe)O + SiO_2.(Al,Fe)_2O_3.(Mg,Fe)O$.

**Hornblende**—metasilicate of calcium, magnesium, iron, and aluminium, $2SiO_2.CaO.(Mg,Fe)O + SiO_2.(Al,Fe)_2O_3.(Mg,Fe)O$.

**Spodumene**—metasilicate of lithium, sodium, and aluminium, $4SiO_2.Al_2O_3.(Li, Na)_2O$.

**Leucite**—metasilicate of potassium and aluminium, $4SiO_2.Al_2O_3.K_2O$.

**Beryl**—metasilicate of beryllium and aluminium, $6SiO_2.Al_2O_3.3BeO$.

### (*c*) *Isomorphous Mixed Silicates.*

**Felspars**—isomorphous mixtures of Orthoclase and Albite, or of Albite and Anorthite.

**Orthoclase**, or Potash-felspar—silicate of potassium and aluminium, $6SiO_2.Al_2O_3.K_2O$.

**Albite**, or Soda-felspar—silicate of sodium and aluminium, $6SiO_2.Al_2O_3.Na_2O$.

**Anorthite**, or Lime-felspar—orthosilicate of calcium and aluminium, $2SiO_2.Al_2O_3.CaO$.

**Scapolites** — isomorphous mixtures of Meionite and Marialite.

**Meionite**—silicate of calcium and aluminium, $6SiO_2.3Al_2O_3.4CaO$.

**Marialite**—chloro-silicate of sodium and aluminium, $18SiO_2.3Al_2O_3.3Na_2O.2NaCl$.

**Chlorites** — isomorphous mixtures of Serpentine and Amesite.

**Serpentine**—hydrated silicate of magnesium, $2SiO_2.3MgO.2H_2O$.

**Amesite**—hydrated silicate of magnesium and aluminium, $SiO_2.Al_2O_3.2MgO.2H_2O$.

(*d*) *Hydrated Silicates, with "Water of Constitution."*

**Hemimorphite**—hydrated orthosilicate of zinc, $SiO_2.2ZnO.H_2O$.

Dioptase—hydrated orthosilicate of copper, $SiO_2.CuO.H_2O$.

**Chrysocolla**—hydrated orthosilicate of copper, $SiO_2.CuO.2H_2O$.

Prehnite—hydrated silicate of calcium and aluminium, $3SiO_2.(Al,Fe)_2O_3.2CaO.H_2O$.

**Zoisite**—hydrated orthosilicate of calcium and aluminium, $6SiO_2.3Al_2O_3.4CaO.H_2O$.

**Epidote**—hydrated orthosilicate of calcium, aluminium, and iron, $6SiO_2.3(Al,Fe)_2O_3.4CaO.H_2O$.

Piedmontite — hydrated orthosilicate of calcium, aluminium, and manganese, $6SiO_2.3(Al,Mn)_2O_3.4CaO.H_2O$.

**Orthite**—hydrated orthosilicate of calcium, iron, aluminium, and cerium, $6SiO_2.3(Al,Ce)_2O_3.4(Ca,Fe)O.H_2O$.

**Staurolite**—hydrated silicate of iron and aluminium, $5SiO_2.6Al_2O_3.2FeO.H_2O$.

**Vesuvianite**, or Idocrase—hydrated silicate of calcium, magnesium, aluminium, and iron, $Si_2O_7(Al,Fe)(OH,F)(Ca,Mg)_2$.

**Cordierite**—hydrated metasilicate of magnesium, iron, and aluminium, $10SiO_2.4(Mg, Fe)O.4Al_2O_3.H_2O$.

**Muscovite**, or Potash-mica—hydrated orthosilicate of potassium and aluminium, $6SiO_2.3Al_2O_3.K_2O.2H_2O$.

Paragonite, or Soda-mica—hydrated orthosilicate of sodium and aluminium, $6SiO_2.3Al_2O_3.Na_2O.2H_2O$.

**Phlogopite**, or Magnesian-mica—hydrated silicate of magnesium, potassium, and aluminium, $6SiO_2.2Al_2O_3.4(Mg, Fe)O.K_2O.H_2O$.

**Biotite**, or Magnesian-iron-mica—hydrated orthosilicate of magnesium, potassium, iron, and aluminium, $6SiO_2.2(Al, Fe)_2O_3.4(Mg, Fe)O.K_2O.H_2O$.

Margarite—hydrated silicate of calcium and aluminium, $2SiO_2.2Al_2O_3.CaO.H_2O$.

Chloritoid, or Ottrelite—hydrated silicate of iron and aluminium, $SiO_2.Al_2O_3.FeO.H_2O$.

**Talc**—hydrated silicate of magnesium, $4SiO_2.3MgO.H_2O$.

**Kaolinite**—hydrated silicate of aluminium, $2SiO_2.Al_2O_3.2H_2O$.

### (*e*) *Hydrated Silicates, with "Water of Crystallization"* (*Zeolite Group*).

**Natrolite**—hydrated silicate of sodium and aluminium, $3SiO_2.Al_2O_3.Na_2O.2H_2O$.

**Analcite**—hydrated silicate of sodium and aluminium, $4SiO_2.Al_2O_3.Na_2O.2H_2O$.

Chabazite—hydrated silicate of sodium, calcium, and aluminium, $4SiO_2.Al_2O_3.(Ca, Na_2)O.6H_2O$.

Stilbite—hydrated silicate of sodium, calcium, and aluminium, $6SiO_2.Al_2O_3.(Ca, Na_2)O.6H_2O$.

Heulandite—hydrated silicate of sodium, calcium, and aluminium, $6SiO_2.Al_2O_3.(Ca, Na_2)O.3H_2O$.

### (*f*) *Borosilicates.*

**Datolite**—hydrated boro-silicate of calcium, $2SiO_2.B_2O_3.2CaO.H_2O$.

**Axinite**—hydrated boro-silicate of calcium, iron, manganese, and aluminium, $8SiO_2.B_2O_3.2Al_2O_3.6(Ca, Fe, Mn)O.H_2O$.

**Tourmaline**—hydrated boro-silicate of sodium, magnesium, and aluminium. According to Clarke,* the tourmaline series consists of salts of an acid :

$$Al_5(SiO_4)_6(BO_2)_2.BO_3H_2.H_{12}.$$

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* See *Amer. Journ. of Sci.*, vol. viii., 1899, p. 111.

# PART II

## DESCRIPTIVE MINERALOGY

## CHAPTER I

### THE ROCK-FORMING MINERALS

ALTHOUGH no doubt the greater number of the rocks that constitute the visible portion of the earth's crust are of sedimentary origin, it is to the crystalline rocks that we must look for variety in mineral composition; and even those minerals that are found in the sedimentary strata are derived in great measure from rocks of igneous or metamorphic origin. The common constituents of the crystalline rocks are quartz, the felspars, the micas, the amphiboles, the pyroxenes, and the olivines; while chlorite, serpentine, talc, kaolinite, the carbonates of lime and magnesia (calcite, dolomite, etc.), hydrated silicates of alumina (clay), the zeolites, etc., are produced by their decomposition, and are termed *secondary minerals*. The relative proportion in which the minerals composing the superficial crust of the earth occur has been roughly calculated to be as follows:

| | | |
|---|---|---|
| Felspar ... ... ... ... | 48 | per cent. |
| Quartz ... ... ... ... | 35 | „ |
| Mica, chlorite, talc, etc. ... ... | 13 | „ |
| Hornblende, augite, olivine, and serpentine ... ... ... | 1 | „ |
| Carbonates of lime and magnesia | 1 | „ |
| Clay (hydrated silicate of alumina) | 1 | „ |
| Other substances (including ores, salts, etc.) ... ... ... | 1 | „ |

These numbers serve to give a rough idea of the composition of the external layers of the earth. Lower zones must have a different composition; for there the basic silicates, together with the heavy metals and their compounds, doubtless play a more important rôle.

## QUARTZ GROUP.

**Quartz.**—Pure silica. $SiO_2$ (silicon, 46·7). Crystallizes in the hexagonal (rhombohedral) system. Usual habit, prismatic with rhombohedral terminations. The prism faces have a characteristic horizontal striation; occasionally they are absent, the crystals then consisting of the double pyramid of twelve faces.

Other and rarer forms also occur; indeed, so numerous are they, and so varied their association, that no two quartz crystals can be said to be absolutely identical.

The crystals are frequently distorted, the distortion being the result of the undue development of some of the faces at the expense of their fellows, but in every case the angle between any given pair of faces remains constant. One kind of distortion gives rise to what is known as *sceptre-quartz*.

When pure, quartz is colourless. Streak, white. Lustre, vitreous. Transparent. Index of refraction, 1·551. Double refraction, weak ($\epsilon - \omega = 0{\cdot}009$), positive. Rhombohedral cleavage, imperfect. Brittle. Fracture, conchoidal. Hardness, 7. Density, 2·65. Infusible. Insoluble in acids (excepting hydrofluoric). Insoluble in potash (distinction from opaline silica).

The mineral may be recognized by its hardness, pellucidity, and vitreous lustre. Usually it is quite colourless and transparent, but coloured and translucent or even opaque varieties also occur—*e.g.*, brown or yellow (*smoky quartz*, *cairngorm*, *jasper*), pink (*rose-quartz*), purple (*amethyst*), green (*chrysoprase*), white and translucent (*milky quartz*). When pure and crystallized, it is known as *rock-crystal;* when crypto-crystalline, as *chalcedony*.

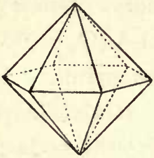

FIG. 58.—QUARTZ.

Bi-pyramidal crystal—a combination of the rhombohedral forms R ($10\bar{1}1$) and z ($01\bar{1}1$).

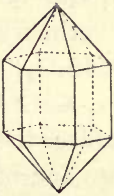

FIG. 59.—QUARTZ.

A combination of the rhombohedral forms R ($10\bar{1}1$), z ($10\bar{1}1$), and the prism M ($10\bar{1}0$).

The chief rocks in which quartz occurs are granite, quartz-porphyry, felsite, rhyolite, gneiss, mica-schist, quartzite, sand, sandstone, clay, and shale. It is also a common companion of the ores, being a frequent vein-stone, or gangue material.

## THE FELSPAR GROUP.

Under the name felspar is included a series of important rock-forming minerals, which, while varying in chemical composition, are similar in physical character and crystalline form. They are silicates of alumina, with one or more of the bases—potash, soda, and lime—and can be regarded as isomorphous mixtures of three primary minerals—namely, *potash-felspar* $K_2O.Al_2O_3.6SiO_2$; *soda-felspar*, $Na_2O.Al_2O_3.6SiO_2$; and *lime-felspar*, $CaO.Al_2O_3.2SiO_2$. These primary felspars exist in nature: the potash-felspar as orthoclase (pseudo-monoclinic) and microcline (triclinic); the soda-felspar, as albite (triclinic); and the lime-felspar, as anorthite (triclinic).

There are two principal isomorphous series—namely, a lime-soda series (the *plagioclases*) and a potash-soda series (*anorthoclase*, etc.), the former being the most important.

If the symbol Ab be used to represent the albite molecule—$\frac{1}{2}(Na_2O.Al_2O_3.6SiO_2)$, and the symbol An for the anorthite molecule—$CaO.Al_2O_3.2SiO_2$, then, as Tschermak has shown, the lime-soda or plagioclase series may be represented by the general formula $m\,\mathrm{Ab} + n\,\mathrm{An}$. The nature of the variation in chemical composition is illustrated by the following selected points in the series:

| Formula. | Percentage Composition. | | | |
|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Na_2O$ | CaO |
| Ab | 68·7 | 19·5 | 11·8 | 0 |
| $Ab_3\ An_1$ | 62·0 | 24·0 | 8·7 | 5·3 |
| $Ab_2\ An_1$ | 60·2 | 25·2 | 7·9 | 6·7 |
| $Ab_1\ An_1$ | 55·6 | 28·3 | 5·7 | 10·4 |
| $Ab_1\ An_2$ | 51·7 | 30·9 | 4·0 | 13·4 |
| $Ab_1\ An_5$ | 47·4 | 33·8 | 2·0 | 16·8 |
| An | 43·2 | 36·7 | 0 | 20·1 |

For convenience, the following names are given to the intermediate members of the series:

Oligoclase = Ab to $Ab_3\ An_1$
Andesine = $Ab_3\ An_1$ to $Ab_1\ An_1$
Labradorite = $Ab_1\ An_1$ to $Ab_1\ An_3$
Bytownite = $Ab_1\ A_3$ to An

The physical properties also show a progressive variation from one end of the series to the other. Thus, the density and the index of refraction increase from the albite to the anorthite end, as will be seen in the following table:

| Formula. | Density. | Mean Index of Refraction. |
|---|---|---|
| Ab | 2·605 | 1·535 |
| $Ab_3\ An_1$ | 2·649 | 1·545 |
| $Ab_2\ An_1$ | 2·660 | 1·549 |
| $Ab_1\ An_1$ | 2·679 | 1·558 |
| $Ab_1\ An_2$ | 2·710 | 1·567 |
| $Ab_1\ An_5$ | 2·733 | 1·577 |
| An | 2·765 | 1·585 |

The potash-soda series may be represented by the general formula $(K,Na)_2O.Al_2O_3.6SiO_2$. It is known as the anorthoclase or microcline-albite series. The first known member of this series was described by Förstner as soda-orthoclase from Pantelleria, near Sicily. Its chemical composition can be represented as $2(K_2O.Al_2O_3.6SiO_2) + 3(Na_2O.Al_2O_3.6SiO_2)$.

**Orthoclase.**—$K_2O.Al_2O_3.6SiO_2$ (potash, 17; alumina, 18; silica, 65 per cent). Although now generally assumed to be triclinic, with pseudo-monoclinic symmetry, orthoclase is still usually treated as a monoclinic mineral. The common forms are:

Basal plane, P (001).
Prism, *l* (110).
Clinopinacoid, M (010).
Orthopinacoid, *k* (100).
Orthodome, *x* $(\bar{1}01)$.
Orthodome, *y* $(\bar{2}01)$.
Clinodome, *n* (021).
Hemipyramid, *o* $(\bar{1}11)$.

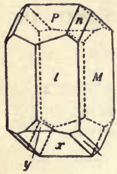

Fig. 60.—Crystal of Orthoclase.

There are three chief crystal habits — viz.: (1) elongated along the edge PM, as in the Baveno crystals; (2) tabular along M, as in the variety known as sanidine from the Drachenfels; (3) elongated vertically, with dominant prism faces, as in the variety known as adularia, from St. Gothard.

Crystals of the sanidine and adularia habits generally have a roof-like termination produced by the combination of the basal plane (P) with one or other of the orthodomes *x* and *y*.

Crystals of orthoclase are frequently twinned, most often on what is known as the Carlsbad type. In this the two individuals are usually united on the clinopinacoid (M); and the basal planes (P) of the crystals are inclined in opposite directions, each being brought into close juxtaposition with the orthodome of the other individual. The relative position of two individuals twinned on this type can be explained by an imaginary rotation of one of them through 180° about the vertical axis.

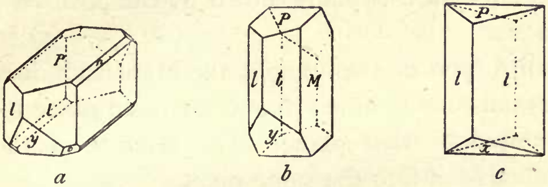

Fig. 61.—Crystals of Orthoclase.
*a*, Baveno habit ; *b*, sanidine habit ; *c*, adularia habit.

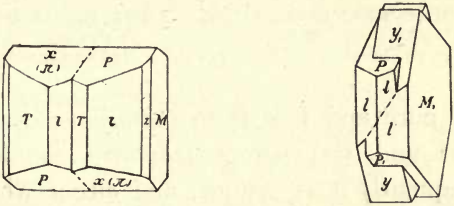

Fig. 62.—Orthoclase Crystals Twinned on the Carlsbad Type.

Another type of twinning is the Baveno, in which the crystals are twinned about the clinodome *n* (021), and united by that plane. Since the angle made by the basal plane (P), and by the clinopinacoid (M), with the clinodome *n* is, in each case, very nearly 45°, crystals of the Baveno habit, twinned on the Baveno type, differ very little in shape from the untwinned individuals; but that they are twins is shown by the position of the cleavages.

A third type of twinning is the Manebach, in which the crystals are twinned about the basal plane P (001), and united by that plane. The faces M of the two individuals fall into the same plane.

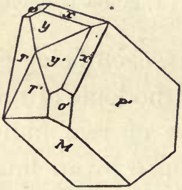

FIG. 63.—ORTHOCLASE TWINNED ON THE BAVENO TYPE.

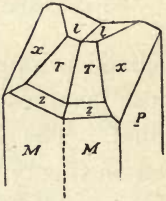

FIG. 64.—ORTHOCLASE TWINNED ON THE MANEBACH TYPE.

When pure and free from inclusions, orthoclase is colourless and transparent (*adularia*, *sanidine*); but more frequently it is opaque, and either white, flesh-coloured, or red. Although this opacity and coloration may in some instances be due to extraneous matter included in the crystal during its formation, it is more frequently the result of alteration produced by weathering. During this process the felspar substance undergoes chemical change, kaolin (a hydrated silicate of alumina) being formed, while silica is set free. In certain cases muscovite and talc are also products of its decomposition.

Streak, colourless. Lustre, vitreous. Index of refraction, 1·524. Double refraction, weak ($\gamma - a = 0{\cdot}006$). Fracture, conchoidal. Brittle. Hardness, 6. Density, 2·5. Fusibility, 5. Insoluble in acids.

There are two perfect cleavages—namely, parallel to the basal plane, P, and to the clinopinacoid, M; and it is noteworthy that the cleavage planes intersect at right angles. There is also an imperfect prismatic cleavage.

Orthoclase is an essential constituent of the more acid igneous rocks, such as granite, syenite, and porphyry, also of the foliated granitic rocks or gneisses. The clear fissured sanidine variety is common in the volcanic rocks—rhyolites and trachytes. It is found in those sedimentary rocks which are derived directly from the waste of granitic rocks, such as felspathic grits and sandstones. Orthoclase is also common as a vein-stone, being a chief constituent of the pegmatites.

**Microcline.**—Triclinic potash felspar. Identical in chemical composition with orthoclase. The angle made by P (001) with M (010) is about 89° 30′. A characteristic feature of microcline is its polysynthetic twinning on both the albite and pericline types. The resulting twin-lamellation is in two directions at right angles, producing a rectangular cross-hatching, which is especially visible in suitably oriented thin sections when examined between the crossed nicols of a polarizing microscope. In other physical properties microcline does not differ from orthoclase; and it is to be noted that if we imagine microcline crystals to be polysynthetically twinned on an ultra-microscopic scale, such crystals would be indistinguishable from orthoclase: on this reasoning some authors regard orthoclase as triclinic, with pseudo-monoclinic symmetry acquired by twinning.

**Albite.**—$Na_2O.Al_2O_3.6SiO_2$ (soda, 11·8; alumina, 19·5; silica, 68·7 per cent.).—Crystallizes in the triclinic system, the angle between the basal plane (P) and the brachypinacoid (M) being 86° 24′.

Common forms are:

Basal plane, P $(001)$.
Prisms, T $(1\bar{1}0)$ and *l* $(110)$.
Brachypinacoid, M $(010)$.
Macropinacoid, *k* $(100)$.
Macrodome, *x* $(10\bar{1})$.
Macrodome, *y* $(20\bar{1})$.
Brachydome, *n* $(021)$.
Pyramid, *o* $(11\bar{1})$.

Twinning on the Carlsbad, Baveno, and Manebach types, as in orthoclase; but the characteristic feature of albite, and, indeed, of all plagioclase felspars, is the Albite type of twinning, in which the crystals are twinned about the brachypinacoid (M), and united on that plane.

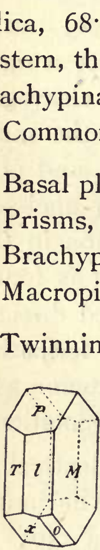

FIG. 65.

In this type there is usually a repeated or polysynthetic arrangement of individuals, the crystal being divided into a number of parallel lamellæ, each of which is in the twinning position with regard to its immediate neighbours; alternate lamellæ, however, are similarly situated. The structure of the twinned crystal can be explained by an imaginary rotation of alternate lamellæ about an axis normal to the brachypinacoid (M). The basal planes of all the lamellæ lie on the same side of the crystal, but slope alternately towards and away from one another so as to produce a series of parallel ridges and depressions, the general effect of which is a parallel striation parallel to M, which is best seen on the surfaces produced by the basal cleavage.

In the Pericline type the crystals are twinned about a plane normal to the brachydiagonal, and the relative position of the two individuals may be imagined as produced by rotation through 180° of one of them about the brachydiagonal. In this type the M faces of the two individuals do not fall into the same plane.

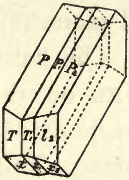

FIG. 66.—POLYSYNTHETIC TWIN OF PLAGIOCLASE.
("Albite-type.")

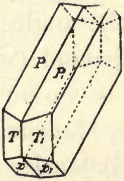

FIG. 67.—DUAL TWIN OF ALBITE.
*P*, Basal plane of first individual; $P_1$, basal plane of second individual.

Albite is usually colourless and transparent. Streak, colourless. Lustre, vitreous. Index of refraction, 1·533. Double refraction, positive and moderate ($\gamma - \alpha = 0{\cdot}008$). Basal cleavage, perfect. The brachypinacoidal and prismatic cleavages, imperfect. Fracture, uneven. Brittle. Hardness, 6. Density, 2·63. Fusibility, 4. Insoluble in acids.

Albite and orthoclase occur in intimate intergrowth, the albite being in narrow lamellæ intercalated in the orthoclase along planes parallel to the orthopinacoid. In sections parallel to the basal plane or to the clinopinacoid, the included albite appears as strips and patches, which are distinguishable from the orthoclase by their twin striation. Such intergrowths are known as *perthite* and *microperthite*.

**Anorthite.**—$CaO.Al_2O_3.2SiO_2$ (lime, 20·1; alumina, 36·7; silica, 43·2 per cent.) Crystallizes in the triclinic system, the angle between the basal plane (P) and the brachypinacoid (M) being 85° 50′. The habit of the crystals is varied. Twinning occurs on the Albite, Pericline, Manebach, and Carlsbad types. Colourless. Streak, colourless. Lustre, vitreous. Transparent. Index of refraction, 1·585. Double refraction, negative and moderate ($\gamma - a = 0{\cdot}013$). Basal cleavage, perfect. Brachypinacoidal cleavage, less perfect. Fracture, conchoidal. Brittle. Hardness, 6·5. Density, 2·75. Fusibility, 5. Decomposed by hydrochloric acid with gelatinization.

The isomorphous series of plagioclase felspars formed by albite and anorthite has already been dealt with (p. 86).

The plagioclase felspars occur in many igneous rocks —*e.g.*, in the intrusive diorites, gabbros, dolerites, and in the volcanic andesites, porphyrites, and basalts. The variety oligoclase often accompanies orthoclase in granite and trachyte. Oligoclase and albite are also frequent constituents of the schists, occurring in them in a clear granular form in association with quartz (*secondary* or *granulitic felspar*).

Like orthoclase, plagioclase is prone to decomposition, giving rise to epidote, zoisite (in the so-called saussurite), calcite, and kaolin.

### THE FELSPATHOID GROUP.

**Nepheline.** — Orthosilicate of soda, potash, and alumina: $(NaK)_2O.Al_2O_3.2SiO_2$. Pure sodium-nepheline which has been prepared artificially has the composition: $SiO_2 = 42·3$, $Al_2O_3 = 35·9$, $Na_2O = 21·8$; but in nepheline, as it occurs naturally, the proportion of $Na_2O$ to $K_2O$ is usually about 5 : 1. Crystallizes in the hexagonal system in small six-sided prisms (combination of hexagonal prism and basal plane). Colourless to white or grey. Transparent to translucent. Lustre, vitreous to resinous. Streak, white. Index of refraction, 1·54. Double refraction, negative and weak ($\omega - \epsilon = ·005$). Basal and prismatic cleavages, imperfect. Hardness, 5·5-6. Density, 2·6. Fusibility, 4. Soluble in hydrochloric acid with separation of gelatinous silica, the solution giving cubes of common salt, when evaporated.

Nepheline is found in the cavities of volcanic ejected blocks (Monte Somma, Laacher See); as an essential constituent of certain lavas (phonolite, nepheline-basalt, tephrite, etc.); and as a constituent of the soda-series of the plutonic rocks (syenites and alkali-gabbros).

**Leucite.**—Metasilicate of alumina and potash: $K_2O.Al_2O_3.4SiO_2$ (silica, 55; alumina, 23·5; potash, 21·5 per cent.) Pseudo-regular.

This mineral occurs crystallized in icositetrahedra, and no doubt at the temperature at which it was formed crystallized in the regular system, but on cooling broke up into rhombic or monoclinic sectors. In consequence the crystals exhibit weak double refraction; but when heated to 500° C. they become optically isotropic. Index of refraction, 1·508. Colour, dirty white or grey. Lustre, vitreous. Transparent to opaque. Streak, white. Prismatic cleavage very imperfect. Brittle. Fracture, uneven to conchoidal. Hardness, 5 - 6. Density, 2·45 - 2·50. Infusible. Slowly decomposed by hydrochloric acid with separation of silica.

Leucite occurs as a constituent of the more recent volcanic rocks—leucitophyre, leucite-tephrite, and leucitite; also in members of the alkali series of the plutonic rocks.

**Sodalite.** — Chloro-orthosilicate of aluminium and sodium: $3SiO_2.Al_2O_3.(AlCl)O.2Na_2O$. Regular, with cubic habit; also massive. Colourless to yellowish; greenish white; or pale blue. Index of refraction, 1·484. Lustre, vitreous. Transparent to opaque. Streak, white. Cubic cleavage, fair. Fracture, conchoidal to uneven. Hardness, 5·5 - 6. Density, 2·2 - 2·4. Fusibility, 3·5 - 4. Gelatinizes easily with hydrochloric acid.

Occurs in blue, greenish, or colourless grains in syenites and in volcanic ejectamenta.

**Haüyne** and **Nosean.**—Isomorphous sulpho-orthosilicates of alumina, lime, and soda. The soda end of the isomorphous series with little or no lime is nosean $= 3SiO_2.Al_2O_3.(AlNaSO_4)O.2Na_2O$, with $SiO_2 = 31{\cdot}7$, $SO_3 = 14{\cdot}1$, $Al_2O_3 = 26{\cdot}9$, and $Na_2O = 27{\cdot}3$. When $Na_2 : Ca = 3 : 2$, the composition of haüyne is $SiO_2 = 32{\cdot}0$, $SO_3 = 14{\cdot}2$, $Al_2O_3 = 27{\cdot}2$, $CaO = 10{\cdot}0$, $Na_2O = 16{\cdot}6$.

These minerals crystallize in the regular system. Habit, dodecahedral. Colour, blue (haüyne) or grey (nosean). Lustre, vitreous. Transparent to opaque. Streak, white. Index of refraction, 1·496. Dodecahedral cleavage, fair. Fracture, sub-conchoidal to uneven. Hardness, 5-6. Density, 2·25-2·5. Gelatinize easily with hydrochloric acid; on evaporation, needles of gypsum are formed in the case of haüyne, none in the case of nosean.

Haüyne and nosean are essentially volcanic minerals occurring in volcanic ejectamenta and in phonolites, andesites, and basalts.

**Melilite.**—Silicate of alumina, iron, lime, magnesia, and soda: $12(Ca,Mg)O.2(Al,Fe)_2O_3.9SiO_2$. Tetragonal; occurring in small square tables and prisms, also in irregular grains. Colour, white to yellow. Lustre, vitreous. Translucent. Index of refraction, 1·629. Double refraction, weak. Hardness, 5-5·5. Density, 2·9-3·1. Fracture, conchoidal to uneven. Brittle. Fusibility, 4. Gelatinizes easily with hydrochloric acid.

Occurs as a constituent of certain basalts (melilite-basalt) and of nepheline and leucite rocks.

## THE SCAPOLITE GROUP.

Silicates of alumina, lime, and soda + sodium chloride. The scapolite group, like the lime-soda plagioclase group, may be regarded as isomorphous mixtures of two molecules — viz., the meionite (Me) molecule ($4CaO.3Al_2O_3.6SiO_2$), with silica = 40·5, alumina = 34·4, and lime = 25·1 per cent, and the marialite (Ma) molecule ($Na_4Al_3Si_9O_{24}Cl$), with silica = 63·9, alumina = 18·1, soda = 14·7, and chlorine = 4·20 per cent. (oxygen for chlorine to be deducted). **Wernerite** includes scapolites with Me : Ma ranging from 3 : 1 to 1 : 1; **Mizzonite** those with Me : Ma ranging from 1 : 2 to 1 : 3. *Couseranite* and *Dipyre* are varieties of mizzonite.

The scapolites crystallize in the tetragonal system, with prismatic habit. Colourless to white, also bluish, greenish, or reddish. Streak, white. Lustre, vitreous. Index of refraction, 1·55-1·59. Cleavage parallel to the prism of the second order (100), fair. Fracture, conchoidal to uneven. Brittle. Hardness, 5-6. Density, 2·57-2·74.

Of infrequent occurrence in igneous rocks; oftener in gneisses and crystalline schists and in contact-altered limestones, calc-silicate rocks, etc.

## THE MICA GROUP.

The micas are hydrated* silicates of alumina and the alkalies, potash, soda, or lithia, with which iron and

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* Most of the water is only given off at a high temperature, and must be regarded as water of constitution.

magnesia are associated in some varieties. They crystallize in the monoclinic system, but possess pseudo-hexagonal symmetry. The crystals consist of six-sided tablets, of which the six sides are made up of the four faces of a prism, and two of the clino-pinacoid, the broad terminal faces being those of the basal plane. Mica has a very perfect cleavage parallel to the basal plane, permitting of its separation into laminæ of extraordinary thinness; it is characteristic for mica, as distinguished from other allied minerals (talc, chlorite), that these laminæ are elastic, and cannot therefore be permanently bent. The density varies from 2·76 to 3·2. Hardness, 2-3.

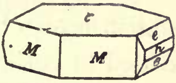

FIG. 68.—MICA-CRYSTAL.

*c*, Basal plane; *M*, prism; *h*, clino-pinacoid; *e*, clino-dome.

For practical purposes the micas may be conveniently separated into two broad subdivisions: the *white* or *light-coloured*, and the *black* or *dark-coloured* varieties. Chief among the former is **muscovite**, or **potash-mica**, which is essentially a hydrated silicate of alumina and potash. This variety of mica is not attacked by hydrochloric acid. It is generally pale-coloured to silvery white, with pearly lustre on the cleavage surfaces. It occurs in flakes, scales, and laminæ, in many granites, gneisses, and phyllites. Fragments are often present in sandstones and shales (derived, no doubt, originally from granitic rocks); and by their parallel arrangement impart to these rocks a fissile character.

Less common than muscovite are the following light-coloured micas:

**Paragonite,** or soda-mica.
**Lepidolite,** or lithia-mica.

**Biotite.**—The most important dark mica; essentially a hydrated ferro-magnesian and aluminous silicate. Unlike muscovite, this mica is attacked by hot hydrochloric acid. It has a dark brown to black colour and sub-metallic lustre, and is transparent to opaque. It occurs in granites and mica-traps and in certain syenites, diorites, trachytes, and andesites. Loose crystals of a reddish-brown biotite (*rubellan*) are frequently found imbedded in volcanic tuff. By decomposition mica readily passes into chlorite, assuming then a green colour.

Those varieties in which there is much magnesia and little iron are distinguished as **phlogopite.** They are generally somewhat lighter in colour than biotite. Those which are rich in lithium and iron are known as **zinnwaldite.**

The micas may also be conveniently classified by the relation of their percussion-figures to the position of the plane of the optic axes as shown by the interference figure obtained by the examination of a cleavage flake under the microscope in convergent polarized light. The percussion-figure is a 6-rayed star obtained by driving a needle into a cleavage flake by means of a sharp blow with a light hammer. It will be found that one of the rays is either parallel to, or at right angles to, the plane of the optic axes. This, therefore, gives the direction of the plane of symmetry. Micas in which the plane of the optic axes is perpendicular to the plane of symmetry are known as micas of the first class, and include all the alkali-micas; those in which the optic axial plane is parallel to the plane of symmetry are known as micas of the second class, and include biotite, phlogopite, and zinnwaldite. Those anomalous ferro-magnesian micas which are found to belong to the first class are named **anomite** by Tschermak, to whom this classification owes its origin.

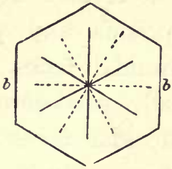

FIG. 69.—MICA, SHOWING THE PERCUSSION FIGURE (THE 6-RAYED STAR, OF WHICH THE LONGEST RAY IS PARALLEL TO THE PLANE OF SYMMETRY, *b*), AND THE PRESSURE FIGURE (THE 6-RAYED STAR, SHOWN BY PECKED LINES).

## THE AMPHIBOLE AND PYROXENE GROUPS.*

These minerals are silicates, mainly of magnesia and lime; but some varieties contain iron and alumina or manganese, soda or lithia in addition. All the varieties resist the action of acids excepting hydrofluoric. Their density varies from 2·90 to 3·55; their hardness from 5 to 6. The commoner species of both groups crystallize in the monoclinic system, but rhombic and triclinic varieties also occur. The main feature distinguishing the amphiboles from the pyroxenes is the angle between

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* "Amphibole" and "pyroxene" are used here as group names, while "hornblende" and "augite" are reserved for the specific rock-forming varieties which crystallize in the monoclinic system.

the faces of the prism, which in the former measures 124°, in the latter 87°.

The crystals are usually short-columnar, and consist of prisms and pinacoids, terminated by a pair of pyramidal faces. In the amphiboles the prism-faces usually predominate over the pinacoids, the orthopinacoidal faces being often even absent; in the pyroxenes, on the other hand, they are about equally developed. The cross-section of an amphibole crystal is consequently lozenge-shaped; that of a pyroxene octagonal.

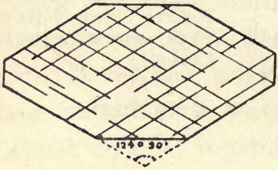

FIG. 70.—CROSS-SECTION OF AN AMPHIBOLE CRYSTAL, SHOWING THE LINES OF PRISMATIC CLEAVAGE INTERSECTING AT AN ANGLE OF 124°.

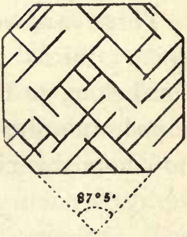

FIG. 71.—CROSS-SECTION OF A PYROXENE CRYSTAL, SHOWING THE LINES OF PRISMATIC CLEAVAGE INTERSECTING AT AN ANGLE OF 87°.

The crystals are occasionally twinned—namely, on the orthopinacoid (see Fig. 71). A cleavage exists in both minerals parallel to the faces of the prism. In the amphiboles it approaches a high degree of perfection, the cleaved surfaces being smooth and lustrous; but in the pyroxenes it is far less perfect, and the cleavage surfaces are consequently uneven.

The common variety of both groups is a black mineral; but green, blue, and white varieties also occur.

The chemical constitution of the more important pyroxenes and amphiboles is given in the following table:

| PYROXENES. | AMPHIBOLES. |
|---|---|
| *Rhombic.* | *Rhombic.* |
| Enstatite—$MgO.SiO_2$. | |
| Hypersthene—$(Mg,Fe)O.SiO_2$. | Anthophyllite—$(Mg,Fe)O.SiO_2$. |
| *Monoclinic.* | *Monoclinic.* |
| Diopside—$MgO.CaO.2SiO_2$. | Tremolite—$CaO.3MgO.4SiO_2$. |
| | Actinolite—$CaO.3(Mg,Fe)O.4SiO_2$. |
| Augite—$CaO.MgO.2SiO_2 + MgO.(Al,Fe)_2O_3.SiO_2$. | Hornblende—$CaO.3(MgFe)O.4SiO_2 + CaO.2MgO.Al_2O_3.3SiO_2$. |
| Ægirine (Acmite)—$Na_2O.Fe_2O_3.4SiO_2$. | Arfvedsonite—$4(Na_2,Ca,Fe)O.4SiO_2 + 2(Ca,Mg)O.2(Al,Fe)_2O_3.2SiO_2$. |
| *Triclinic.* | *Triclinic.* |
| Rhodonite—$MnO.SiO_2$. | Ænigmatite (Cossyrite)—$2Na_2O.9FeO.(Al,Fe)_2O_3.12SiO_2$. |

The following facts emerge from a study of the above table: (1) that these minerals are, in the main, metasilicates; (2) that the pure metasilicate of magnesia is rhombic, that of lime and magnesia, monoclinic,* and that of manganese, triclinic; (3) that the monoclinic varieties, known as augite and hornblende, are characterized by the presence of the sesquioxides of

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* The pure lime metasilicate, wollastonite, is monoclinic. By some authors it is considered to be a pyroxene, although it does not possess the characteristic prismatic cleavage.

aluminium and iron;* (4) that in the monoclinic class the amphibole molecule is double that of the pyroxenes, which explains why, at high temperatures, augite is more stable than hornblende.

**Diopside—Augite.**—Crystallizes in the monoclinic system with short-columnar habit in the direction of the vertical axis.

The common forms are:

Orthopinacoid, *a* (100).
Clinopinacoid, *b* (010).
Prism, *m* (110).
Hemipyramid, *s* ($\bar{1}11$).

M : m = 92° 50′.

Twinning on the orthopinacoid, *a* (100).

Colour, various shades of green to colourless (diopside); also brown to black (augite). Lustre, vitreous.

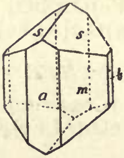

FIG. 72.—AUGITE.
*a*, Orthopinacoid; *b*, clinopinacoid; *s*, hemipyramid; *m*, prism.

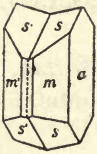

FIG. 73.—TWINNED CRYSTAL OF AUGITE.

Transparent to opaque. The plane of the optic axes coincides with clinopinacoid. Index of refraction, 1·7; double refraction, positive and strong ($\gamma - \alpha = 0{\cdot}030$). Streak, white to grey. Prismatic cleavage, fairly perfect.

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* Augite may be regarded as a combination of *m* molecules of diopside with *n* molecules of Tschermak's silicate—

$$(MgFe)O.(AlFe)_2O_3.SiO_2.$$

Parting, parallel to the orthopinacoid (diallage). Fracture, uneven to subconchoidal. Hardness, 5-6. Density, 3·2-3·6. Fusibility, 4. Insoluble in acids.

Common augite occurs in dolerite, basalt, and in certain trachytes and andesites. The green and white varieties (diopside) are found in peridotites, and as an accessory constituent in some metamorphic limestones. Diallage is an essential constituent of gabbro; while the rhombic pyroxenes occur in some varieties of diorite, gabbro, dolerite, andesite, and peridotite.

**Actinolite—Hornblende.**—Crystallizes in the monoclinic system, with long or short columnar habit, due to the predominance of the prism, *m* (110), frequently without the orthopinacoid, *a* (100), but seldom without the clinopinacoid, *b* (010) (see Fig. 72).

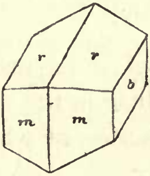

FIG. 74.—HORNBLENDE.
*m*, Prism; *b*, clinopinacoid; *r*, hemipyramid.

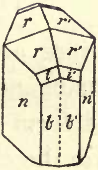

FIG. 75.—TWINNED CRYSTAL OF HORNBLENDE.

Twinning about the orthopinacoidal plane is frequent.

Colour, various shades of green to almost colourless (actinolite); also dark brown to black (hornblende). Streak, white to grey. Lustre, vitreous. Transparent to opaque. Index of refraction, 1·64. Double refraction strong, negative. Optic axial plane, the clinopinacoid. Prismatic cleavage, perfect. Fracture, uneven to subconchoidal. Brittle. Hardness, 5-6. Density, 2·9-3·4. Fusibility, 3-4. Insoluble in acids.

Common hornblende occurs in certain varieties of granite and syenite, also in diorite, trachyte, and andesite. Actinolite is found in blades, needles, and fibres in schists, amphibolites, and epidiorites. Nephrite, a variety of actinolite, forms a closely knit plexus of minute fibres and blades in the hard and tough substance which is so much prized under the name of *jade*. Tremolite occurs in metamorphic limestones.

## THE OLIVINE GROUP.

The olivines are ortho-silicates of lime, magnesia, iron, and manganese. They crystallize in the rhombic system, and form an isomorphous series, of which the following are the chief members:

**Forsterite**: $2MgO.SiO_2$.
**Monticellite**: $CaO.MgO.SiO_2$.
**Fayalite**: $2FeO.SiO_2$.
**Tephroite**: $2MnO.SiO_2$.
**Common Olivine**: $2(Mg,Fe)O.SiO_2$.

Common olivine occurs in tabular or prismatic combinations of pinacoids and domes; also in irregular grains. Twinning on the brachydome (011). Colour, black, olive-green, or yellow. Lustre, vitreous. Transparent to translucent. Index of refraction, 1·678.

Double refraction, positive and strong ($\gamma - \alpha = \cdot036$). Optic axial plane (001). Brachy-pinacoidal cleavage, imperfect. Brittle. Fracture, conchoidal. Infusible. Decomposed by hydrochloric acid with separation of gelatinous silica.

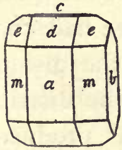

FIG. 76.—OLIVINE.
*c*, Basal plane; *a*, macro-pinacoid; *b*, brachy-pinacoid; *e*, pyramid; *m*, prism; *d*, macro-dome.

Certain yellowish-green and leek-green varieties of olivine are used as gem-stones, under the names of chrysolite and peridote.

As a rock constituent, olivine is characteristic of the basic and ultra-basic rocks, occurring in basalts, dolerites, and gabbros, and being the chief constituent of the peridotites. Under the influence of the weather and percolating waters it is peculiarly liable to alteration, giving rise in some cases to serpentine, with separation of iron ore, in others to dolomite or calcite.

## SECONDARY MINERALS.

The rock constituents described above have been produced by crystallization from a molten, or at least a plastic, condition; but a considerable proportion of the rocks that make up the earth's crust are composed of minerals that have been accumulated and deposited by water. Such rocks, for instance, are the sandstones, clays, shales, and many limestones. The minerals composing these rocks are of earlier origin than the rocks themselves, being derived from pre-existing mineral aggregates by processes of disintegration and denudation. These mineral aggregates, of course, may also have been of aqueous origin, but if we could trace back the history of such a series of changes sufficiently far, we should arrive finally at a primary crust, which must have had an igneous birth. The part played by water in the disintegration and decomposition of rocks, and in the distribution and rearrangement of the materials thus produced, is best exemplified by a specific case. Granite is a rock composed chiefly of quartz, felspar, with one or more micas or other ferro-magnesian constituent. Submitted to meteoric influences (rain, frost, percolating water, etc.), it decomposes into a loose, crumbling mass, which is ultimately washed away to form new combinations. Let us endeavour to trace the history of the three constituent minerals. First the quartz: this mineral, though chemically unaffected, becomes mechanically separated from its associates, and reduced by trituration to small partially rounded grains, in which condition it goes to form deposits of sand, and these when consolidated give rise to sandstone. Mixed with the quartz, one would naturally expect to find occasional fragments of felspar and of light mica; and such indeed is the case, as may be seen in certain felspathic and micaceous varieties of sandstone.

But most of the felspar is decomposed under the influence of acid surface waters: its alkalies are removed in solution as carbonates, and there remain behind certain hydrated silicates of alumina, which, although they constitute several distinct minerals, are for convenience generally referred to as *kaolin.* These substances are also found in clays, which are in great part derived from the decomposition of felspathic rocks.

Finally, the dark mica, or the ferro-magnesian constituent, is first converted into chlorite, which may in turn undergo decomposition, the products being removed in solution.

With regard to the dissolved portions, the alkalies (potash and soda) and alkaline earths (lime and magnesia) unite with materials derived from other sources to form chemical precipitates of various salts—*e.g.*, calcite, dolomite, magnesite, gypsum, rock-salt, etc.

Most of these minerals are included with the salts in Chapter III. (p. 208); but a few notes on chlorite, serpentine, talc, kaolinite, epidote, and the zeolites are appended here.

**Chlorite Group.**—The minerals included under this head are hydrated silicates of magnesia, iron and alumina, the water of which (about 12 per cent.) is only given off at a high temperature. Monoclinic, with pseudo-hexagonal symmetry. Generally in small scales or fibres, sometimes aggregated to spherular or spiral forms.

The well-crystallized varieties are known as *orthochlorites;* those that occur in scales and fibres, *leptochlorites.* The orthochlorites are regarded by Tschermak as isomorphous mixtures of a serpentine molecule (Sp) and an amesite molecule (At).

The isomorphous series may be represented thus:

**Serpentine**: Sp = $2H_2O.3(Mg,Fe)O.2SiO_2$.
**Penninite**: Sp. At.
**Prochlorite**: $Sp_3$, $At_{17}$.
**Corundophilite**: Sp. $At_4$.
**Amesite**: At = $2H_2O.2(Mg,Fe)O.Al_2O_3.SiO_2$.

The chlorites are dark green in colour. Streak, white. Index of refraction, 1·6. Double refraction, weak ($\gamma - \alpha = 0·003$). Basal cleavage, perfect. The cleavage flakes are pliable, not elastic, as with mica. Hardness, 2-3. Density, 2·6-3·0. Fusible with difficulty. Decomposed by sulphuric acid.

In one form or another the chlorites are a very frequent alteration product, especially in the more basic igneous rocks. The green colour of many of the latter (greenstones) is due to the presence of the mineral.

**Serpentine.**—Hydrated silicate of magnesia and iron: $2H_2O.3(Mg,Fe)O.2SiO_2$. Crystal system, uncertain. Occurs massive as an aggregate of blades, scales, and fibres. Colour, dull green, often stained red and yellow by iron oxides. Lustre, dull to resinous. Translucent to opaque. Streak, white to grey. Hardness, 3-4. Density, 2·5-2·7. Index of refraction, 1·57. Double refraction, negative, moderate ($\gamma - \alpha = 0·01$). Fusibility, 6. Decomposed by hydrochloric acid.

Occurs as an alteration product of olivine and other ferro-magnesian silicates. Veins of fibrous serpentine (*chrysotile*) are worked as a source of commercial asbestos. In these the direction of the fibres is at right angles to the vein, whereas in fibrous hornblende, which is also known and used as asbestos, the long axis of the fibres is parallel to the seams in which they occur.

**Talc**, steatite, or soapstone, is a hydrated silicate of magnesia ($H_2O.3MgO.4SiO_2$) crystallizing in the monoclinic system, but with pseudo-hexagonal symmetry. It is a pale green or colourless mineral, very soft, and with a greasy feel. Lustre, pearly. Translucent. Index of refraction, 1·55. Double refraction, strong ($\gamma - \alpha = 0{\cdot}040$). Hardness, 1. Density, 2·7-2·8. Cleavage, basal; flakes, non-elastic. Fusibility, 6. Insoluble in acids. Talc occurs as an alteration product of magnesian minerals in igneous and metamorphic rocks.

**Kaolinite** is a constituent of kaolin, and probably of all clays. It is a hydrated silicate of alumina ($2H_2O.Al_2O_3.2SiO_2$), crystallizing in the monoclinic system, but with pseudo-hexagonal symmetry. It occurs in minute colourless six-sided plates and scales. Hardness, 1-2. Density, 2·34-2·57.

Kaolinite is one of the minerals produced in the alteration of felspar. Under the influence of the change known as *kaolinization*, felspar loses its glassy appearance, becomes dull, and finally crumbles down into a white mealy powder (kaolin), which contains kaolinite. Kaolin mixed with quartz is, consequently, often found in the immediate neighbourhood of granite.

**Epidote.**—Silicate of lime, alumina, and iron: $H_2O.4CaO.3(Al,Fe)_2O_3.6SiO_2$. Monoclinic with elongated habit parallel to the orthodiagonal axis. Colour, yellowish green. Lustre, vitreous. Translucent. Streak, grey. Index of refraction, 1·75. Double refraction, negative, strong ($\gamma - \alpha = 0·04$). Perfect cleavage parallel to the basal plane. Hardness, 6·5. Density, 3·4. Fracture, uneven. Fusibility, 3·5. Partially decomposed by hydrochloric acid.

Epidote occurs as a frequent alteration product of the ferro-magnesian minerals, in gabbros, diorites, epidiorites, and hornblendic and chloritic schists. It is also found veining these rocks, or associated with other secondary minerals in the amygdules of old lavas.

**The Zeolite Group.**—A group of hydrated silicates of various bases: alumina, potash, soda, lime, baryta, and strontia. They are secondary products, occurring in igneous rocks as the infillings of amygdaloidal cavities (especially of melaphyres and basalts), or as pseudomorphs after decomposed minerals (*e.g.*, nepheline).

Generally speaking, the zeolites are colourless to white, and occur in fibrous and radiate aggregates. The index of refraction is low. All of them also exhibit low double refraction. They are easily decomposed by hydrochloric acid, with separation of gelatinous silica.

Some of the more commonly occurring varieties are: **heulandite, natrolite, analcime, phillipsite, laumontite, scolecite,** and **apophyllite.** The composition of these is given in the following tables:

| Name. | Crystallographic System. | Formula. |
|---|---|---|
| Heulandite ... | Monoclinic | $H_4CaAl_2(SiO_3)_6+3H_2O$ |
| Natrolite ... | Rhombic | $Na_2Al_2Si_3O_{10}+2H_2O$ |
| Analcime ... | Regular | $NaAl(SiO_3)_2+H_2O$ |
| Phillipsite ... | Monoclinic | $(K_2,Ca)Al_2(SiO_3)_4+4\frac{1}{2}H_2O$ |
| Laumontite ... | Monoclinic | $H_4CaAl_2Si_4O_{14}+2H_2O$ |
| Scolecite ... | Monoclinic | $Ca(AlOH)_2(SiO_3)_3+2H_2O$ |
| Apophyllite ... | Tetragonal | $H_7KCa_4(SiO_3)_8+4\frac{1}{2}H_2O$ |

| Name. | Percentage Composition. | | | | | |
|---|---|---|---|---|---|---|
| | $SiO_2$. | $Al_2O_3$. | CaO. | $Na_2O$. | $K_2O$. | $H_2O$. |
| Heulandite ... | 59·2 | 16·8 | 9·2 | — | — | 14·8 |
| Natrolite ... | 47·4 | 26·8 | — | 16·3 | — | 9·5 |
| Analcime ... | 54·5 | 23·2 | — | 14·1 | — | 8·2 |
| Phillipsite ... | 48·8 | 20·7 | 7·6 | — | 6·4 | 16·5 |
| Laumontite ... | 51·1 | 21·7 | 11·9 | — | — | 15·3 |
| Scolecite ... | 45·9 | 26·0 | 14·3 | — | — | 13·8 |
| Apophyllite ... | 53·7 | — | 25·0 | 5·2 | — | 16·1 |

## MINERALS OF THE GRANITE CONTACT ZONE.

**Andalusite.**—Silicate of alumina: $Al_2O_3.SiO_2$ (silica, 36·8; alumina, 63·2 per cent.). Rhombic; occurring in square thick-set prisms, terminated by the basal plane.

Crystals of this mineral usually appear dark-coloured (reddish-brown), owing to the presence of included carbonaceous matter. In thin section, however, the grains are either colourless or pink. Lustre, vitreous. Translucent. Streak, colourless. Index of refraction, 1·638. Double refraction, negative, moderate ($\gamma - a =$ ·011). Cleavage prismatic. Fracture, uneven. Brittle. Hardness, 7-7·5. Density, 3·1-3·2. Infusible. Insoluble in acids. Occurs in slates and shales that have undergone metamorphism in contact with granite; also in gneisses and crystalline schists, and as an accessory constituent of granite (*e.g.*, at the Cheesewring in Cornwall). **Chiastolite** is a variety of andalusite, containing graphitic material arranged along the diagonals of the prism. It is found in small light-coloured prisms in chiastolite-slate in the neighbourhood of granite (*e.g.*, Skiddaw).

**Sillimanite.**—Silicate of alumina: $Al_2O_3.SiO_2$ (silica, 36·8; alumina, 63·2 per cent.). Rhombic; with prismatic habit, without definite terminal faces, often in long and slender crystals; sometimes fibrous (*fibrolite*). Colour, brown to greyish-green; in thin section, colourless. Lustre, vitreous. Transparent. Streak, white. Index of refraction, fairly high (1·667); double refraction, moderate, stronger than that of andalusite. Cleavage parallel to the brachypinacoid, perfect. Hardness, 6-7. Density, 3·23-3·24. Infusible. Insoluble in acids. Occurs in gneisses and crystalline schists, often in the aureoles of metamorphism around granite, in association with cordierite, corundum, andalusite, and kyanite.

**Kyanite.**—Silicate of alumina: $Al_2O_3.SiO_2$ (silica, 36·8; alumina, 63·2 per cent.), like sillimanite and andalusite. Triclinic; usually in long prismatic crystals.

Colour, white to blue. Lustre, vitreous. In thin section, colourless to pale blue, with weak pleochroism. Index of refraction, high (1·72). Double refraction, negative, strong ($\gamma - \alpha = 0·016$). Cleavage parallel to the macropinacoid, perfect, with partings parallel to the basal plane. Fracture, fibrous. Brittle. Hardness = 4 - 7. Density = 3·5 - 3·7. Kyanite occurs in gneisses and crystalline schists in association with garnet, staurolite, and sillimanite; often in the aureoles of metamorphism round granite. It is also found in sands and clays in association with rutile, tourmaline, zircon, etc. According to Vernadsky, kyanite, when heated to 1300° C., is converted into sillimanite.

**Staurolite.**—Hydrated silicate of alumina, iron, and magnesia: $2H_2O.6(Fe,Mg)O.12Al_2O_3.11SiO_2$. Rhombic. In prismatic forms terminated by the basal plane; commonly twinned, forming symmetrical Maltese and St. Andrew's crosses. Colour, reddish-brown. Lustre, vitreous to resinous. Translucent to opaque. Index of refraction, high (1·74). Double refraction, moderate but slightly stronger than quartz. Brachypinacoidal cleavage, perfect. Fracture, conchoidal to uneven. Hardness, 7-·75. Density, 3·3-3·8. Infusible. Unattacked by acids. Occurs in the crystalline schists, and in rocks of the granite contact-zone.

**Cordierite.**—Hydrated silicate of alumina, iron, and magnesia: $H_2O.4(Mg,Fe)O.4Al_2O_3.10SiO_2$. Rhombic; with pseudo-hexagonal symmetry. Often twinned. Colour, dark blue; in thin section usually colourless.

Lustre, vitreous to resinous. Transparent to translucent. Pleochroic. Refractive index, 1·536. Double refraction ($\gamma - \alpha = \cdot 007$), slightly lower than that of quartz. Brachypinacoidal cleavage perfect. Parting parallel to basal plane. Fracture, subconchoidal. Hardness, 7-7·5. Density, 2·6.

Cordierite occurs in granites and gneisses (cordierite-gneiss); more rarely in volcanic rocks (*e.g.*, basalt, andesite). It alters easily into mica-like decomposition products (pinite, esmarkite, praseolite, gigantolite, etc).

**Idocrase** or vesuvianite.—Hydrated silicate of lime and alumina; probably $2H_2O.12CaO.3Al_2O_3.10SiO_2$. Small quantities of manganese, iron, magnesium, and alkalies, are often present. Tetragonal. In square prisms, with basal plane and pyramid. Colour, dark green, brown, red, or yellow. Lustre, vitreous. Index of refraction, high (1·72). Double refraction, weak ($\omega - \epsilon = \cdot 001$). Prismatic cleavage imperfect. Fracture, uneven. Hardness, 6-7. Density, 3.35-3.45. Fusibility, 3. Scarcely attacked by acids. Occurs in limestones that have undergone alteration by contact with igneous rocks.

**Axinite.**—A borosilicate of calcium and aluminium: $7CaO.2Al_2O_3.B_2O_3.8SiO_2$, in which lime may be partially replaced by manganese, iron, and magnesium. Triclinic. In broad crystals with acute edges. Colour, honey-yellow to clove-brown. In thin section, colourless to pale yellow or violet. Lustre, vitreous. Transparent to translucent. Index of refraction, high (1·677).

Double refraction, moderate ($\gamma - \alpha = {\cdot}009$). Brachypinacoidal cleavage, distinct. Fracture, conchoidal to uneven. Brittle. Hardness, 6·5-7·0. Density, 3·271-3·29. Occurs in the contact-aureoles of granite.

**Topaz.**—A silicate and fluoride of aluminium: $Al_2O_2(OH,F)_2.SiO_2$. Rhombic. In short prismatic crystals with pyramidal and basal terminations. Colourless, wine-yellow or tinted blue, red, or green. In thin section, colourless. Lustre, vitreous. Transparent to translucent. Index of refraction, 1·62. Double refraction, moderate ($\gamma - \alpha = {\cdot}009$). Basal cleavage, perfect. Hardness, 8. Density, 3·4-3·6. Infusible, and unattacked by acids. Occurs in some granites and pegmatites; also in the contact-aureoles of granite.

**Datolite.**—A basic orthosilicate of calcium and boron: $H_2O.2CaO.B_2O_3.2SiO_2$ with $SiO_2 = 37{\cdot}6$, $B_2O_5 = 21{\cdot}8$, $CaO = 35{\cdot}0$ and $H_2O = 5{\cdot}6$ per cent. Monoclinic. In stumpy, prismatic forms, or irregular grains. Colourless to white. Lustre, vitreous. Transparent to translucent. Index of refraction, moderate (1·65). Double refraction, very strong ($\gamma - \alpha = {\cdot}0448$). No defined cleavage. Fracture, subconchoidal. Hardness, 5. Density, 2·9-3·0. Fusibility, 2-2·5. Not attacked by acids. Occurs in association with zeolites and calcite in the amygdaloidal cavities of basalt; also in the zones of contact-metamorphism.

# CHAPTER II

## THE ORES

THE ores are those minerals from which the metals can be profitably extracted. They consist of the oxides, sulphides, chlorides, carbonates, sulphates, etc., of the metals, and, in a few cases, of the native metals themselves—*e.g.*, gold, platinum, silver, and copper. Although they exceed the rock-forming minerals in number, in bulk they constitute an insignificant fraction of the earth's crust, occurring as ore-bodies in its fissures and cavities, or as small particles and grains disseminated through its constituent rocks. Only exceptionally are masses of ore encountered that are large enough to bear comparison with the rocks themselves—*e.g.*, in the case of certain iron ores.

It is outside the scope of this small book to discuss either the mode of occurrence or the genesis of the ore-deposits. For the present purpose it must suffice to distinguish between (1) *ore-deposits formed in situ*, whether occurring as lodes, veins, masses, or beds, and of whatever mode of origin—whether formed by magmatic differentiation (*i.e.*, concentration in an igneous magma), pneumatolysis (deposition from vapours), hydatogenesis (deposition from water), or metasomasis (chemical replacement); and (2) *detrital or placer deposits*, in which the minerals have been derived by erosion from pre-existing formations, and have been accumulated in hill-talus, river-gravels, or sea-beaches —*e.g.*, alluvial gold, stream tin, and iron sand.

The first-named is by far the larger of the two classes of ore-deposits, and is in general also the more important as a source of the metals. For, although a larger quantity of gold or tin may in any given district be temporarily won from superficial detrital deposits ('placers'), these become comparatively soon exhausted, or their working is prohibited by State legislation on account of the injury done to the soil by the disposal of the débris from the gold-washings;* and the miner must then perforce turn his attention to the more lasting veins and beds of ore that extend deep down into the crust of the earth. Here again a further distinction is necessary between the *primary ores*, found in those parts of the lodes and beds that are below the permanent water-level, and the *secondary, oxidized ores* that characterize those superficial portions within the belt of weathering. Whereas the latter are remarkable for their variety and complexity, and comprise the bulk of the multifarious minerals classed as ores, the former are in general limited to a few simple sulphides.

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* Thus, Central California, which at one time had an output of gold from placer-mining, valued at three and a half millions sterling per annum, has, in consequence of the action of the State, entirely ceased to produce gold from this class of deposit.

Thus, the great class of secondary copper ores are derived in the main from the primary sulphide of copper and iron known as *chalcopyrite* or *copper pyrites*. Similarly, both lead and silver ores mostly take their origin from primary sulphides of these metals, which often occur in isomorphous association in the same mineral (*galena*). Again, *blende* (sulphide of zinc) is the primary source of zinc ores, and also of rather rare cadmium minerals, the two metals being closely allied and frequently associated.

Gold, also, although not chemically combined with, is closely associated with, and even mechanically included in, *pyrites*, *chalcopyrite*, and *mispickel*, and is only set *free* by the breaking down (oxidation) of these pyritic ores when brought within the zone of weathering by the natural lowering of the ground-water level during the ordinary process of denudation.

In the following pages a brief description is given of the metals: platinum, gold, mercury, copper, silver, lead, zinc, nickel, cobalt, iron, manganese, bismuth, antimony, arsenic, vanadium, tin, titanium, molybdenum, tungsten, uranium, and aluminium.

### ORES OF PLATINUM.

The native metal is the sole source of commercial platinum. A compound with arsenic (*sperrylite*) is known, but it has only been found in one or two places. On account of its infusibility and the difficulty with which it is attacked by acids, platinum constitutes a valuable material for chemical vessels — crucibles, dishes, etc. It is also largely used in the electric light industry and in the dental and photographic trades, as well as by manufacturing jewellers. At £8 per ounce, it is almost twice as valuable as gold.

**Native Platinum** occurs in small flattened grains and scales, but occasionally in larger nuggets. It crystallizes in the regular system; but crystals are rare, only small cubes having been occasionally found. Its colour lies between a steel grey and a silver white. It takes a higher polish than silver. Hardness, 4·5-5; fracture, hackly; density, 14-19, amounting in chemically pure platinum to 21·5. Platinum is thus one of the heaviest metals known. Malleable and ductile. Infusible before the blowpipe, except in the very thinnest wire. Insoluble in acids, except aqua regia, in which it is easily dissolved to platinum chloride. It is also attacked by caustic alkalies.

Platinum occurs as a primary constituent of the peridotites of the Urals (Nischne Tagilsk, Mount Solovief); but the chief source of supply are the placers in the valleys of the rivers (Issa, Wyja, Tura, and Njassma) draining the same districts. It is associated in the sands of these placers with chromite and magnetite. The ore consists of a mixture of platinum with osmium-iridium, and the metal is besides alloyed with palladium, rhodium, iridium and smaller quantities of osmium and iridium. Iron is invariably present, in quantities from 4 to 13 per cent. The output of the Russian deposits amounts to 200,000 ounces per annum.

Outside Russia, the State of Colombia (districts of Choco and Barbacoas) is the largest producer (7,000 ounces per annum). It is also found in British Columbia (Tulameen River), Northern California, Brazil (Minas Geraes), Assam, Borneo, and New Zealand (River Tayaka).

**Sperrylite.**—Arsenide of platinum: $PtAs_2$ (platinum 56·47 per cent.). Crystallizes in the regular system, with pentagonal hemihedrism. Habit, cubic or octahedral. Colour, tin white. Opaque. Lustre, metallic. Streak, black. Fracture, conchoidal. Brittle. Hardness, 6-7. Density, 10·6. Infusible. Soluble in aqua regia.

A rare mineral, and only interesting as the one ore of platinum known besides the native metal. Occurs in Ontario, Canada (Vermilion Mine), and North Carolina (Cowee Valley).

### ORES OF GOLD.

The chief supply of the noble metal is *native gold*, other ores being comparatively rare. It is true the tellurides (*sylvanite*, *krennerite*, *calaverite*, *petzite*, etc.) are worked in a few places, but, in proportion to the production of the whole world, the supply from this source is extremely small. *Gold amalgam* (a compound of the noble metal with mercury) is of no importance as an ore.

The original source of the bulk of native gold is in auriferous quartz veins, and in conglomerate beds (" banket "); but a small proportion is possibly a primary *syngenetic* constituent of ingenous rocks. Within the belt of weathering the gold of these deposits occurs free, and the ore is "free-milling"—*i.e.*, it is amenable to amalgamation when, after suitable crushing, the ore mixed with water (the *pulp*) is passed over copper plates coated with quicksilver; but below the permanent water-level it is closely associated with, and to a considerable extent mechanically included in, pyrites (*auriferous pyrites*), and in the treatment of such ores ("pyritic ores") it is essential to reduce them to a sufficient state of fine subdivision to enable the gold to be extracted by cyanide solution. What the exact genetic relation is between the pyrites and the gold has not been satisfactorily settled, but it is clear that a community of origin is indicated.

Besides being associated with pyrites, gold, being isomorphous with silver, lead, and copper, is almost always present in the ores of these metals, and it is usually an important by-product both in the metallurgy of silver and of copper. Sometimes, however, the gold is, from the economic standpoint, the dominant constituent, as in the gold-copper pyrrhotite veins of Rossland in British Columbia, and in the gold-silver telluride veins of Transylvania, of Cripple Creek in Colorado, of Tonapah in Nevada, of Mexico, and of Kalgoorlie in West Australia.

A large quantity of gold is won from transported material. Such are the screes and talus débris of mountain slopes (*drift gold*), the sands of the rivers that drain them (*alluvial gold*), and the beach gravels that accumulate near the mouths of the rivers (*beach placer gold*). Transported or *placer* gold is derived from the disintegration of the gold-bearing quartz veins, so common in the old crystalline rocks of mountain districts. The metal is also found in mudstones, sandstones and conglomerates, in which it may have either accumulated at the time of the formation of the deposit or been introduced subsequently by deposition from solution.

The most important gold-fields are situated in Australasia (Western Australia, Victoria, New South Wales, Queensland, New Zealand), the United States (California, Nevada, Arizona, Montana, Colorado, and Alaska), Canada (British Columbia and the Yukon), Mexico, Colombia, Venezuela, Guiana, Chili, Peru, Brazil, South Africa (Witwatersrand, Barberton, and Lydenburg, in the Transvaal, and Rhodesia), West Coast of Africa, East Indies (Sumatra, Java, Borneo), British India (Kolar gold-field in Mysore), Russia (Siberia and the eastern slopes of the Ural Mountains).

**Native Gold** crystallizes in the regular system; but crystal forms (as a rule, octahedral or dodecahedral) are rare, indistinct, and distorted. More usually it occurs in branched or wiry aggregates, in leaf-like expansions, or in a finely divided condition as *mustard gold*, *paint gold*, and *sponge gold*; also as minute grains, generally in intimate association with pyrites disseminated through quartz. It is also found in gravels and sands as dust, and in loose grains and nuggets. Large nuggets are occasionally found: thus, one from Upper

California weighed 161 pounds; and others have been found in Australia, one of which yielded 2,268 ounces of gold.

Gold is the most malleable and the most ductile of all metals. It is soft, having a hardness of only 2·5-3. Its fracture is hackly. Its colour and streak vary from a reddish to a brassy yellow, the variation being caused by the presence of small quantities of silver and copper. The amount of silver present in native gold varies from 1 to 40 per cent.; alloys with over 20 per cent. are termed *electrum*. The density of native gold ranges from 15·6 to 19·4, being less with increasing percentage of silver. The density of pure gold is 19·37. The metal is insoluble in single acids, but dissolves readily in a mixture of nitric and hydrochloric acids (aqua regia). Fusible with ease in the flame of the blowpipe (2·5-3 on Von Kobell's scale).

**Auriferous Pyrites.**—In the deeper-seated portions of quartz veins, the gold is often found in intimate but mechanical association with iron, copper, arsenical, or magnetic pyrites; and no doubt a considerable proportion of the so-called "free gold" occurring in the oxidized (weathered) zone of gold-bearing deposits has been liberated by the decomposition of these minerals.

**Gold Amalgam.**—An alloy of gold with mercury. In soft, yellowish-white grains and balls. Density, 15·5. Occasionally accompanies native gold in California and Colombia.

**Calaverite.**—Telluride of gold: $AuTe_2$ (Au 44·03, Te 55·97, per cent.). As a rule silver is also present. Occasionally crystallized in striated crystals of prismatic habit, but more commonly massive. Colour, bronze yellow, with metallic lustre. Fracture, uneven to semi-conchoidal. Brittle. Hardness, 2-3. Density, 9. Fuses easily (1 on Von Kobell's scale), yielding on charcoal before the blowpipe a globule of gold. Soluble in aqua regia. Occurs in California (Calveras County), Colorado (Cripple Creek) and Western Australia (Kalgoorlie).

**Sylvanite.**—Telluride of gold and silver: $AuAgTe_4$ (Au 24·45, Ag 13·39, Te 62·16, per cent.). Crystallizes in the monoclinic system, with tabular habit after the clinopinacoid (010), or with predominant orthodome (101) and basal plane (001), or pseudo-rhombic with dominant pinacoids (010) and (100). Often twinned and reticulated (*graphic tellurium*), and in scaly to granular aggregates. Colour and streak, silver white to steel grey, with metallic lustre. Cleavage, perfect parallel to the clinopinacoid. Fracture, uneven. Sectile. Hardness, 1-2. Density, 7·9-8·3. Easily fused (1 on Von Kobell's scale). Imperfectly soluble in nitric acid (with separation of gold); soluble in aqua regia, with separation of silver chloride. Occurs in Transylvania in Hungary, Colorado (Cripple Creek), Western Australia (Kalgoorlie).

**Krennerite.**—Telluride of gold and silver: $(Au,Ag)Te_2$ (the percentage of gold varies from 24·45 to 44·03). Crystallizes in the rhombic system, with prismatic habit and basal termination. Vertically striated. Colour, silver white to light brassy yellow, with metallic lustre. Cleavage, perfect parallel to the basal plane. Fracture, uneven to semi-conchoidal. Hardness, 2-3. Density, 8·35. Easily fusible (1 on Von Kobell's scale). Occurs in Transylvania (Nagyag), Colorado (Cripple Creek), and West Australia (Kalgoorlie).

**Petzite.**—Telluride of silver and gold: $(Ag,Au)_2Te$. When free from gold, petzite contains theoretically 63·27 per cent. of silver; it may contain, however, as much as 25 per cent. of gold. With Ag : Au = 3 : 1, the percentages are—silver, 42; gold, 25·5. Crystallizes in the regular system, in cubes or distorted forms; also massive or granular. Colour, leaden grey to steel grey, with metallic lustre. Hardness, 2-3. Density, 8·3-9·0. Fracture, uneven to semi-conchoidal. Sectile to brittle. Easily fusible (1·5). Occurs in the Altai, Transylvania, California, Colorado (Cripple Creek), and other places.

## ORES OF MERCURY.

The only important source of mercury is the sulphide, *cinnabar;* but the metal also occurs, though rarely, in the native state, globules of quicksilver being found as an alteration product in the oxidation zone of quicksilver deposits. *Metacinnabarite,* the black sulphide, is also an alteration product of cinnabar, and other rare associates are the chloride, the telluride, and the selenide of mercury. A gold amalgam (Au,Hg) and a silver amalgam (Ag,Hg) are also known, but on account of their rarity they are of no importance as ores. Mercury finds a variety of uses in the arts: it is greatly used in the extraction of gold and silver from their ores (in the so-called "amalgamation" processes), in dentistry, and in the manufacture of scientific instruments (*e.g.*, the barometer and thermometer); its salts are also employed in medicine.

**Cinnabar.**—Sulphide of mercury: $HgS$ (mercury 86·2 per cent.). Crystallizes in the hexagonal system, with rhombohedral hemihedrism. Occurs in thick tabular crystals, composed of the basal plane in combination with a series of rhombohedral faces. More frequently, however, it is found massive or as an earthy incrustation. Colour, a bright crimson or cochineal red. Streak, scarlet. Transparent to translucent. Lustre, adamantine. Prismatic cleavage, perfect. Fracture, conchoidal to uneven. Sectile. Hardness, 2 - 2·5. Density, 8-8·2. Volatile before the blowpipe. Heated carefully in the open tube, yields metallic mercury and fumes of sulphur. Decomposed by aqua regia, with separation of sulphur.

Cinnabar is important as the sole source of the mercury of commerce. It occurs in veins, irregular masses, or disseminated in grains through sandstone, and is often accompanied by pyrites, marcasite, chalcopyrite, stibnite, realgar, and mispickel.

The chief mines are in Southern Spain (Almaden), Austria (Idria in Carniola), Italy, Russia, California

(New Almaden, New Idria, Sulphur Bank, Clear Lake), Mexico (Guadalcazar, Huitzuco), Peru (Huancavelica), China (Kweichou).

## ORES OF COPPER.

Copper, one of the earliest metals known to man, was much prized by the ancients on account of its toughness. It was used by them, for instance, in an alloy with one-tenth of its weight of tin, for the manufacture of weapons and tools. The alloy with zinc (brass) was also in great use for ornamental work. There are a great number of minerals containing copper, but comparatively few are of commercial importance as a source of the metal. In the upper weathered portion of the lodes are found the oxidized ores, which, besides the oxides, *cuprite* and *melaconite*, include the carbonates, *malachite* and *chessylite;* the silicate, *chrysocolla;* the sulphate, *chalcanthite;* the sulphide, *covellite;* and *native copper.* In the zone of secondary enrichment which occurs immediately below the belt of weathering are found the rich sulphides, *chalcocite* and *bornite*, and the sulpharseniate, *enargite;* while in the deepest parts of the deposits the copper is confined to the primary ore, *chalcopyrite*, either alone or in association with iron pyrites (*cupriferous pyrites*). Besides these simple compounds, copper is also obtained in considerable quantity from certain complex ores, such as the sulphantimonite and sulpharsenite of copper, silver, iron, and zinc (*e.g.*, *fahl-ore* and *tennantite*).

Copper is one of the most valuable metals employed in the arts, and perhaps its greatest application is as a conductor of electricity. A great quantity also goes into consumption in the form of sheet copper or as castings, and the metal is largely used in the manufacture of brass, bronze, and other alloys, in electrolysis, and as a chemical agent in the form of blue vitriol (copper sulphate) and other salts.

The production of copper is about 847,000 tons (of 2,240 pounds) per annum (1910), distributed as follows:

| | Tons. |
|---|---|
| United States ... ... ... | 483,000 |
| Mexico ... ... ... | 59,000 |
| Spain and Portugal ... ... | 48,000 |
| Australasia ... ... ... | 42,000 |
| Chili ... ... ... ... | 41,000 |
| Japan ... ... ... ... | 41,000 |
| Germany ... ... ... | 24,000 |
| Russia ... ... ... | 23,000 |
| Canada ... ... ... | 22,000 |
| Peru ... ... ... ... | 20,000 |
| Africa ... ... ... ... | 16,000 |
| Other countries ... ... ... | 28,000 |
| | 847,000 |

**Native Copper.**—Regular. When crystallized, this metal occurs in small and large crystals, having the forms of the octahedron, the cube, and the rhombic dodecahedron, all of which are usually much distorted, and aggregated to irregular branching masses. Most frequently, however, no crystalline form is visible, the metal occurring in irregular lumpy masses, in wiry and mossy coils, or as foil and in plates. Its colour is the familiar copper-red, but the surface is often tarnished, and is then of a dirty yellow or brown colour. Lustre, metallic. The metal is malleable, ductile, and tenacious. No cleavage. Fracture, hackly. Its hardness is 2·5 - 3; its density, 8·5 - 8·9; and its fusibility, 3 on Von Kobell's scale. Native copper is usually chemically pure, but it sometimes contains iron and silver. Soluble in nitric and hydrochloric acids.

Copper occurs, chiefly in association with secondary ores,* in Cornwall and many places in Europe, Siberia, Brazil, Chili, Bolivia (Corocoro), Australia and Tasmania, the United States (*e.g.*, in the copper-mines of Lake Superior). A great mass, weighing 400 tons, was discovered in one of the mines at the last-named locality, and forty men were employed for twelve months in its extraction.

**Cuprite**, or red copper ore.—Copper monoxide or cuprous oxide: $Cu_2O$ (copper 88·8 per cent.). Crystallizes in the regular system, in well-formed octahedra, either alone or in combination with the cube and the rhombic dodecahedron. It is also found massive and granular, or as a brick-red earth (*tile ore*). It has a brilliant cochineal-red colour, which is best seen in transparent, or at least translucent, crystals,

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* Metallic copper is easily produced from cuprite by the action of sulphuric acid: $Cu_2O + H_2SO4 = Cu + CuSO4 + H_2O$.

or on reducing opaque specimens to powder. Lustre, metallic to adamantine, and streak, brownish-red. Its octahedral cleavage is fairly perfect. Fracture, conchoidal to uneven. Brittle. Hardness, 3·5-4. Density, 5·7-6·2. Fusibility (Von Kobell's scale), 2·5-3. Before the blowpipe on charcoal it yields a metallic globule of copper. The ease with which it can be reduced makes it one of the best ores for the extraction of the metal, but it is only found as a decomposition product in the upper or oxidized portions of copper sulphide lodes.

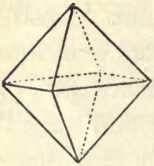

FIG. 77.—CUPRITE. Octahedron.

Of widespread occurrence, if limited in quantity—for instance, in Cornwall (Liskeard, Redruth), France (Chessy), Nassau, Harz, Saxony, Silesia, Bohemia, Hungary, Italy, Spain, Siberia, Australia (Wallaroo, Moonta, Burra Burra, and Cobar), Tasmania (Mount Lyell), Namaqualand in South Africa, Arizona (Clifton, Morenci, Bisbee, and Globe), Lake Superior, Alaska (Mount Wrangell), Mexico (Boleo), Peru, Chili, Bolivia (Corocoro), etc.

**Melaconite**, or tenorite.—Black oxide of copper, or cupric oxide: $CuO$ (copper 79·86 per cent.). Crystallizes in the triclinic system, with pseudo-monoclinic symmetry and tabular habit (100). Twinning parallel to the macropinakoid (100) and the brachydome (011). Also massive, powdery, earthy, scaly, and cellular. Colour, black to grey. Lustre, metallic to dull.

Opaque. Streak, dirty green. Cleavage, basal. Fracture, conchoidal to uneven. Thin flakes are elastic. Hardness, 3-4. Density, 5·8-6·3. Fusibility, 3. Soluble in hydrochloric and nitric acids.

Occurs in the oxidized portion of copper lodes as a decomposition product of chalcopyrite, bornite, etc., but not in sufficient quantity to be of great importance as a source of copper. It is found on Vesuvius in lava as a sublimation product. Other localities are Cornwall, Spain (Huelva), Siberia (Bogoslowsk and Nischne Tagilsk), Japan, Australia, Bolivia, Mexico (Boleo), Chili, Peru, United States (Tennessee, Arkansas, and Michigan).

**Chalcocite**, copper glance, or redruthite.—Sulphide of copper: $Cu_2S$* (copper 79·83 per cent.). Crystallizes in the rhombic system. The crystals have a pseudo-hexagonal symmetry, occurring often in flat six-sided tablets, composed of pyramids and brachydomes, or of prisms and brachypinacoids, terminated in both cases by the basal plane. They are frequently twinned, the twinning plane being a face of the prism. More frequently, however, the ore is massive, platy, or nodular. Colour, dull black. Lustre, metallic. Superficially often iridescent or tarnished by incipient alteration to covellite or bornite. Streak,

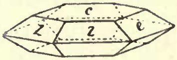

FIG. 78.—COPPER-GLANCE.
*c*, Basal plane; *z*, pyramid; *e*, brachydome.

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* The impure sulphide, CuS (with copper 66·9 per cent.), **Covellite**, is a blue microcrystalline mineral (hexagonal), and rather rare.

blackish-grey. Opaque. Prismatic cleavage, imperfect. Fracture, conchoidal. Slightly sectile. Hardness, 2·5-3. Density, 5·5-5·8. Fusibility, 2-2·5. After careful washing and rinsing with carbonate of soda, yields, before the blowpipe, a globule of copper.

Chalcocite is a rich ore of copper, of frequent occurrence in copper lodes, especially in the zone of secondary enrichment. Notable examples are to be found in Cornwall, Saxony, Hungary (Kapnik, Rézbánya, Oravicza), Italy (Monte Catini), Caucasus (Kiadebek), Eastern Russia (Bogoslowsk, Nischne Tagilsk, Spassky), South-West Africa (Namaqualand), Transvaal (Messina), Australia (Wallaroo, Moonta, Burra Burra), Japan (Ashio, Besshi), Alaska (Mount Wrangell), California (Shasta County), Montana (Anaconda, near Butte), Arizona (Bisbee, Jerome, Clifton, etc.), Bolivia (Corocoro).

**Chalcopyrite**, or copper pyrites. — Sulphide of copper and iron, or sulphoferrite of copper: $Cu_2S.Fe_2S_3$ (copper 34·56, iron 30·52 per cent.). Tetragonal, the commonest form being the hemihedral sphenoid; but the crystals are usually small and distorted, and consequently difficult to determine. Twinning on various types; most frequently with (111) as twinning plane (see Fig. 77). Mostly, however, it occurs massive, in large nodular, kidney-shaped, or botryoidal masses, and in scattered grains and specks. Its colour is brassy to golden yellow, being a stronger yellow than that of iron pyrites. The surface of the mineral is often iridescent in blue or red tints, which are the result of tarnish (*peacock ore*). Streak, black. Cleavage, parallel to (201), imperfect. Fracture, conchoidal to imperfect. Hardness, 3·5-4. Density, 4·1-4·3. Fusibility, 2. Before the blowpipe, on charcoal, yields black magnetic globule; when mixed with carbonate of soda yields a ferruginous copper globule. Dissolves in nitric acid, with separation of sulphur. It may be distinguished from iron pyrites by its less hardness, and from gold by its brittleness, since it crumbles under the point of the knife.

Chalcopyrite is the most widely distributed of all copper ores, and is responsible for the bulk of the world's output of copper. It occurs as a mineral of sedimentary origin, as a product of magmatic concentration in igneous rocks, and as a true vein deposit. A well-known example of the sedimentary ores is the Kupferschiefer, a thin bed of bituminous shale in the Zechstein (Permian) formation of the Southern Harz, in which chalcopyrite occurs as a fine dust in association with bornite, chalcocite, iron pyrites, and galena. These sulphides have been deposited from a solution of the metallic sulphates by the reducing

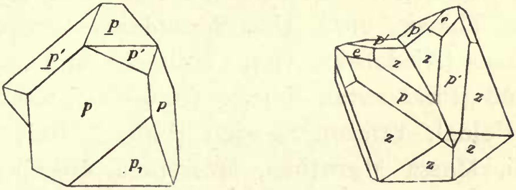
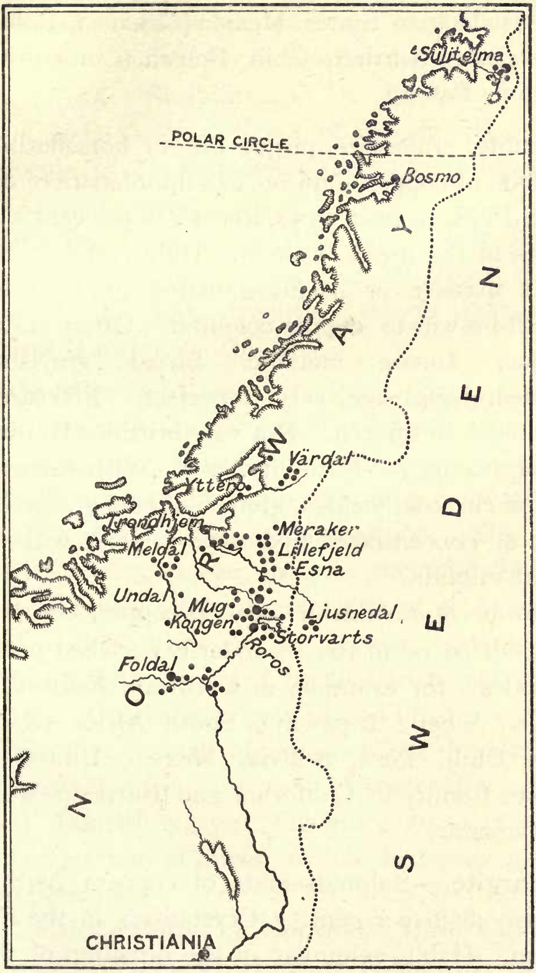


Fig. 79.—Twinned Crystals of Chalcopyrite.

action of decomposing animal matter. Chalcopyrite is invariably found in copper lodes when depths below the zones of weathering and of secondary enrichment are reached. It is the primary copper mineral, from which the other sulphides (chalcocite and bornite), and the oxides and carbonates that characterize the upper portions of the lodes, are derived. It is impossible to enumerate the localities for chalcopyrite, since it occurs wherever copper is mined; the mention of a few of the copper-mining districts where this mineral bulks largely must suffice: Germany (Mansfeld, Rammelsberg), Saxony (Annaberg), Spain and Portugal (Huelva District, Rio Tinto, Tharsis, etc.), Ural Mountains (Bogoslowsk), Caucasus (Kiadabek), Altai (Tschudak and Songatof), Finland (Pitkäranta), Norway (Sulitelma, Røros, Vigsnäs, Foldal, Ytterø), Sweden (Falun), Italy (Monte Catini, Massa Marittima, Mossetana, Boccheggiano), Austro-Hungary (Kitzbühel in the Tyrol, Schmöllnitz in Hungary, and Rézbánya in the Banat), South Africa (Ookiep, Spectakel, Nababeep, and Kopeberg, in Little Namaqualand), Australia (Great Cobar in New South Wales; Wallaroo, Moonta, and Burra Burra, in South Australia; Mount Morgan in Queensland), Tasmania (Mount Lyell), Japan (Ashio, Ani Osarisawa, Besshi, and Kosaka), China (Yunnan and Kweichou Provinces), Canada (Rossland, Sudbury, Capeltown), Montana (Anaconda and other mines at Butte), Arizona (United Verde, Copper Queen, and other mines in the Jerome, Bisbee, Clifton, Morenci, and Globe Districts), California (Mountain Copper in Shasta County), Alaska



Map showing Copper Ore Deposits in Norway.

(Copper Mountain, Mount Wrangell), many places in the Appalachian States, Mexico (Cananea, Boleo, and Montezuma), Northern Chili, Bolivia (Corocoro), Peru (Cerro de Pasco).

**Bornite**, erubescite, purple ore, or horseflesh ore.—Sulphide of copper and iron, or sulphoferrite of copper: $3Cu_2S.Fe_2S_3$ (copper 55·57, iron 16·36 per cent.). Crystallizes in the regular system. Habit, cubic. Usually occurs massive or in disseminated grains. Colour, reddish-brown to copper-coloured. Often iridescent. Opaque. Lustre, metallic. Streak, greyish-black. Octahedral cleavage, very imperfect. Fracture, subconchoidal to uneven. Not very brittle. Hardness, 3. Density, 4·9-5·4. Fusibility, 2·5. With carbonate of soda on charcoal yields a globule of copper. Soluble in nitric or concentrated hydrochloric acid, with separation of sulphur.

Bornite is a valuable ore of copper, occurring in the oxidized or in the secondarily enriched portion of the lodes—for example, in Cornwall, Norway, Harz, Saxony, Siberia (Spassky), South Africa (Namaqualand), Chili, Peru, Bolivia, Mexico, United States (Shasta County in California and Butte in Montana), and Canada.

**Enargite.**—Sulpharseniate of copper: $As_2S_5.3Cu_2S$ (copper 48·36 per cent.). Crystallizes in the rhombic system. Habit, columnar in the direction of the vertical, with vertical striation, or tabular parallel to the basal plane. Also massive, granular, or columnar.

Colour, grey to iron black. Lustre, metallic. Streak, greyish-black. Cleavage, perfect, parallel to the prisms (110). Fracture, uneven. Brittle. Hardness, 3. Density, 4·4-4·5. Fusibility, 1. On charcoal with carbonate of soda yields a globule of copper. Heated in the open tube, gives off arsenical and sulphurous fumes. Soluble in aqua regia.

Enargite occurs as an ore of copper in the United States (Anaconda mine at Butte in Montana, Tintic mines in Utah, etc.), Argentine (Sierra Famatina), Philippines (Luzon).

**Tetrahedrite,** fahl-ore, or grey copper ore.—Sulphantimonite of copper, with a variable amount of copper replaced by silver, iron, and zinc: $3(Cu_2,Ag_2,Fe,Zn)S.(Sb,As)_2S_3$. The corresponding sulpharsenite of copper, $3Cu_2S.As_2S_3$, is **tennantite.** The pure sulphantimonite of copper contains theoretically 46·84 per cent. of copper; the sulpharsenite of copper, 52·64 per cent. Crystallizes in the regular system, with tetrahedral habit. Twinned parallel to a face of the octahedron. Colour, steel grey to iron black. Opaque. Lustre, metallic. Streak, black to reddish. No cleavage. Fracture, conchoidal to uneven. Very brittle. Hardness, 3-4. Density, 4·4-5·1. Fusibility, 1·5. A valuable ore of copper and of silver (of which it may contain up to 30 per cent.).

Tetrahedrite occurs in Cornwall, Harz (Andreasberg), Saxony (Freiberg), Hungary (Kremnitz), Silesia, Bohemia (Przibram), Nassau (Dillenburg), Spain, Russia (Bogoslowsk), Chili, Bolivia (Huanchaca, where it is worked as a silver ore), Peru, Mexico, and United States (Arkansas, Utah, Nevada, California), Australia (Broken Hill).

**Malachite.**—The green hydrated basic carbonate of copper: $CuCO_3.Cu(OH)_2$, or $2CuO.CO_2.H_2O$ (copper 59·3 per cent.). Crystallizes in the monoclinic system, but usually occurs massive or with a smooth mamillary surface and concentric fibrous internal structure. Colour, bright green. Streak, pale green. Lustre, silky to dull. Hardness, 3·5-4. Density, 4. Fusibility, 3. Reduced on charcoal before the blowpipe to globule of copper; colours the flame green. Gives off water when heated in the closed tube. Dissolves in acids with effervescence.

Malachite is of universal occurrence in the upper part of copper lodes, together with the other oxidized ores of copper, and is a valuable ore, when in sufficient quantity for profitable extraction. Well-known occurrences are the following: Cornwall, Chessy in France, Spain, Siberia (Nischne Tagilsk, especially at the mine Mednoroudiansk), South Australia (Burra Burra), Katanga in Central Africa, United States (especially Arizona), Mexico (Boleo), Chili, etc.

**Chessylite**, or azurite.—The blue hydrated basic carbonate of copper: $2CuCO_3.Cu(OH)_2$ (copper 55·3 per cent.). Crystallizes in the monoclinic system, but also occurs in massive or in earthy forms. Colour, deep blue. Streak, pale blue. Lustre, vitreous. Fracture, conchoidal. Hardness, 3·5-4. Density, 3·5-3·8. Fusibility, 3. Behaviour before the blowpipe and with acids same as for malachite. It accompanies malachite in the oxidized form of copper lodes, but is of less frequent occurrence. For localities, see the list given under *malachite.*

**Chrysocolla.**—Hydrated silicate of copper: $CuO.SiO_2.2H_2O$ (copper 36 per cent.). Amorphous. Massive and compact. Opaline to earthy. Vitreous to greasy lustre, or dull. Translucent to opaque. Colour, green to blue. Streak, bluish-white. Fracture, conchoidal. Brittle. Hardness, 2-4. Density, 2-2·2. Infusible. Mixed with carbonate of soda on charcoal before the blowpipe, yields metallic copper. Decomposed by acids, with separation of silica. Heated in the open tube, yields water. Occurs as a decomposition product of copper ores in the belt of weathering of lodes. Russia (Bogoslowsk, Nischne Tagilsk), South Africa (Namaqualand), United States (Michigan, Arizona, California), Mexico (Boleo), Chili.

**Dioptase.**—Hydrated silicate of copper: $CuO.SiO_2.H_2O$ (copper 40·2 per cent.). Crystallizes in the hexagonal-rhombohedral system, with short columnar habit, with rhombohedral terminations. Colour, emerald green. Streak, green. Lustre, vitreous. Translucent to transparent. Rhombohedral cleavage perfect. Fracture, conchoidal to uneven. Brittle. Hardness, 5. Density, 3·3. Double refraction, strong, positive. Before the blowpipe turns black, but does not melt. Colours the flame green. With carbonate of sodium on charcoal yields a globule of copper. Decomposed by hydrochloric acid with separation of silica.

Dioptase is of rather rare occurrence. A well-known locality is the Kirghese Steppes, where it occurs in limestone. It has also been found in Chili, Peru, Arizona, and Central Africa (Congo).

**Chalcanthite.**—Hydrated sulphate of copper: $CuSO_4 . 5H_2O$ (copper 25·4). Crystallizes in the triclinic system. Also occurs massive or as incrustations. Colour, blue. Streak, white. Lustre, vitreous. Brittle. Hardness, 2·5. Density, 2·2. Fracture, conchoidal. Fusibility, 3. Soluble in water. Yields water when heated in the open tube. Occurs in small quantities only, as a decomposition product of chalcopyrite.

**Atacamite.** — Hydrated oxychloride of copper: $CuCl_2 + 3Cu(OH)_2$ (copper 59·4). Crystallizes in the rhombic system. Also occurs massive. Colour, dark green. Lustre, vitreous. Streak, light green. Hardness, 3-3·5. Density, 3·7-3·8. Fusibility, 3-4. Yields a globule of copper on charcoal before the blowpipe. Gives off water when heated in the open tube. Soluble in acids. Occurs chiefly in the dry desert regions of Chili and Peru (Atacama), where it is worked as an ore of copper; also in Mexico (Boleo).

## ORES OF SILVER.

Silver occurs in the native state, but this is not an important source of supply. The largest amount of the metal is obtained from *argentiferous galena*, $(Pb,Ag_2)S$, which may be regarded as an isomorphous mixture of argentite ($Ag_2S$) and galena ($PbS$), both crystallizing in the regular system. A rhombic sulphide of silver—*acanthite*—also exists, and has been found, for example, in the silver-mines of Freiberg. If this mineral be regarded as isomorphous with the rhombic sulphide of copper—chalcocite—an explanation is afforded of the constitution of *argentiferous chalcocite* or *stromeyerite*, $(Cu,Ag)_2S$, which also occurs at Freiberg and in the Altai. Silver also replaces copper in *tetrahedrite*, some varieties of which contain up to 30 per cent. of silver, and are then regarded as silver ores. Other important ores of silver are the sulphantimonites and sulpharsenites of silver, lead and copper. Their chemical relationship is shown in the following table:

| Name. | Chemical Formula. | Cystallographic System. |
|---|---|---|
| Argentite | $Ag_2S$ | Regular |
| Argentiferous galena | $(Pb,Ag_2)S$ | Regular |
| Acanthite | $Ag_2S$ | Rhombic |
| Stromeyerite | $(Cu,Ag)_2S$ | Rhombic |
| Polybasite | $9(Ag,Cu)_2S.Sb_2S_3$ | Monoclinic |
| Pearcëite | $9(Ag,Cu)_2S.As_2S_3$ | Monoclinic |
| Stephanite | $5Ag_2S.Sb_2S_3$ | Rhombic |
| Pyrargyrite | $3Ag_2S.Sb_2S_3$ | Hexag-rhombohedral |
| Proustite | $3Ag_2S.As_2S_3$ | Hexag-rhombohedral |
| Tetrahedrite | $3(Cu,Ag)_2S.Sb_2S_3$ | Regular |
| Freieslebenite | $5(Pb,Ag_2)S.2Sb_2S_3$ | Monoclinic |

Of the haloid compounds of silver, the chloride, *kerargyrite*, is important; the chloro-bromide, *embolite*, less so; while the iodide, *iodyrite*, is quite rare.

Silver ores occur in veins belonging to two main groups: (1) Those associated with volcanic rocks of late Mesozoic or Tertiary age; and (2) those of much earlier age.

The first group is well illustrated by occurrences in the Carpathians of Transylvania (Nagyág-Verespatak) and Hungary (Schemnitz, Kremnitz and Nagybánya-Kapnik); in the Andes of Bolivia (Potosi, Huanchaca, Oruro), Peru (Cerro de Pasco), and Colombia (Tolima); in the Sierras of Mexico (Durango, Fresnillo, Zacatecas, Guanajuato, Puchuca) and of Arizona; in the Sierra Nevadas of California (San Bernardino) and Nevada (Comstock, Esmeralda, etc.); in the Wahsatch Range of Utah (Hornsilver, etc., in Beaver County); in the Rockies of Colorado (Boulder, San Juan, Silver Cliff, Rosita, etc.); in the Coromandel peninsula (Hauraki) of New Zealand; and finally in Japan (Akita and the island of Sado).

The second group is illustrated by occurrences in the silver-lead deposits of Saxony (Freiberg, Annaberg, and Schneeberg), of the Harz (Clausthal and Andreasberg), Bohemia (Przibram), and Norway (Kongsberg).

A large amount of silver is now obtained from Cobalt in Northern Ontario, Canada, where silver ores (native silver and argentite) are associated with ores of nickel and cobalt (smaltite, niccolite, chloanthite, and cobaltite), as well as bismuth and mispickel.

The world's output of silver amounts to close on 220,000,000 ounces per annum, having a value of, roughly, £23,500,000.

**Native Silver.**—Regular. Native silver, when crystallized, presents cubical or octahedral forms, but the crystals are usually distorted or united to divergent branching masses. Most frequently, however, the metal occurs in strings and wiry coils, occasionally even assuming a moss-like character; it is also found as plate or foil, or in massive lumps. One such mass from Kongsberg in Norway, which is preserved in the Copenhagen Museum, weighs about 5 hundredweight.

Silver is very malleable and ductile, ranking next to gold in these qualities. In hardness it lies between gold and copper, its position in Mohs' scale ranging from 2·5 to 3. The density of native silver varies from 10·1 to 11; that of pure silver is 10·5. Although naturally of a white colour, it is often tarnished superficially to a red, brown, or blackish colour. Lustre, metallic; fracture, hackly. The native ore contains traces of copper, arsenic, antimony, and iron. It is soluble in nitric acid, and gives a precipitate with hydrochloric acid. Fusibility, 2 (Von Kobell's scale).

Native silver occurs in veins, associated with the other ores of silver, or intermingled with native copper as at Lake Superior. Other occurrences in the United States are in Arizona, Nevada (Comstock Lode), Colorado, North Carolina, etc. It is also found in Ontario (Cobalt), and in Australia. Large deposits occur in the mines of Peru and Mexico. In Europe it is found in Norway (Kongsberg), the Harz, Saxony, Silesia, Hungary, Spain (Sierra Morena), and the Dauphiné.

**Argentite.**—Sulphide of silver: $Ag_2S$ (silver 87 per cent.). Crystallizes in the regular system in cubes, octahedra, and rhombic dodecahedra, but also occurs massive. Colour and streak, a dull black or lead grey. Lustre, metallic. Opaque. Cubic cleavage imperfect. Fracture, conchoidal. Sectile. Hardness, 2-2·5. Density, 7-7·4. Fusibility, 1·5. Yields a globule of silver on charcoal.

An important ore of silver in many silver-mines, as, for example, those of Saxony, Bohemia, Hungary, and Norway, in Europe; those of Peru and Chili, in South America; those of Mexico, Arizona, Idaho, Colorado, Nevada (Comstock Lode), Utah, and Ontario (Cobalt), in North America; and those of Australia and Tasmania.

**Stephanite**, or brittle silver ore.—A sulphide of silver and antimony, or sulphantimonite of silver. Represented by the formula $5Ag_2S.Sb_2S_3$, which gives a silver percentage of 68·36. It occurs massive, or crystallized in thick six-sided tablets or in short prisms of the rhombic system. This mineral has an iron-black colour, metallic lustre, is soft (hardness, 2-2·5), and has a density of 6·2-6·3. It cleaves parallel to the brachypinacoid (010), has an uneven to semi-conchoidal fracture, and is brittle. Before the reducing flame of the blowpipe on charcoal it yields a button of silver.

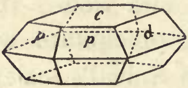


FIG. 80.—STEPHANITE. *c*, Basal plane; *p*, pyramid; *d*, brachydome.

Stephanite occurs with other silver ores in Saxony

(Freiberg), Bohemia, Hungary (Schemnitz, Kremnitz, and Hodritsch), Chili, Peru, Mexico, and Nevada (Comstock Lode).

**Pyrargyrite**, or dark ruby silver ore.—A sulphide of silver and antimony, or sulphantimonite of silver: $3Ag_2S.Sb_2S_3$ (silver 59·97, antimony 22·21, sulphur 17·82, per cent.). Crystallizes in the hexagonal-rhombohedral system (hemimorphic). Habit, short columnar with manifold rhombohedral and scalenohedral terminations. Often twinned. Also occurs massive. Cleavage, rhombohedral ($10\bar{1}1$). Fracture, conchoidal to uneven. Brittle. Hardness, 2-3. Density, 5·77-5·86. Lustre, metallic-adamantine. Translucent in thin splinters. Colour in reflected light, black or grey-black; in transmitted light, deep cochineal red. Streak, red. Fusibility, 1 (Von Kobell). Before the blowpipe gives off dense antimonial fumes; yields a globule of silver when fused with carbonate of soda on charcoal. Occurs with other silver ores, and frequently with galena, the gangue being often calcite.

Pyrargyrite occurs in Saxony, Bohemia, Hungary (Schemnitz, Kremnitz), Transylvania, the Harz (Andreasberg), Norway, Spain, Montana, Nevada (Comstock Lode), Mexico, Chili, Peru, Bolivia, Canada (Cobalt).

**Proustite**, or light ruby silver ore.—A sulphide of silver and arsenic, or sulpharsenite of silver: $3Ag_2S.As_2S_3$ (silver 65·4, arsenic 15·17, sulphur 19·43, per cent.). Crystallizes in the hexagonal-rhombohedral system (hemimorphic), in similar forms to pyrargyrite, with which it is isomorphous. Also massive. Cleavage, rhombohedral ($10\bar{1}1$). Fracture, conchoidal to uneven. Brittle. Hardness, 2. Density, 5·55-5·64. Lustre, adamantine. Transparent to translucent. In reflected light, black or grey-black; in transmitted light, proustite has a brighter colour than pyrargyrite, inclining to scarlet-red. Streak, red. Fusibility, 1 (on Von Kobell's scale). Heated on charcoal before the blowpipe, gives off arsenical fumes (smelling of garlic), and yields a globule of silver with carbonate of soda.

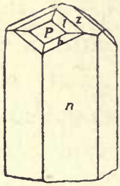


FIG. 81.—PYRARGYRITE.
*P*, Rhombohedron $(+R)$; *z*, a more obtuse rhombohedron $(-\frac{1}{2}R)$; *h*, a scalenohedron; *n*, prism.

Occurrence, same as pyrargyrite. Chañarcillo, a mine in Chili, is a noted locality.

**Polybasite.**—A sulphide of silver, copper, and antimony, or sulphantimonite of silver and copper: $9(Ag,Cu)_2S.Sb_2S_3$ (with 62 to 75 per cent. silver and from 0 to 10 per cent. copper). The corresponding arsenical compound is also known (**pearceïte**). Monoclinic, in thin six-sided tables with pseudo-rhombohedral symmetry. Also occurs in scaly aggregates. Metallic lustre. Colour, iron black; in thin fragments by transmitted light cherry red. Basal cleavage, perfect. Fracture, uneven. Hardness, 2-3. Density, 6-6·2. Fusibility, 1 (Von Kobell's scale). Before the blowpipe gives off antimonial fumes; with carbonate of soda on charcoal yields globule of cupriferous silver.

Occurrence—with other silver sulphides, in Saxony (Freiberg), Harz (Andreasberg), Bohemia (Joachimsthal, Przibram) Hungary (Schemnitz, Kremnitz, Hodritsch), Colorado, Nevada (Comstock Lode), Montana, Arizona, Mexico, Peru, Chili.

**Kerargyrite**, chlorargyrite, or hornsilver.—Chloride of silver: AgCl (silver 75·3 per cent.). Crystallizes in the regular system, with cubic habit, but usually occurs massive or in scales and plates. Colour, whitish-grey. Lustre, resinous to adamantine. Translucent. Malleable. Sectile. Hardness, 1-2. Density, 5·58-5·6. Easily fused (fusibility, 1), yielding a globule of silver on charcoal. A valuable ore of silver, but not of very common occurrence. The largest deposits are in Mexico (Oajaca), Chili, and Peru. It is also found in Nevada (Comstock Lode), California (Pine Hill), and New South Wales (Broken Hill).

**Embolite.**—Chlorobromide of silver: Ag(Cl,Br) (silver 65 per cent.). Crystallizes in the regular system, but occurs in small disseminated particles. Colour, greenish. Translucent. Sectile. Hardness, 2-3. Density, 5·79-5·80. Fusibility, 1. Yields a globule of silver on charcoal. Of rare occurrence. Mexico (Oajaca), Chili (Chañarcillo).

## ORES OF LEAD.

Lead occurs native, but it is a rare mineral. The bulk of the ore mined is *galena*. This, the simple monosulphide of lead, is the primary lead mineral, and is invariably encountered in lead ore deposits when the mines are carried below the belt of weathering. In the upper oxidized portions of the deposits it has been replaced, although rarely completely, by the carbonate (*cerussite*) and the sulphate (*anglesite*). The red oxide, *minium* ($Pb_3O_4$), also occurs, but is unimportant as an ore.

Lead ores occur as vein deposits of hydatogenetic origin and as metasomatic replacements. In the vein deposits the dominant gangue material may be quartz, dolomite, or barytes. In the quartz veins the galena is accompanied by chalcopyrite, and by silver ores in the dolomite and barytes veins; while zinc-blende is present in all three types.

The bulk of the metasomatic deposits were originally formed by the replacement of limestone by galena, the sulphide of lead being carried in solution by alkaline sulphides. In most cases a secondary concentration has accumulated the ores in fissures, cavities, joints and bedding planes, whence they have spread out into the adjoining country rock. Such deposits occur in limestones of all ages—Archæan, Ordovician, Devonian, Carboniferous, Triassic, Cretaceous, and Tertiary.

Lead has a multifarious application in the arts: it is used in the form of sheets, pipe, shot, glazier's lead, wire; for type metal and other alloys; and in the manufacture of the pigments—white lead (basic carbonates) and red lead (oxide, $Pb_3O_4$). Litharge ($PbO$) and lead acetate (sugar of lead) are also important articles of commerce.

The world's production of pig lead amounts to a little over one million tons per annum.

**Galena.**—Sulphide of lead: PbS (lead 86·6 per cent.). Crystallizes in the regular system, generally as a combination of the cube and octahedron; the cubical habit is usually dominant, with frequent twinning parallel to the octahedron (111). It also occurs massive in granular aggregates.

In *argentiferous galena* enough silver is present to make the mineral a valuable source of that metal. A small amount of gold is usually associated with the silver.

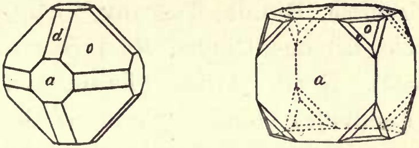


FIG. 82.—GALENA.

*a*, Cube; *o*, octahedron; *d*, rhombic dodecahedron; *e*, icosi-tetrahedron.

Colour, lead grey. Streak, greyish-black. Opaque. Lustre, metallic. When massive, dull. Tarnishes on exposure to air. Cubical cleavage, perfect. Fracture, even. Hardness, 2-2·5. Density, 7·4-7·6. Fusibility, 2. On charcoal with sodium carbonate, yields a globule of lead. Soluble in concentrated nitric acid, with separation of sulphur.

Galena is the most widely distributed, the most abundant, and the most important, ore of lead. The following are localities of some of the more important lead-mining districts in which galena occurs below the oxidation zone, generally in association with blende: Cardigan and Montgomery (Welsh Potosi, Van, Cwm Ystwith), Flintshire (Halkyn), Denbighshire (Minera), Isle of Man (Laxey and Foxdale), Anglesey (Parys, Mona), Cornwall, Northumberland, Cumberland (Threlkeld), Durham (Weardale), Yorkshire (Swaledale), and Derbyshire; Saxony (Freiberg, Schneeberg, Annaberg, Altenberg), Silesia (Katzbach), Nassau (Ems, Holzappel), Harz, Bohemia (Przibram, Pilsen, Kuttenberg), Styria (Graz), Carinthia (Raibl and Bleiberg), Carniola, Bosnia, Tuscany, Sicily, Sardinia, Spain (Murcia, Linares, Ciudad Real, Sierra Morena), Sweden (Sala), North Africa (Tunis, Constantine), Colorado (Leadville), Idaho (Cœur d'Alene), Utah (Frisco, Wisconsin, Oquirrh, Bingham), Illinois, Dakota, Arkansas, Nevada (Eureka), Missouri (Joplin), Mexico (Sierra Mojada), Canada (Ontario), New South Wales (Broken Hill), Tasmania (Zeehan, Mount Read), South Africa (Transvaal).

**Cerussite.**—Carbonate of lead: $PbCO_3$ (lead 77·5 per cent.). Crystallizes in the rhombic system, being isomorphous with aragonite. The crystals are partly of a pyramidal habit, partly tabular, and are often twinned on a face of the prism (110). They are usually colourless and pellucid; but less transparent and white, or slightly tinted, varieties occur, occasionally forming delicate silky and fibrous aggregates. The crystals are characterized by a brilliant adamantine lustre. Prismatic cleavage, imperfect. Fracture, conchoidal. Brittle. Hardness, 3-3·5. Density, 6·4-6·6. Fusibility, 1·5. Yields a globule of lead when fused on charcoal with carbonate of soda. Soluble in dilute nitric acid, with effervescence.

Cerussite is an important ore occurring in the oxidized zone of lead deposits. Well-crystallized specimens, represented in most collections, are usually from Cornwall (Pentire Glaze), Nassau (Friedrichsegen mine, near Ems), Bohemia (Mies), Siberia (Nertschinsk), New South Wales (Broken Hill), Colorado (Leadville), Rhodesia (Broken Hill).

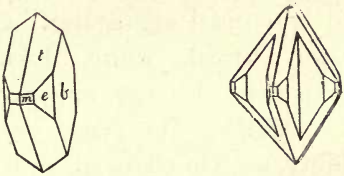


Fig. 83.—Simple and Twinned Crystals of Cerussite.
*t*, Pyramid ; *m*, prism ; *e*, brachyprism ;
*b*, brachypinacoid.

**Anglesite.**—Sulphate of lead : $PbSO_4$ (lead 68·3 per cent.). Crystallizes in the rhombic system, being isomorphous with barytes and celestite. Habit, tabular. Also occurs massive. Colourless. Streak, white. Lustre, adamantine to resinous. Transparent. Cleavage, prismatic and basal, fair. Brittle. Fracture, conchoidal. Hardness, 3. Density, 6·3. Fusibility, 2. Yields globule of lead with carbonate of soda on charcoal. Soluble with difficulty in nitric acid. Anglesite occurs in the oxidation zone of lead ores as an alteration product of galena, and often constitutes an important ore of lead. It derives its name from Anglesey, where it is found at the Parys copper mine. Other well-known localities are Sardinia (Monte Poni), Westphalia (Siegen), Harz, Pennsylvania (Phœnixville), and many lead-mines in the United States.

**Pyromorphite.** — Chlorophosphate of lead: $3Pb_3(PO_4)_2.PbCl_2$ (lead 76·4 per cent.). Crystallizes in the hexagonal system. Habit, prismatic. Also occurs in uniform and botryoidal aggregates. Colour, green, yellow, or brown. Streak, white. Lustre, resinous. Translucent. Prismatic cleavage, imperfect. Fracture, subconchoidal. Brittle. Hardness, 3·5-4. Density, 6·5-7·1. Fusibility, 2. On charcoal, with carbonate of soda, yields a globule of lead. Soluble in nitric acid. Occurs in association with other ores of lead.

## ORES OF *ZINC*.

*Blende*, the monosulphide of zinc, is the source of the bulk of the zinc of commerce (*spelter*). It is the primary zinc ore, and is invariably found in the deeper parts of the deposits; while within the belt of weathering it is replaced by the carbonate (*calamine*), the silicates (*smithsonite* and *willemite*), and the oxide (*zincite*).

As in the case of lead, zinc ores occur both as veins and as metasomatic replacements.

The same three types of vein deposit hold for zinc ores as for lead ores, blende and galena being frequently associated in the same veins.

The metasomatic ores have been formed by the replacement of limestone, sulphide of zinc being deposited as blende from solution in alkaline sulphides. The subsequent distribution of the ore along fissures and other openings is regulated by solution, redeposition, and concentration. Where oxidation is possible, secondary zinc ores are also formed.

The chief uses of zinc are in the manufacture of galvanized iron (sheet iron coated with zinc), in electro-zincing, and for alloys (especially brass, which is an alloy of zinc with copper, and German silver, in which zinc is alloyed with copper and nickel). Its compounds are also used as pigments (zinc oxide in zinc white, and zinc sulphide in admixture with barium sulphate in lithopone), and for many other purposes.

The world's output of spelter amounts to close on 800,000 tons per annum.

Note.—The metal cadmium is also obtained from zinc ores. Zinc and cadmium are closely allied metals, and their compounds occur in isomorphous intermixture. Thus, blende often contains from 0·3 to 3 per cent. of cadmium sulphide (CdS), as at Ouro Preto in Brazil, and in Kentucky, Illinois, and the Joplin District of Missouri, in the United States. Cadmium is used in fusible alloys for soft solders, electric fuses, and (in alloy with mercury) in dental amalgam. It may also take the place of bismuth in *cliché* metal.

**Zinc-Blende**, sphalerite, or "Black Jack."—Sulphide of zinc: ZnS (zinc 67·06 per cent.). Iron is a common constituent of blende, especially of the darker-coloured varieties,* and cadmium is frequently present. Crystallizes in the regular system, with tetrahedral symmetry. Habit, usually dodecahedral. Twinned crystals frequent, the twinning axis being the normal to a face of the octahedron (see Fig. 82). Also occurs massive, or in granular, nodular, and botryoidal aggregates. Colour, usually brown to black ("Black Jack"), but also yellow to colourless. Transparent to translucent. Lustre, resinous to adamantine. Streak, yellow or brown. Dodecahedral cleavage, perfect. Conchoidal fracture. Brittle. Hardness, 3-4. Density, 3·9-4·1. Fusibility, 5. Gives off sulphur fumes when heated. Soluble in nitric acid, with separation of sulphur.

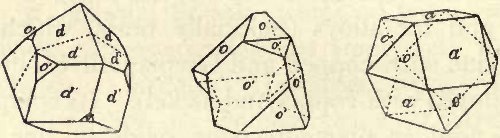


FIG. 84.—TWINNED CRYSTALS OF BLENDE.
*o*, Octahedron; *a*, cube; *d*, rhombic dodecahedron.

Blende is the most widely distributed and most abundant ore of zinc, being found, in association with galena, below the oxidation zone of all zinc-lead ore

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* The iron is probably present as sulphide of iron (FeS) in isomorphous admixture with blende (ZnS).

deposits. For localities, see those given for galena. A few may be specially mentioned: North of England (Alston Moor), Belgium, Sardinia, the Alps, Westphalia (Iserlohn), Upper Silesia, Hungary (Schemnitz), Carinthia (Raibl), Greece (Laurium), Northern Spain (Asturias), Algeria, New South Wales (Broken Hill), Missouri-Kansas (Webb City, Joplin, Galena, Duenweg, Oronogo, Granby, Alba Neck, Badger, Miami, and Carthage).

MAP OF THE MISSOURI-KANSAS ZINC AND LEAD FIELDS.

Blende also occurs in association with chalcopyrite, as in the complex ores of Huanchaca in Bolivia.

**Calamine,** or zinc spar (smithsonite of Dana).—Carbonate of zinc: $ZnCO_3$ (zinc 52 per cent.). Crystallizes in the hexagonal system, with rhombohedral symmetry, being isomorphous with calcite. When crystallized, it occurs in small crystals with curved faces. Usually, however, it is found in kidney-shaped and botryoidal aggregates, or massive. Though colourless when pure, it is often tinted grey, yellow, brown, or green. Lustre, vitreous to pearly. Streak, white. Hardness, 5. Density, 4·3-4·35. Infusible. Soluble in warm dilute hydrochloric acid, with effervescence.

An important ore of zinc in those deposits, or portions of deposits, which lie within the belt of weathering. It is largely worked in the zinc-mines of Siberia (Nertschinsk), Aix-la-Chapelle (Altenberg), Northern Spain (Santander), Greece (Laurium), Virginia (Austin Mines), Illinois (Jo Davies County), Arkansas, Iowa, Kansas, Kentucky, Rhodesia (Broken Hill).

**Willemite.** — Silicate of zinc: $SiO_2.2ZnO$ (zinc 58·7 per cent.). Crystallizes in the hexagonal system, with rhombohedral symmetry, occurring in small crystals. More usually it is found massive, granular, or in kidney-shaped aggregates. Colour, white, yellow, or brown. Transparent to translucent. Lustre, vitreous. Cleavage, basal. Fracture, subconchoidal. Hardness, 5-6. Density, 4·02-4·18. Infusible. Gelatinizes with hydrocloric acid.

In Europe it occurs at Aix-la-Chapelle (Altenberg) and a few other localities; but it is only found in workable quantities in New Jersey in the United States (Franklin Furnace and Sterling Hill), where it occurs in association with zincite and franklinite, and constitutes a valuable ore of zinc.

**Hemimorphite** (calamine of Dana).—Hydrated silicate of zinc: $SiO_2.2ZnO.H_2O$ (zinc 41 per cent.). Crystallizes in the rhombic system, with hemimorphic development—*i.e.*, the crystals present different combinations at the two ends of the vertical axis (hence its name). The crystals are usually small tablets (parallel to 010), which are combined to fan-shaped, spherical, and kidney-shaped aggregates. Occurs also in fibrous and granular masses. Twinning parallel to the basal plane. Although often colourless or white, it is also grey, yellow, brown, or even of a green or blue tint. The crystals are usually transparent, and have a glassy lustre. Streak, white. Prismatic cleavage, perfect. Fracture, uneven. Brittle. Hardness, 4-5. Density, 3·4-3·5. Strongly pyroelectric. Infusible. Loses water at a red heat only.

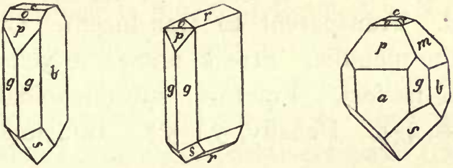

FIG. 85.—CRYSTALS OF HEMIMORPHITE.
*c*, Basal plane; *b*, brachypinacoid; *a*, macropinacoid; *g*, prism; *o*, and *p*, macrodomes; *m*, brachydome.

An ore of zinc, often associated with the carbonate (calamine), as at Aix-la-Chapelle (Altenberg), Westphalia (Iserlohn and Siegen), Carinthia (Bleiberg and Raibl), Spain (Santander), Siberia (Nertschinsk), Virginia (Austin Mines), Missouri (Granby, Duenweg, Joplin, Spring City, Aurora, Sarconie).

**Zincite.**—Oxide of zinc: $ZnO$ (zinc 80·31 per cent.). Crystallizes in the hexagonal system, with hemimorphic development. Habit, columnar, with prism $(10\bar{1}0)$, pyramid $(10\bar{1}1)$, and basal plane $(0001)$. Occurs usually massive or in granular aggregates. Colour, dark red. Transparent to translucent. Lustre, adamantine to metallic. Streak, orange to yellow. Basal cleavage, perfect. Fracture, subconchoidal. Brittle. Hardness, 4-5. Density, 5·4-5·7. Infusible. Soluble in acids.

Occurs as an ore of zinc in association with willemite and franklinite in the zinc-mines of New Jersey (Franklin Furnace and Sterling Hill).

**Franklinite.**—An epitritoxide of zinc, manganese, and iron: $(Zn,Fe,Mn).O(Fe,Mn)_2O_3$ (percentage of zinc variable). A member of the spinel group. Crystallizes in the regular system, with octahedral habit. Usually occurs massive or granular. Colour, iron black or dark brown. Streak, brown. Opaque. Lustre, metallic. Fracture, uneven. Brittle. Hardness, 6. Density, 5·15. Slightly magnetic. Infusible. Soluble in hydrochloric acid.

Occurs as an ore of zinc in association with zincite and willemite in the zinc-mines of New Jersey (Franklin Furnace and Sterling Hill), where the zinc is first extracted, and the residue then treated as an iron ore.

## ORES OF NICKEL.

The chief source of nickel is *nickeliferous pyrrhotite* (see under *pyrrhotite*), which occurs in the marginal portions of large intrusions of norite near Sudbury* in Ontario, Canada. In this ore the nickel appears to be present in the form of *pentlandite*—(Fe,Ni)S. Another source is the indefinite hydrated silicate of nickel known as *garnierite*, which is mined at Noumea in New Caledonia. *Linnæite*, the sulphide of cobalt and nickel, is also a source of nickel. The remaining nickel ores—viz., *niccolite*, *chloanthite*, and *gersdorffite*—are responsible for the production of a comparatively small amount of the metal;† while the nickel minerals—*millerite*, *annabergite*, and *zaratite*—only occur as decomposition products in the weathered portions of the lodes. Nickel is used principally in the manufacture of certain white alloys—*e.g.*, German silver, which is an alloy of nickel with copper and zinc—also for nickel-plating.

**Pentlandite.**—A sulphide of iron and nickel: (Fe,Ni)S (nickel 10 to 39 per cent.). Crystallizes in the regular system, but usually occurs massive. Colour, yellowish-

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* Sudbury is responsible for more than half the world's annual production of nickel.

† The nickel derived from this source of supply is chiefly contained in the silver ores shipped from the Cobalt district of Ontario, Canada.

bronze. Streak, black. Lustre, metallic. Octahedral cleavage. Fracture, uneven. Hardness, 3·5-4. Density, 4·95-5. Fusibility, 5. Soluble in nitric acid.

This mineral occurs in association with pyrrholite and chalcopyrite in the so-called *nickeliferous pyrrhotite* of Sudbury, Ontario, which is the most important source of the metal nickel.

**Niccolite.**—Arsenide of nickel: NiAs (nickel 44·1 per cent.). Crystallizes in the hexagonal system, but occurs mostly massive or in granular and botryoidal aggregates. Colour, copper red. Opaque. Lustre, metallic. Streak, brownish-black. No cleavage. Fracture, conchoidal to uneven. Fairly brittle. Hardness, 5. Density, 7·3-7·7. Fusibility, 2. On charcoal, yields a white, brittle, metallic globule, and gives off arsenical fumes. Soluble in aqua regia and in nitric acid, with separation of sulphur.

Occurs as an ore of nickel in association with silver and cobalt ores. Cornwall, Harz (Andreasberg), Saxony (Schneeberg, Annaberg), Bohemia (Joachimsthal), Norway, Sweden, Chili (Chañarcillo, and Huasco), Ontario (Cobalt).

**Chloanthite.**—Arsenide of nickel: $NiAs_2$ (nickel 28·1 per cent.). Crystallizes in the regular system, with pentagonal hemihedrism. Usual form, the cube. Also massive or granular. Colour, tin white to steel grey. Opaque. Streak, greyish-black. Lustre, metallic. Octahedral cleavage, imperfect. Fracture, uneven. Brittle. Hardness, 5-6. Density, 6·3-7. Fusibility, 2, yielding magnetic globule on charcoal, with production of arsenical fumes. Decomposed by nitric acid, yielding a green solution.

Occurs as an ore of nickel in the Erzgebirge, Harz, Saxony, Chili, Peru, United States, Canada (Cobalt), etc.

**Gersdorffite.** — Arsenosulphide of nickel: NiAsS (nickel 35·31 per cent.). Crystallizes in the regular system, with pentagonal hemihedrism. Usual form, the octahedron, often in combination with the cube. Also granular and massive. Colour, silver white to steel grey. Streak, greyish-black. Opaque. Lustre, metallic. Cubic cleavage, fair. Fracture, uneven. Brittle. Hardness, 5-5·5. Density, 5·6-6·2. Fusibility, 2. Gives off sulphurous and arsenical fumes on heating. Decomposed by nitric acid.

Occurs as an ore of nickel in Westphalia, Rhine Province, Nassau, Harz, Saxony, Hungary, Canada (Ontario).

**Millerite.** — Sulphide of nickel: NiS (nickel 64·69 per cent.). Crystallizes in the hexagonal system, in acicular or capillary prisms or in fibrous aggregates. Colour, brassy yellow. Lustre, metallic. Opaque. Streak, greenish-black. Rhombohedral cleavage, perfect. Fracture, uneven. Brittle. Hardness, 3-4. Density, 5·3-5·6. Fusibility, 1·5-2. Yields a magnetic globule. Soluble in nitric acid, with separation of sulphur.

Millerite is not itself of importance as an ore of nickel, but occurs with other nickel ores, as at the Gap Mine, Lancaster County, Pennsylvania, and at Cobalt, Ontario.

**Garnierite**, genthite, noumeite. — Rather indefinite hydrated silicates of nickel, magnesium, and iron: $2(Mg,Ni)O.3SiO_2 + nH_2O$ (nickel 15-30 per cent.). No crystal form; occurs massive, often as an incrustation. Colour, apple green. Translucent to opaque. Lustre, resinous. Streak, greenish-white. Fracture, uneven. Hardness, 3-4. Density, 2·2-2·8. Infusible. Decomposed by hydrochloric acid, with separation of silica. Usually occurs in serpentine, sometimes in association with chromite.

It is worked as an ore of nickel at Noumea in New Caledonia, where it is found in a decomposed serpentine rock; also, but to a smaller extent, near Frankenstein in Silesia.

**Annabergite**, or nickel-bloom.—Hydrated arseniate of nickel: $Ni_3(AsO_4)_2.8H_2O$ or $3NiO.As_2O_5.8H_2O$ (nickel 29·5 per cent.). Not crystallized. Occurs as earthy deposit, resulting from the decomposition of nickel ores. Colour, apple green. Streak, greenish-white. Hardness, 1·5-2·5. Fusibility, 4.

A decomposition product of nickel ores. Itself of no importance as an ore. Original locality, Annaberg in Saxony.

**Zaratite**, or emerald-nickel.—Hydrated nickel carbonate: $NiCO_3.2Ni(OH)_2.4H_2O$ or $CO_2.3NiO.6H_2O$ (nickel 26 per cent.). Not crystallized. Massive.

Usually as an incrustation. Colour, emerald green. Lustre, vitreous. Translucent. Streak, pale green. Hardness, 3-3·2. Density, 2·6-2·7. Brittle. Infusible. Dissolves with effervescence in hydrochloric acid.

Of no importance as an ore. A decomposition product of other nickel ores. Locality, Texas in Pennsylvania.

## ORES OF COBALT.

The chief ores of cobalt are *linnæite* (the sulphide), *smaltite* (the arsenide), and *cobaltite* (the arsenosulphide). *Glaucodot* (the arsenosulphide of cobalt and iron) is of less importance; while *erythrite* or *cobalt-bloom* (a hydrated arseniate of cobalt) only occurs as a decomposition product in the superficial portions of the lodes. Most nickel ores contain some cobalt, and the metal also occurs in mispickel (*q.v.*). Both cobalt and nickel are found in some copper ores.

The main supply of cobalt is from the mines of Ontario and of New Caledonia. It is largely obtained as a by-product in the smelting of the silver ores from Cobalt in Ontario. The principal use of cobalt is as a pigment, especially in its application to glass-making and pottery. *Zaffer*, a roasted cobalt ore, and the oxide, arsenate and phosphate of cobalt, are all used for imparting a blue colour to glass, or in glazing and painting on porcelain and glass.

**Linnæite**, a sulphide of cobalt and nickel: $(Co,Ni)_3S_4$ (cobalt and nickel 57·88 per cent.). Crystallizes in the regular system, with octahedral habit. Also occurs massive or granular. Colour, light steel grey. Streak, blackish-grey. Opaque. Lustre, metallic. Cubical cleavage, imperfect. Fracture, uneven. Brittle. Hardness, 5-6. Density, 4·8-5. Fusibility, 2. Soluble in nitric acid.

An important ore of cobalt and nickel, found in association with galena, chalcopyrite, and pyrites, as in Westphalia, Sweden, and Missouri in the United States.

**Smaltite.**—Arsenide of cobalt: $CoAs_2$ (cobalt 28·2 per cent.). Crystallizes in the regular system, with pentagonal hemihedrism. Usual form, the cube. Also massive or granular. Colour, tin white to steel grey. Opaque. Streak, grey-black. Lustre, metallic. Octahedral cleavage, imperfect. Fracture, uneven. Brittle. Hardness, 5-6. Density, 6·3-7. Fusibility, 2-3. Yields a magnetic globule on charcoal, and gives off arsenical fumes. Decomposed by nitric acid, yielding a pink solution.

Occurs as an ore of cobalt in the Erzgebirge, Harz, Saxony, Chili, Peru, Ontario (Cobalt), United States, Transvaal.

**Cobaltite.**—Arsenosulphide of cobalt: $CoAsS$ (cobalt 35·5 per cent.). Crystallizes in the regular system. Usual form, the pentagonal dodecahedron, modified by the cube. Also granular or massive. Colour, silver white, with a reddish tint. Opaque. Streak, greyish-black. Lustre, metallic. Cubical cleavage, fair. Fracture, uneven. Brittle. Hardness, 5-6. Density, 6-6·4. Fusibility, 2-3. Yields a magnetic globule on charcoal. Decomposed by nitric acid.

Occurs in crystalline schists, together with chalcopyrite. Also in ore veins, as in Westphalia (Siegen), Hungary, Caucasus, Norway (Skutterud and Snarum), Sweden (Tunaberg), Chili, Ontario (Cobalt).

**Glaucodot.** — Arsenosulphide of cobalt and iron: $(Co,Fe)AsS$ (cobalt 4 to 25, iron 12 to 33 per cent.). Rhombic, with habit similar to that of mispickel. Colour, tin white to reddish silver white. Opaque. Metallic lustre. Streak, black. Basal cleavage, perfect. Fracture, uneven. Brittle. Hardness, 5. Density, 5·9-6. Fusibility, 2-3. Yields a magnetic globule on charcoal. Decomposed by nitric acid, with separation of sulphur. Of little importance as an ore of cobalt.

Occurs in Norway (Skutterud, Sulitelma), Sweden (Håkansböda), United States (New Hampshire).

**Erythrite,** or cobalt-bloom. — Hydrated arseniate of cobalt: $Co_3(AsO_4)_2.8H_2O$ or $3CoO.As_2O_5.8H_2O$ (cobalt 29·5 per cent.). Crystallizes in the monoclinic system, in slender prismatic needles. Also massive, earthy, or as an incrustation. Clinopinacoidal cleavage, perfect. Colour, crimson to peach colour. Lustre, pearly to vitreous or dull. Streak, pale red. Translucent. Sectile. Hardness, 1·5-2·5. Density, 2·95. Fusibility, 2·5.

Occurs as a decomposition product of cobalt ores. Of no importance as an ore.

## Ores of Iron.

The ores of iron are abundant and of widespread occurrence. Those in chief use for the extraction of the metal are the oxides, *magnetite* and *hæmatite*, the group of hydrated oxides embraced under the general term *limonite*, and the carbonate, *chalybite*. The sulphides—*pyrites*, *marcasite*, *pyrrhotite*, etc.—are not mined for their iron, but for their sulphur content* ; but these minerals are the original source of much of the oxidized iron ore which is found within the belt of weathering of the earth's crust,† although the largest proportion of the oxides is derived, in the first instance, from the decomposition of the numerous iron-bearing minerals (ferromagnesian silicates, etc.) that occur in igneous rocks and are especially abundant in the more basic subdivisions. Chalybite is an intermediate product, and hæmatite and limonite ores often pass downwards into spathic ores (chalybite), from which they have been derived by oxidation and hydration; while the chalybite itself has, in some cases, been traced to the decomposition of pyrites. Of the oxides, magnetite alone occurs in considerable quantity as a mineral of igneous origin, the deposits of this ore near the periphery of large intrusions of basic igneous rocks, having been formed by magmatic concentration, while the rock

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* The iron oxide residue, which remains after the iron sulphides have been roasted in the manufacture of sulphuric acid, is frequently used in blast-furnaces for the production of pig-iron.

† For example, the limonite gossan deposits.

was still in a state of igneous fusion. Chromite, and in a less degree hæmatite, also occur as minerals of igneous origin.

*Native iron* occurs as a constituent of meteorites, and as small nodules in certain basalts (*e.g.*, Disco Island in West Greenland). There seems to be some doubt whether it occurs in the latter as an original or as a secondary constituent. The existence of iron in the native state is only of scientific interest: native iron is not an ore of the metal.

The world's annual output of iron ore amounts at the present time to about 133,000,000 tons, from which some 60,000,000 tons of pig-iron are produced. The distribution of the ores mined is shown by the following table, which summarizes the output (for 1909) of the ten principal producers:

| | |
|---|---|
| United States ... ... | 53,034,000 tons |
| Germany ... ... | 25,095,000 ,, |
| United Kingdom ... ... | 14,980,000 ,, |
| France ... ... ... | 12,254,000 ,, |
| Spain ... ... ... | 9,056,000 ,, |
| Sweden ... ... | 3,823,000 ,, |
| Austria ... ... ... | 2,450,000 ,, |
| Canada ... ... ... | 239,000 ,, |
| Belgium ... ... | 203,000 ,, |

An interesting estimate of the actual and potential ore reserves of the world has been published by the Eleventh International Geological Congress, which sat in Stockholm in 1910. It is quoted here, as it serves

IRON ORE OCCURRENCES IN SCANDINAVIA.

admirably to illustrate the distribution of the known iron ores of the world:

| | | Actual Reserves. Million Tons. | Potential Reserves. Million Tons. |
|---|---|---|---|
| Europe | ... | 12,032 | 41,029 |
| America | ... | 9,855 | 81,822 |
| Australia | ... | 136 | 69 |
| Asia ... | ... | 260 | 457 |
| Africa ... | ... | 125 | not estimated |
| Total | ... | 22,408 | 123,377* |

**Magnetite**, or magnetic iron ore.—The epitritoxide of iron: $Fe_2O_3.FeO$ (iron 72·4 per cent.). Crystallizes in the regular system, occurring in very perfect octahedra or rhombic dodecahedra. Twinning on the spinel type: twinning plane (111). More frequently, however, it is found in granular and compact masses; in minute particles, scattered through many igneous rocks and crystalline schists; or in loose rounded granules ("iron sand") that have been washed out of igneous rocks. It possesses an iron-black colour, black streak, and metallic lustre. Its fracture is conchoidal to uneven. There is no cleavage, but planes of parting parallel to the octahedron are characteristic. Hardness, 5·5-6·5. Density, 4·9-5·2. Its magnetic properties are pronounced, and it was these qualities that caused it to

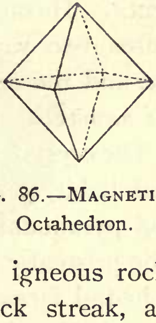

FIG. 86.—MAGNETITE. Octahedron.

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* Plus an unknown amount.

be esteemed by the ancients under the name of the *lodestone.* When powdered it is easily soluble in hydrochloric acid. Before the blowpipe it fuses only with difficulty (fusibility, 5-5·5).

Magnetite is often associated with plutonic igneous rocks of basic composition, and such association denotes a community in origin. Important deposits occur in Sweden (Kirunavaara, Luossavaara, Gellivare, and Taberg), Norway (Sydvaranger and Dunderland), Russia (Gora Blagodat and Gora Magnitnaja in the Urals and the Caucasus), Spain (Lugo), Transvaal (Bushveld). In England, the ore has been worked at Rosedale in Yorkshire.

**Hæmatite.**—Sesquioxide of iron : $Fe_2O_3$ (iron 70 per cent.). Hexagonal-rhombohedral. This iron ore comprises two varieties: the *crystallized* or *specular iron ore,* and the amorphous and earthy material known as *red hæmatite.*

The crystals are partly of a rhombohedral and pyramidal habit, partly tabular, according as rhombohedral and pyramidal faces or the basal plane predominates. The prismatic faces are always subordinate. The rhombohedral faces are often curved, passing gradually over into the basal plane. Specular iron ore also occurs in granular and scaly aggregates, this variety being known as *micaceous hæmatite.* The ordinary red iron ore is not crystallized, its structure being either crypto-crystalline or earthy. It occurs in nodular and botryoidal masses, having a smooth exterior and a radiating internal structure (*kidney ore*), and it also forms stalactitic aggregates.

The earthy variety is termed *red ochre*, and is used as a paint. Lustre, metallic to dull. Colour, iron black to dark steel grey. Streak, cherry red. The colour of the earthy varieties is red. No true cleavage. Fracture, conchoidal to uneven. Infusible before the blowpipe. Soluble in concentrated hydrochloric acid.

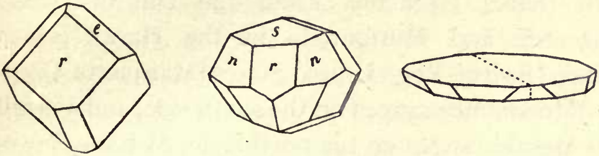

FIG. 87.—SOME COMMON FORMS OF HÆMATITE.
*r*, Rhombohedron; *s*, a more obtuse rhombohedron; *e*, a negative rhombohedron; *n*, a deutero-pyramid.

Hæmatite is an important source of iron, and the ore has a very widespread distribution. Small quantities are found in Cornwall, Devon, and South Wales (Forest of Dean); but the largest English mines are in North Lanca-

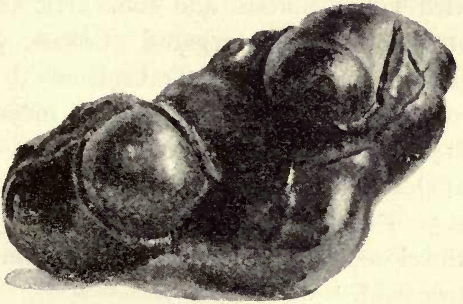

FIG. 88.—KIDNEY IRON ORE.
A variety of hæmatite. (From a photograph.)

shire and Cumberland (Ulverston and Whitehaven). The chief foreign mining centres are France (Normandy and the Pyrenees), Spain (Bilbao, Almeria, Oviedo), Italy (Elba), Germany (Lahn and Dill districts, Elbingerode and Hüttenrode in the Harz), Southern Russia (Kvivoj-Rog), United States (Marquette, Gogebic, and Menominee ranges on the south side, and Vermilion and Mesabi ranges on the north side, of Lake Superior, Adirondack district, Clinton mines in Alabama), Cuba, Brazil (itabirite ores).

**Goethite.**—Hydrated oxide of iron: $Fe_2O_3.H_2O$ (iron 80·91 per cent.). Crystallizes in the rhombic system. Habit, columnar to acicular or capillary, with striated prism faces, or tabular parallel to the brachypinacoid (010). Also in kidney-shaped or botryoidal masses with radial, fibrous, and concentric structures, or in fibrous or scaly aggregates. Colour, yellowish or reddish-brown to black. Translucent to opaque. Lustre on smooth faces, adamantine to metallic, also dull to silky. Streak, yellow to reddish-brown. Brachypinacoidal cleavage, perfect. Fracture, uneven. Brittle. Hardness, 5. Density, 3·8-4·4. Fusibility, 5-5·5. Yields water in the closed tube. Slowly soluble in concentrated hydrochloric acid.

An ore of iron, but not so common as hæmatite or limonite. Occurs in Cornwall (Lostwithiel, Botallack, Redruth), Scotland, Westphalia, Nassau, Harz, Saxony (Schneeberg, Freiberg), Silesia, Bohemia (Przibram), Russia (Ekaterinburg), United States (Marquette, Mesabi, etc., in the Lake Superior district).

**Limonite**, or brown iron ore.—Hydrated oxide of iron: $Fe_2O_3 + nH_2O$. Does not occur crystallized, but has a crypto-crystalline to earthy texture, and forms nodular, botryoidal, kidney-shaped, or stalactitic masses, frequently with an internal fibrous structure. The amount of water is variable. Some authors use the water-content as a means of distinction between the following mineral species: *turgite*, with 5·3 per cent. of water, corresponding to $2Fe_2O_3.H_2O$; *limonite*, with 14·5 per cent. of water, corresponding to $2Fe_2O_3.3H_2O$; *xanthosiderite*, with 18·4 per cent. of water, corresponding to $Fe_2O_3.2H_2O$; *limnite*, with 25·2 per cent. of water, corresponding to $Fe_2O_3.3H_2O$. But it is somewhat doubtful whether these definite hydrates really exist.

The different varieties of limonite have been classified by Tschermak, according to texture, as follows: *fibrous limonite* (including turgite); *compact brown iron ore*, including oolitic ironstone and the decomposition products of chalybite and pyrites; *ochreous limonite*, including xanthosiderite and the various ochres, umbers, and siennas; *pitchy limonite* (stilpnosiderite), characterized by a black colour, glazed surface, and conchoidal fracture; *earthy and sandy limonite*, including limnite, bog iron ore, and lake iron ore, found as a brownish-yellow deposit from ferrous carbonate in marshes, wet moorland, and shallow lakes; *pisolitic and oolitic limonite*, including the so-called "minettes"; *limonitic cement and impregnation*, found in clays, sandstones, conglomerates, and as concretions.

Limonite varies in colour from yellow to blackish-brown, and has a yellowish-brown streak. It is opaque, and has a dull to silky lustre. Its hardness is from 1 to 5·5, according to the variety, and its density from 3·3 to 4. Fracture, according to the variety, fibrous, conchoidal, or earthy. Brittle. Fusible with difficulty. Heated in the closed tube, yields water. Limonite is an important iron ore on account of its abundance and widespread distribution. The percentage of iron depends, of course, upon the amount of sandy and clayey impurity. The considerable percentage of phosphoric acid depreciated the value of some of these ores until the introduction of the basic process.

Limonitic ores occur in the British Isles: in South Wales (Forest of Dean) and Antrim. Large supplies are also derived from the oolitic iron ores of Jurassic age in North Yorkshire (Cleveland district), Northamptonshire, and Lincolnshire. Similar oolitic ores (the so-called "minette" ores) furnish large supplies in Lorraine, Luxemburg, and Belgium. Mention must also be made of the deposits, of recent age, of bog and lake iron ore of Silesia, the Banat, Finland, and Scandinavia (Småland, Vestragötland, and Dalarne). Other important iron-mining centres where limonite ores are exploited are Prussia (Ilsede and Salzgitter, north of the Harz), Bavaria, Würtemberg, Spain (Lugo, Santander, Murcia, Oviedo), Russia (Nischne-Novgorod, Kaloga, and Kertch), United States (Appalachian Mountains and the Marquette, Gogebic, Menominee, Vermilion, and Mesabi ranges of the Lake Superior district).

**Chalybite**, siderite, or spathic iron ore. — Carbonate of iron: $FeCO_3$ (iron 48·2 per cent.). Crystallizes in the hexagonal system, usually in flat rhombohedra with curved faces. Also occurs massive or mixed with clay (*clay ironstone*), and often contains carbonates of lime, magnesia, and manganese. Cleavage, rhombohedral. Colour, buff or fawn. Streak, white. Hardness, 3·5-4·5. Density, 3·7-3·9. Soluble in acids, with liberation of carbon dioxide, but not so readily soluble as calcite. Fusibility, 4·5-5.

The nodules of clay ironstone, which are found in the shales of the Coal Measures, are termed *sphærosiderite.* This variety of the ore forms the staple material of the British iron production. The varieties used in smelting contain from 25 to 35 per cent. of iron. The *blackband ironstone* is an impure carbonate of iron interstratified in thin seams in the Coal Measures of the North of England. It is especially valuable on account of its contained coaly matter.

Clay ironstone is worked in all the principal coalfields of the British Isles—*e.g.*, those of Scotland, Northumberland and Durham, Derbyshire and Yorkshire, North Staffordshire, South Wales and Coalbrookdale. The Jurassic ironstones of Yorkshire, Northamptonshire, and Lincolnshire also consist largely of spathic ores (chalybite) in the deeper parts of the deposits. Other centres of the iron-mining industry where spathic ores are worked are France (Normandy and the Pyrenees), Spain (Leon), Germany (Siegerland), Austria (Styrian Erzberg and the Hüttenberger

Erzberg of Carinthia), Hungary (Vares), United States (the Appalachian coalfields of Pennsylvania, Ohio, Kentucky, etc.).

**Chromite**, or chrome iron ore.—Oxides of iron and chromium: $FeO.Cr_2O_3$* (oxide of chromium 68 per cent.). Crystallizes in the regular system, but usually occurs massive, granular, or compact; also in loose grains. Colour, iron black to brownish-black. Opaque. Streak, brown. Lustre, submetallic. Fracture, uneven. Hardness, 5·5. Density, 4·4. Infusible. Imparts a characteristic green coloration to the borax bead.

This mineral is valuable on account of its chromium content, which is required for a variety of purposes—*e.g.*, the manufacture of ferro-chrome for chromium steels, and of refractory furnace linings; and the preparation of the compounds used as pigments, mordants, oxidizing agents, etc. The ore is widely distributed in serpentines, and as peripheral concentrations in the ultrabasic rocks (peridotites) from which the serpentines are derived. It is also found in sands. Examples of its occurrence are Silesia, Bohemia, Greece, Russia (Ural Mountains), New South Wales, New Zealand, British Columbia, United States, Transvaal, Rhodesia, New Caledonia, and Asia Minor, the two latter being the largest producers.

**Ilmenite**, menaccanite, or titaniferous iron ore.—Oxides of iron and titanium: $FeO.TiO_2$, with or with-

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* Ferrous oxide is replaceable to some extent by magnesia (MgO), and chromic oxide by alumina ($Al_2O_3$).

out $Fe_2O_3$. Crystallizes in the hexagonal system, with rhombohedral symmetry. Isomorphous with hæmatite. Habit, tabular parallel to the basal plane, with dominant rhombohedral faces. Also occurs massive; in granular and scaly aggregates; and as rolled grains (*menaccanite sand*). Colour, iron-black. Streak, black to brown. Opaque. Lustre, semi-metallic—metallic on freshly fractured faces. Although there is no true cleavage, the mineral separates along basal and rhombohedral twinning planes. Fracture, conchoidal. Hardness, 5·6. Density, 4·5-5·3. The density increases with the $Fe_2O_3$ content. As a rule non-magnetic. Infusible. Soluble when finely powdered in boiling hydrochloric acid, the solution heated with tinfoil giving a violet colour.

A very common mineral, especially as an accessory constituent of igneous rocks; also in sediments, schists, and as sand. Of no value as an iron ore. Original locality, the Ilmen Mountains in the Urals. A common companion of the diamond in the kimberlite pipes of South Africa. The black sands in the beach placers of the United States and New Zealand are rich in ilmenite.

**Iron Pyrites.**—Disulphide of iron: $FeS_2$ (iron 46·64, sulphur 53·36, per cent.). Crystallizes in the regular system. The cube, either alone or combined with the faces of the pentagonal dodecahedron and the octahedron, is the most frequent form. The faces of the cube are usually striated, in consequence of the tendency to oscillatory combination of that form with the pentagonal dodecahedron. The latter form also occurs alone, in which case its faces are striated by oscillation with the cube. Twinning parallel to a face of the rhombic dodecahedron.

The crystals are of all sizes, and occur either singly or grouped. Nodular, botryoidal, kidney-shaped, compact masses, round pellets, and irregular grains—all these forms are of common occurrence. The colour of unaltered pyrites is brassy yellow; but the surface is frequently tarnished, and the mineral alters easily into a dark brown limonite, the change being one of oxidation and hydration. The streak is brownish-black. Lustre, metallic. Opaque. Fracture, conchoidal to uneven. A cubic cleavage is scarcely perceptible. Brittle. Hardness, 6-6·5. Density, 4·9-5·1. The superior hardness is an important distinction from copper pyrites and from gold. Pyrites strikes fire with steel. Fusibility, 2·5-3. Yields a magnetic globule before the blowpipe. Decomposed by nitric acid, with separation of sulphur.

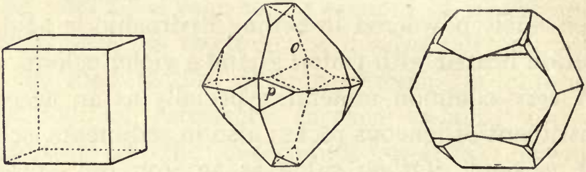

FIG. 89.—CRYSTALS OF IRON PYRITES.

Iron pyrites is very widely diffused through the crust of the earth, occurring both as an accessory constituent of rocks and in veins and large masses, either independently or as a very common companion of other sulphide ores; but, in spite of its high percentage of iron, it is not used for the production of that metal. The chief use of pyrites is for the manufacture of sulphuric acid, for which purpose it is imported from Spain, Portugal, and Belgium, besides being exploited largely in British metalliferous mines. Pyrites is often associated with gold, and in such cases the latter is usually mechanically included within its crystals (*auriferous pyrites*).

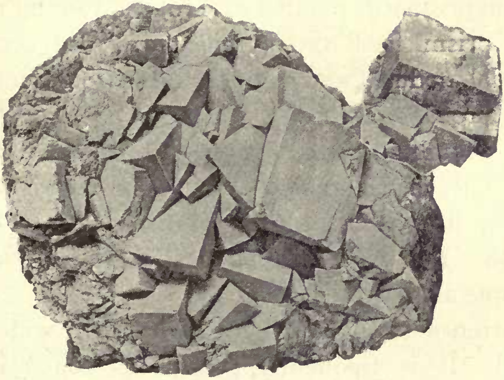

FIG. 90.—IRON PYRITES (AFTER J. M. BONTWELL, U.S. GEOL. SURVEY).

On account of its ubiquity, it is useless to give localities for pyrites: it is associated with marine and brackish water sediments of every age, appearing as grains disseminated through shales and clays or in seams and layers, as in the Coal Measures; or, again, as concretionary nodules, as in certain zones of the Chalk or in the Oxford and Kimeridge clays. By oxidation it is converted into the oxides of iron, the liberated sulphuric acid producing gypsum in calcareous clays, and alum shale in those free from lime.

**Marcasite,** or cockscomb pyrites.—Disulphide of iron : $FeS_2$ (same composition as pyrites). Crystallizes in the rhombic system, with tabular habit parallel to the basal plane (001), or with dominant brachydomes; or, again, prismatic, parallel to (110). Twinning parallel to the prism face, often repeated. Also occurs in botryoidal, nodular, and globular forms (sometimes with radial fibrous structure), or massive. Colour, brassy yellow. Metallic lustre. Opaque. Streak, dark greyish-green. Cleavage distinct, parallel to the prism (110). Fracture, uneven. Brittle. Hardness, 6. Density, 4·65-4·88. Behaviour before the blowpipe and with acid, same as pyrites.

Occurrence similar to pyrites, but less widely distributed. It is frequently present as concretions in clays, marls, and limestones (*e.g*, in the chalk of Dover and Folkestone).

**Pyrrhotite**, or magnetic pyrites.—Monosulphide of iron: FeS (iron 63·61 per cent.). Crystallizes in the hexagonal system, with tabular habit parallel to the basal plane. Twinning parallel to a pyramid face $(10\bar{1}2)$. Usually occurs massive or granular. Colour, bronzy yellow to copper-coloured. Lustre, metallic. Streak, greyish-black. Basal cleavage, imperfect. Fracture, uneven. Brittle. Hardness, 3-4. Density, 4·5-4·6. Magnetic—*i.e.*, the fine powder is attracted by the magnet. Fusibility, 2·5-3. On charcoal yields a black magnetic globule. Soluble in hydrochloric acid, with separation of sulphur.

Pyrrhotite is of common occurrence as an accessory constituent of igneous rocks, of limestones and of crystalline schists; it is also found with other sulphides in ore veins, and in large independent lenticular masses in the crystalline schists (*e.g.*, in the Huronian of the Appalachian Mountains of the Eastern United States). When it contains nickel (up to 5 per cent., average 3 per cent.—*nickeliferous pyrrhotite*), it constitutes a valuable ore of nickel, as at Sudbury in Ontario, Canada,* at the Lancaster Gap mine in Pennsylvania, and at Erteli in Norway. In Rossland, British Columbia, it is associated with gold.

## ORES OF MANGANESE.

Manganese is a widely-distributed metal, occurring as a constituent of at least a hundred different minerals. Only some half a dozen (mainly oxides and hydrates of manganese), however, are of importance as ores; and these are all secondary compounds that owe their origin to the decomposing action of percolating alkaline and carbonated waters on primary manganese minerals in igneous and metamorphic rocks. As examples of such primary minerals, the manganese-pyroxene (*rhodonite*), the manganese-olivine (*tephroite*), and the manganese-garnet (*spessartite*), may be quoted.

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* Sudbury is responsible for half the world's annual output of nickel.

The manganese thus derived is carried in solution as a bicarbonate, and reacting on rocks within the zone of weathering (in other words, in the presence of free oxygen) forms replacement deposits. The commonest ores produced in this way are *pyrolusite* (peroxide of manganese), *psilomelane* (hydrated oxide of manganese), and *braunite* (an oxide and silicate of manganese). *Wad* or *bog-manganese* is an indefinite mixture of various hydrated oxides that occur at the surface, especially as lateritic deposits. Other less frequent ores are *manganite* (the hydrated sesquioxide) and *rhodochrosite* (the carbonate). *Franklinite*, which is an ore of zinc occurring at Franklin Furnace in New Jersey, contains sufficient manganese to make its extraction from the zinc-residuum profitable.

Manganese is chiefly used for the preparation of certain alloys of iron and manganese (spiegeleisen and ferromanganese) which are used in the manufacture of steel; but the oxide is also used in the manufacture of chlorine, bromine, and oxygen, as a dryer in paints and varnishes, and as a decolorizer of glass.

**Pyrolusite.**—Peroxide of manganese: $MnO_2$ (manganese 63·22 per cent.). When it occurs in crystals it is pseudomorphous after manganite, but it is mostly found as earthy masses, or in botryoidal, kidney-shaped, and nodular aggregates, with radiate fibrous structure. It also occurs as dendritic markings on the bedding and parting planes of rocks. Colour, steel grey to iron black and opaque, with dull, but sometimes silky, lustre. Streak, black, soiling the fingers. Hardness, 2·25. Density, 4·7-5. Infusible. Soluble in hydrochloric acid with evolution of chlorine.

A widely-distributed mineral, and often an important ore of manganese. It is frequently found as an alteration product of manganite and other manganese-bearing minerals, and largely as a replacement deposit within the zone of weathering, where, together with hydrated oxides of iron and alumina, it forms ores of lateritic origin. It thus often associates with psilomelane and with wad, but it may often be distinguished from these rather similar oxides of manganese by the possession of a crystalline or fibrous structure. It is also of inferior hardness to psilomelane. Examples of occurrence are: Nassau, Moravia, Caucasus, United States, India, etc.

**Manganite.**—Hydrated sesquioxide of manganese: $Mn_2O_3.H_2O$ (manganese 62·5, water 10·23 per cent.). Crystallizes in the rhombic system, with dominant prismatic habit (110). The basal plane is striated parallel to the macrodiagonal. Twinning parallel to the brachydome (011). Also occurs in columnar to fibrous and radiating aggregates. Colour, dark steel grey to iron black. Opaque. Lustre, submetallic. Streak, dark brown. Brachypinacoidal cleavage, perfect. Fracture, uneven. Brittle. Hardness, 3-4. Density, 4·2-4·4. Infusible. Gives off water when heated in the closed tube. Often partially altered to pyrolusite.

Manganite occurs in veins at Ilfeld in the Harz, and with other manganese ores in Nassau and at many other localities.

**Psilomelane.**—A mineral of rather indefinite composition, but probably a hydrated manganese manganate in which a portion of the manganese is replaceable by barium and potassium, corresponding to the formula $(H_2,K_2,Mn,Ba)_2MnO_5$. The highest percentage of manganese possible, in accordance with the formula $Mn_2MnO_5$, is 67·35 per cent. Psilomelane does not occur crystallized, being massive, botryoidal, reniform, or stalactitic. Colour, iron black to dark steel grey. Opaque. Streak, brownish-black, shining. Lustre, submetallic to dull. Fracture, uneven. Hardness, 5-6. Density, 3·7-4·7. Infusible. Soluble in hydrochloric acid, with evolution of chlorine.

Psilomelane is widely distributed, and constitutes the most important ore of manganese, occurring both as a replacement deposit in rocks within the zone of weathering, and, together with the hydrated oxides of iron and aluminium, in ores of lateritic origin. It is mined in India, Russia (Caucasus), Spain, Brazil, and the United States. In India it constitutes, together with braunite, 90 per cent. of the manganese ore exported.

**Wad.**—The name given to an indefinite mixture of various oxides, chiefly of manganese, but also of iron, aluminium, barium, etc., together with a little silica and 10 to 20 per cent. of water. It occurs in amorphous earthy or compact masses or as incrustations. Colour, dull black to brownish-black. Streak, brownish-black to black. Usually very soft, soiling the fingers. Density, 3-4·3. Infusible. Soluble in hydrochloric acid.

Wad is a widely-distributed and abundant surface deposit of manganese, and often still possesses the original slaty or schistose structure of the rocks which it has replaced. It is frequently associated with psilomelane, but may be distinguished from it by its inferior hardness, and from pyrolusite by the absence of crystalline or fibrous structures.

**Braunite.**—An oxide and silicate of manganese, corresponding to the general formula $m\text{MnMnO}_3 + n\text{MnSiO}_3$. It may be regarded as an isomorphous mixture of manganese manganite and manganese silicate. The ratio of $m : n$ is usually 3 : 1; but it may be also 7 : 2 or 4 : 1 (with $m : n = 3 : 1$, manganese = 63·6 per cent.). Braunite crystallizes in the tetragonal system, with dominant pyramid of the first order (111). Also occurs massive and granular. Colour, dark brownish-black to steel grey. Opaque. Lustre, submetallic. Streak, dark brown. Cleavage parallel to the pyramid (111), perfect. Fracture, uneven to subconchoidal. Brittle. Hardness, 6-6·5. Density, 4·75-4·82. Slightly magnetic. Infusible. Soluble in hydrochloric acid, with evolution of chlorine, and yielding a residue of gelatinous silica. An important ore of manganese; as at Ilfeld in the Harz, Telemark in Norway, and at many places in India, etc.

**Rhodochrosite**, or dialogite.—Carbonate of manganese: $\text{MnCO}_3$ (manganese 47·83 per cent.). Crystallizes in the hexagonal system, with rhombohedral symmetry, being isomorphous with calcite; but usually occurs massive. Rhombohedral cleavage, perfect. Colour, pink, rose red and light brown. Lustre, pearly. Translucent. Streak, white. Brittle. Hardness, 3·5-4·5. Density, 3·45-3·6. Infusible. Soluble in hydrochloric acid, with effervescence. Distinguished from rhodonite ($MnSiO_3$), which it resembles in colour, by its inferior hardness and behaviour with hydrochloric acid.

Rhodochrosite is not widely distributed, but is an important ore of manganese when in sufficient quantity. It has been mined in the French Pyrenees and at a few other places.

## ORES OF BISMUTH, ANTIMONY, AND ARSENIC.

*Native bismuth* is the principal source of the metal; but the sulphides of the metal are also worked, and there are several compounds of bismuth with selenium, tellurium, silver, gold, copper, and lead, as well as oxides, carbonates, etc., that are of no importance as ores. Antimony occurs native; but the principal supply of the metal is derived from the sulphide—*stibnite*. It is also found in numerous sulphide compounds, such as *antimonial tetrahedrite*, *pyrargyrite*, etc., and in the oxidation zone as oxides and oxysulphides (*senarmontite*, *cervantite*, and *kermesite*). Besides occurring in the native state, arsenic is found in two forms as sulphides, *realgar* and *orpiment*, and in numerous complex ores of silver, copper, lead, etc.; but the principal supply is obtained from the arsenosulphide of iron—*mispickel*.

Bismuth and antimony are chiefly valuable in the arts for their alloys with lead, tin, and copper. Bismuth is used in fusible alloys and for *cliché* metal; antimony, in alloy with lead (antimonial lead), as type metal, babbitt metal, etc., and arsenic, for the manufacture of arsenious oxide (white arsenic).

**Native Bismuth.**—Bi. Crystallizes in the hexagonal system, but usually occurs in crystalline, granular, or scaly masses or as botryoidal incrustations. Colour and streak, silver white, generally iridescent at the surface. Opaque. Lustre, metallic. Basal cleavage, perfect. Brittle. Fracture, uneven. Hardness, 2. Density, 9·7-9·8. Fusibility, 1. Soluble in nitric acid, the solution giving a white precipitate with water.

Native bismuth, the most important source of the metal, occurs in association with cobalt and silver ores, as in Saxony (Schneeberg), Bohemia (Erzgebirge), Sweden (Dalarne), Bolivia (Tazna, Illampa), Ontario (Cobalt), New South Wales (Cobar).

**Bismuthinite.**—Sesquisulphide of bismuth: $Bi_2S_3$ (bismuth 81·22 per cent.). Crystallizes in the rhombic system, with acicular habit. Usually massive, scaly, or fibrous. Colour, lead grey to tin white. Iridescent on the surface. Opaque. Streak, grey. Lustre, metallic. Brachypinacoidal cleavage, perfect. Hardness, 2. Slightly sectile. Density, 6·4-6·5. Fusibility, 1. Yields a globule of bismuth in the reducing flame. Soluble in hot nitric acid, the solution giving a white precipitate with water.

Bismuthinite occurs in Cornwall, Saxony (Schneeberg), Hungary (Rézbánya), France (Meymac), Sweden (Riddarhyttan), Australia, Bolivia (Tazna, Chorolque), Utah (Beaver City).

**Native Antimony.**—Sb. Crystallizes in the hexagonal system, with rhombohedral habit; but usually occurs massive or as granular or botryoidal incrustations. Colour, tin white. Opaque. Lustre, metallic. Basal cleavage, perfect. Brittle. Fracture, uneven. Hardness, 3. Density, 6·6-6·7. Fusibility, 1. Volatile. Soluble in aqua regia.

Native antimony occurs in Sweden (Sala), Germany (Andreasberg in the Harz), Bohemia (Przibram), Borneo (Sarawak), Chili (Huasco), Peru, New Brunswick (York County).

**Stibnite**, antimonite, or antimony glance.—Sesquisulphide of antimony: $Sb_2S_3$ (antimony 71·76 per cent.). Crystallizes in the rhombic system, occurring in divergent aggregates of long prismatic or acicular crystals, with pyramidal terminations. The prism faces are characterized by a well-developed vertical striation. Colour, lead grey. Streak, lead grey. Opaque. Lustre, metallic, especially bright on cleavage faces. Cleavage parallel to the brachypinacoid (010), perfect. Fracture, subconchoidal. Slightly pliable. Hardness, 2. Density, 4·6-4·7. Easily fusible (fusibility on von Kobell's scale, 1). Volatilizes. Decomposed by hydrochloric acid.

Stibnite occurs in ore deposits in association with galena, blende, cinnabar, and the gangue minerals barytes and quartz. It is of widespread occurrence in Europe—*e.g.*, Westphalia, Harz, Hungary, Bohemia, Italy, Corsica, Sardinia, France, Algeria, Spain, Russia. The bulk of the world's supply, however, is now mined in Japan (Ichinokawa mines in the island of Shikoku), China, and Australia (New South Wales, Victoria, and Tasmania). It is also worked in the United States, Mexico, Peru, Borneo (Sarawak), and New Zealand.

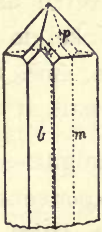

FIG. 91.—ANTIMONITE. *p*, Pyramid; *m*, prism; *b*, macropinacoid.

**Mispickel**, arsenical pyrites, or arsenopyrite.—Arsenosulphide of iron: FeAsS (iron 34·34, arsenic 46·01, sulphur 19·65, per cent.). Crystallizes in the rhombic system, with prismatic habit parallel to (110), or brachydomatic parallel to (012). Twinning parallel to the macrodome (101) or to the prism (110). Also occurs massive and granular. Colour, tin white to steel grey. Opaque. Lustre, metallic. Streak, greyish-black. Cleavage parallel to the prism (110). Fracture, uneven. Brittle. Hardness, 5·5-6. Density, 5·9-6·2. Strikes fire with steel, with smell of garlic. Fusible before the blowpipe to a magnetic globule, with emission of arsenical fumes. Fusibility, 2. Decomposed by nitric acid, with separation of sulphur.

Mispickel is a common companion of ores—*e.g.*, those of silver, cobalt, and nickel, in which it is associated with blende, galena, pyrites, and chalcopyrite; it also accompanies tin ore together with wolframite, fluorspar, and quartz. Together with pyrites it is often associated with gold in gold-quartz veins. Mispickel is the chief source of the arsenic of commerce, and is largely worked as an arsenic ore in Cornwall, at Schneeberg in Saxony, and in Ontario.

**Realgar.**—Monosulphide of arsenic: AsS (arsenic 70·08 per cent.). Crystallizes in the monoclinic system. Habit, short columnar with vertical striation. Also occurs massive or in granular aggregates, and as incrustations. Colour, red to orange red. Streak of the same colour, but lighter in tint. Transparent to translucent. Lustre, resinous. Clinopinacoidal cleavage, fair. Fracture, subconchoidal. Sectile. Hardness, 1-2. Density, 3·56. Fusibility, 1. Volatile, with smell of garlic. Decomposed by aqua regia, with separation of sulphur.

Realgar occurs in association with silver and lead ores: Harz (Wolfsberg), Hungary (Tajova, Nágybánya, Felsöbánya, Kapnik), Transylvania (Nágyág), Italy (Casa Testi, Vesuvius, Etna), Corsica, Chili, Peru, Bolivia.

**Orpiment.**—Sesquisulphide of arsenic: $As_2S_3$ (arsenic 60·96 per cent.). Crystallizes in the rhombic system, with short columnar habit; but occurs more frequently massive, in granular or fibrous aggregates, sometimes with a botryoidal surface. Colour, orange yellow. Streak, the same, but lighter. Translucent. Lustre, resinous. Brachypinacoidal cleavage, perfect. Flexible.

Sectile. Hardness, 1-2. Density, 3·4-3·5. Fusibility, 1. Very volatile. Soluble in aqua regia. Occurrence the same as realgar.

## ORES OF VANADIUM.

Vanadium is found in *dechenite* (vanadate of lead—$PbO.V_2O_5$) and *vanadinite* (chlorovanadate of lead—$9PbO.3V_2O_5.PbCl_2$), and other rare minerals occurring in Spain, Sweden, the Argentine, Mexico, and Colorado; but the only commercial source is an occurrence of vanadinite in Spain. It is used in the form of ferro-vanadium in the manufacture of steel alloys. The addition of from 0·2 to 0·5 per cent. of vanadium to steel increases its tensile strength, its ductility, and its elasticity.

**Vanadinite.**—Chlorovanadate of lead: $9PbO.3V_2O_5.PbCl_2$ ($V_2O_5$ 19·36 per cent.). Crystallizes in the hexagonal system, being isomorphous with pyromorphite (chlorophosphate of lead) and apatite (fluorophosphate of calcium). Colour, red. Streak, nearly white. Lustre, resinous. Translucent. Cleavage, none. Brittle. Fracture, uneven. Hardness, 3. Density, 6·9-7·1. Fusibility, 1·5. Partly soluble in acids. Occurrence as above.

## ORES OF TIN.

The only important ore of tin is the oxide, *cassiterite*, the sulphide, *stannite*, being of little practical value. A large proportion of the tin ore mined is from detrital deposits, in which cassiterite occurs as a sand in association with quartz, topaz, tourmaline, axinite, garnet, epidote, wolfram, scheelite, fluorspar, monazite, ilmenite, and magnetite, these minerals sharing with cassiterite the property of resisting destruction by weathering. Tin ore is also found in the veins, chimneys, impregnations, etc., which occur at or near the margin of large granite intrusions, and are generally considered to be of pneumatolytic origin—*i.e.*, to have been derived from the granite magma through the agency of vapours and gases dissolved in it at the time of intrusion, and given off during consolidation. In these original deposits cassiterite is associated with tourmaline, fluorspar, axinite, wolfram, and topaz, to all of which, on account of their peculiar composition, pneumatolytic origin is ascribed.

Tin is of great use in the arts on account of its valuable alloys, such as soft solder (an alloy with lead), bronze, gun-metal, bell-metal, specular metal (all alloys with copper), Britannia metal (an alloy with antimony), and babbitt and other friction metals (alloys with antimony and copper). Its largest application is in the tin-plate industry, in which sheet iron is coated with a layer of tin. It is also used for tinning copper utensils, and in the form of tinfoil.

The subchloride of tin (*tin-salt*) is used as a mordant in dyeing. It is a valuable reducing agent.

**Cassiterite**, tinstone, or black tin.—Dioxide of tin: $SnO_2$ (tin 78·82 per cent.). Crystallizes in the tetragonal system, the common form being the pyramid, combined with the prism, of the first order. The edges of both pyramid and prism are, however, sometimes truncated by the faces of the pyramid and prism of the second order. The faces of the first pyramid show a horizontal, those of the prism a vertical, striation. Habit, usually stout columnar. The crystals are often twinned, the twinning plane being a face of the deutero-pyramid (101). Repetitions of the twinning produce ring or star-shaped aggregates of three to five individuals. Tinstone also occurs massive in fibrous nodules (*wood-tin*) in grains dispersed through granite, or in pegmatite veins, but most frequently in loose rounded fragments, mingled with river gravels (*stream-tin*). Colour, usually brown or black, but yellow and grey tints also occur. Lustre, adamantine to resinous. Cleavage parallel to (100), imperfect. Fracture, subconchoidal to uneven. Brittle. Hardness, 6-7. Density, 6·8-7·1. Infusible. Yields a globule of tin with carbonate of soda on charcoal. Insoluble in acids.

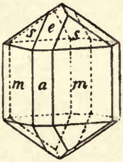

FIG. 92.—CASSITERITE.

*s*, Proto-pyramid ; *m*, proto-prism ; *e*, deutero-pyramid ; *a*, deutero-prism.

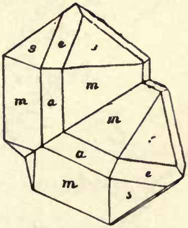

FIG. 93.—CASSITERITE TWINNED CRYSTAL).

Becomes coated with metallic tin when placed on zinc with hydrochloric acid.

Cassiterite was formerly extensively mined in Cornwall, and tin ore is still a staple product of that county. The historical tin deposits of Altenberg and Zinnwald in Saxony also deserve mention; but the main supplies are now derived (1) from the tin deposits (largely of

Map of the Tin-Mining Districts of the Federated Malay States and Dutch East Indies.

alluvial origin) of the Malay Peninsula (Perak, Selangor, Nigri-Sembilan)—and of the Dutch East Indies (Banka and Billiton); (2) from Australasia — Queensland (Herberton), New South Wales (Vegetable Creek, etc.), West Australia, Tasmania (Mount Bischoff and Briseis) — and (3) from Bolivia (La Paz, Oruro, Potosi, and Chorolque). Other producers are Mexico, California, Dakota, Alaska (Seward Peninsula), Japan, and China. An increasing production is being made in South Africa (Swaziland, Transvaal), and extensive alluvial deposits are being explored in Nigeria.

**Stannite**, tin-pyrites, or bell-metal ore. — Sulphostannate of iron and copper: $Cu_2FeSnS_4$ or $SnS_2.Cu_2S.FeS$ (tin 27·68, copper 29·5, iron 13·02, per cent.). Crystallizes in the tetragonal system, with sphenoidal hemihedrism. Habit, pseudo-regular. Twinning axis the normal to (111). Generally occurs massive or in granular aggregates. Colour, steel grey to iron black. Streak, black. Opaque. Lustre, metallic. Basal and prismatic cleavages, indistinct. Fracture, subconchoidal to uneven. Brittle. Hardness, 3-4. Density, 4·3-4·5. Fusibility, 1·5. Gives off sulphur fumes when heated. Decomposed by nitric acid, with separation of sulphur and oxide of tin.

Stannite is rarely of importance as an ore of tin. It occurs in Cornwall, Bohemia (Zinnwald), Bolivia (Oruro and Potosi), Dakota (Black Hills), Tasmania (Zeehan), Japan.

## ORES OF TITANIUM.

Titanium occurs as an oxide ($TiO_2$) in the three minerals *rutile*, *anatase*, and *brookite*, of which the two first named are tetragonal, and the last rhombic. Its occurrence in ilmenite or titaniferous iron ore has been already dealt with on p. 178. The only important source of the metal is rutile, which can be reduced in the electric furnace by the aid of aluminium, the resulting ferrotitanium (10-20 per cent. of titanium) being used for increasing the strength of cast iron and of steel.

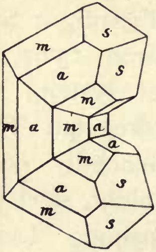

FIG. 94.—RUTILE (REPEATED TWINNING).

**Rutile.**—Dioxide of titanium: $TiO_2$ (titanium 60 per cent.). Crystallizes in the tetragonal system, in prismatic forms similar to those of cassiterite. Twinned on the pyramid of the second order (101). Also occurs massive. Colour, reddish-brown. Streak, yellowish-brown. Lustre, metallic to adamantine. Translucent. Refractive index high; $\omega = 2{\cdot}616$. Double refraction, strong, positive ($\epsilon - \omega = 0{\cdot}287$). Prismatic cleavage, good. Fracture, uneven. Brittle. Hardness, 6·5. Density, 4·3. Infusible. Insoluble in acids. A good test for titanium is to fuse the mineral with sodium bisulphate, acidify the aqueous solution with sulphuric acid, and add hydrogen peroxide. A deep orange colour betrays the presence of titanium.

Rutile is worked as an ore of titanium at Risör and other places in Norway, also in the United States.

## ORES OF MOLYBDENUM.

Only two compounds of molybdenum are of commercial importance: the sulphide, *molybdenite*, and the molybdate of lead, *wulfenite*. The commercial ores should not contain less than 42 per cent. of the metal, and should be free from other metallic minerals. Molybdenum in the form of ferromolybdenum (containing from 75 to 87 per cent. of molybdenum) and nickel-molybdenum (containing 75 per cent.) is used for the manufacture of steel alloys. The effect of the addition of from 2 to 4 per cent. of molybdenum to steel is to increase the hardness, toughness, and elongation, without any corresponding deterioration when the steel is heated or welded.

**Molybdenite.**—Sulphide of molybdenum: $MoS_2$ (molybdenum, 59·96 per cent.). Crystallizes in the hexagonal system. Habit, six-sided tabular (basal plane, prism, and pyramid). Also occurs in scales and grains. Colour, lead grey. Streak, greenish-grey. Opaque. Lustre, metallic. Basal cleavage, perfect. Pliable. Sectile. Hardness, 1. Greasy to the touch. Soils the fingers. Density, 4·7-4·8. Infusible. Heated in open tube yields sulphur fumes. Soluble in warm aqua regia. The powdered mineral, moistened with sulphuric acid and evaporated to dryness in a porcelain crucible, yields a characteristic blue colour.

Molybdenite occurs in small quantities in many granites, pegmatites, gneisses, crystalline limestones, and schists. It is often associated with tin ore.

**Wulfenite.**—Molybdate of lead: $PbMoO_4$ (molybdenum 26·2 per cent.). Crystallizes in the tetragonal system, with tabular habit. Colour, red. Streak, white. Translucent. Lustre, adamantine to resinous. Pyramidal cleavage, fair. Fracture, subconchoidal. Brittle. Refractive index, 2·402. Double refraction, strong. Hardness, 3. Density, 6·7. Fusibility, 2. Decomposed by hydrochloric acid.

Wulfenite occurs in the oxidized zone of lead ores —for example, in Utah, Nevada, Arizona, and New Mexico.

## ORES OF TUNGSTEN.

Tungsten is obtained from the ores *wolframite* (tungstate of iron and manganese) and *scheelite* (tungstate of calcium), which are associates of cassiterite in nearly all tin-mining districts. The pure tungstate of manganese (*hübnerite*) and the pure tungstate of iron (*ferberite*), which are isomorphous with wolframite, are also known, and in places occur in sufficient quantity to be mined as ores.* The chief use for tungsten is in the manufacture of steel alloys for lathe tools. A small percentage of tungsten increases the elastic limit and the tensile strength of steel. Tungsten steel is also self-hardening. On account of its high fusing-point (3080° C.), tungsten has also come into use as a filament in incandescent lamps. The world's production of tungsten ores is about 6,000 tons per annum, based on 60 per cent. ore.

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* A useful chemical test for tungsten is—Digest the pulverized mineral in strong hydrochloric acid; the solution boiled with metallic zinc yields a blue coloration when tungsten is present.

**Wolframite.**—Tungstate of manganese and iron: $(Fe,Mn,)WO_4$ ($WO_3$ 76 per cent.). Crystallizes in the monoclinic system. Colour, black. Streak, dark reddish-brown Lustre, metallic to adamantine. Opaque. Clinopinacoidal cleavage, perfect. Brittle. Fracture, uneven. Hardness, 5·5. Density, 7·3. Fusibility, 3. Decomposed by hydrochloric acid.

Wolframite is a common associate of tin ore, as in Cornwall, Spain, Bohemia, Straits Settlements, Queensland, New South Wales, United States, Bolivia.

**Scheelite.**—Tungstate of calcium: $CaWO_4$ ($WO_3$ 80·6 per cent.). Crystallizes in the tetragonal system, with bipyramidal habit. Colour and streak, white. Lustre, vitreous to adamantine. Translucent. Index of refraction 1·919. Double refraction, strong. Pyramidal cleavage, imperfect. Brittle. Fracture, uneven. Hardness, 4·5. Density, 6. Fusibility, 5. Decomposed by hydrochloric acid.

Scheelite occurs in association with tin ore—*e.g.*, in Cornish, Bohemian, and Australian tin-mining districts.

## ORES OF URANIUM.

The principal ores of uranium are *pitchblende*, *torbernite*, and *autunite*. The rather doubtful mineral, *carnotite*, appears to be a vanadium analogue of autunite. Uranium compounds are used in the coloration of glass and in porcelain-painting; but they have recently acquired importance as the material from which radium compounds are prepared.

**Pitchblende,** or uraninite. — Oxide of uranium: $UO.U_2O_3$ (contains lead and rare elements, including minute quantities of helium and radium). Crystallizes in the regular system, but usually occurs massive, botryoidal, or in grains. Colour, black, grey, or brown. Streak, greyish-black. Lustre, submetallic to resinous. Hardness, 5·5. Density, 9-9·7. Infusible. Soluble in dilute sulphuric acid.

Pitchblende occurs in Cornwall in association with cassiterite; also in Bohemia (Joachimsthal and Przibram), Saxony, Colorado (Gilpin County), and other places.

**Torbernite.** — Hydrated phosphate of uranium and copper: $Cu(UO_2)_2(PO_4)_2.8H_2O$. Crystallizes in the tetragonal system, with tabular habit. Colour, emerald green. Transparent to translucent. Streak, pale green. Lustre, subadamantine to pearly. Basal cleavage, perfect (like mica). Non-flexible. Sectile. Hardness, 2-2·5. Density, 3·4-3·6. Fusibility, 3.

Torbernite occurs in Cornwall, Bohemia (Joachimsthal), Saxony (Schneeberg).

**Autunite.** — Hydrated phosphate of uranium and calcium: $Ca(UO_2)_2(PO_4)_2.8H_2O$. Crystallizes in the rhombic system, with tabular habit similar to torbernite. Colour, citron to sulphur yellow. Translucent. Streak, yellowish. Lustre, subadamantine to pearly. Basal cleavage, perfect. Hardness, 2-2·5. Density, 3·05-3·2. Fusibility, 3.

Autunite occurs in Cornwall.

## ORES OF OTHER RARE METALS.

The minerals *monazite* and *xenotime* are esteemed as a source of ceria and thoria for incandescent gas mantles; but monazite alone occurs in sufficient quantity to be of economic importance. *Columbite* is valued as a source of tantalum for the manufacture of the metallic filaments of electric lamps, and *zircon* for the zirconium used in the electric lamps of the Nernst type.

**Monazite.**—Phosphate of cerium and lanthanum and didymium, with some thorium: $(Ce,La,Di)PO_4$. Crystallizes in the monoclinic system. Colour, yellow to brown. Transparent to translucent. Lustre, resinous. Basal parting. Fracture, uneven. Hardness, 5-5·5. Density, 5·2-5·3. Index of refraction, 1·811. Double refraction, very high. Infusible.

Monazite occurs in brown crystals in the granite of Arendal in Norway; but the commercial material is obtained from alluvial sands in Brazil (Prado), and North and South Carolina.

**Xenotime.**—Phosphate of yttrium: $YPO_4$. Crystallizes in the tetragonal system. Colour, yellow to brown. Transparent to translucent. By alteration it becomes opaque. Lustre, resinous to vitreous. Prismatic cleavage, perfect. Fracture, uneven. Hardness, 4-5. Density, 4·55-5·1. Refraction and double refraction, very high.

Xenotime occurs in granite and in sands, but less frequently than monazite.

**Columbite.**—A niobo-tantalate of iron and manganese: $(Fe,Mn)O.(Nb,Ta)_2O_5$. Crystallizes in the rhombic system, in short, prismatic crystals terminated by the basal plane. Colour, iron black. Lustre, submetallic to adamantine. Streak, black. Opaque. Fracture, uneven. Hardness, 6. Density, 5·2-6·0. Fusibility, 5-5·5.

Columbite occurs in granitic rocks in Sweden, West Greenland, Ilmen Mountains of Siberia, and in Brazil (Minas Geraes).

**Orthite**, or allanite (a member of the epidote group).—Silicate of calcium, iron and aluminium, with small proportions of cerium, lanthanum, didymium, yttrium and erbium. Crystallizes in the monoclinic system. Colour, black. Streak, grey. Opaque to translucent. Lustre, vitreous to resinous. Fracture, uneven to conchoidal. Hardness, 5·5-6. Density, 3-4. Fusibility, 2·5.

Orthite occurs in granites, pegmatites and crystalline schists—*e.g.*, in Sweden, Siberia, and the United States.

## ORES OF ALUMINIUM.

Aluminium compounds are among the most widely distributed of minerals; thus, the felspars, micas, and most of the hornblendes and pyroxenes, which constitute the bulk of the igneous rocks, are all aluminium silicates; and the same minerals, together with quartz and other less complex silicates of aluminium, compose the great group of clays, shales, and slates. The only compounds of aluminium, however, which can be considered as ores—or, in other words, from which the metal can under present economic conditions be profitably extracted—are *bauxite* (a hydrated oxide of aluminium) and *cryolite* (a double fluoride of aluminium and sodium). Bauxite is probably not a definite mineral, but rather a trade name given to any substance in which there are large quantities of aluminium hydrate, in contradistinction to ordinary clay, in which the aluminium is combined with silica, and cannot be profitably extracted.

Aluminium is esteemed on account of its low density, its rigidity, its malleability, and the fact that it takes a high polish. It is largely used, for instance, in the motor industry (for crank-cases, gear-boxes, radiators, etc.). Its high conductivity for electricity makes it a competitor with copper for the transmission of power. It also forms valuable alloys with nickel, copper, zinc, and magnesium.

**Bauxite.**—Hydrated oxide of aluminium: $Al_2O_3.2H_2O$.* (aluminium 39 per cent.). Does not occur crystallized, but in concretionary, pisolitic, or earthy masses. Colour, white, yellow, brown, or red. Opaque. Lustre, dull or earthy. Hardness most variable. Density, 2·55. Infusible. Insoluble in acids.

Bauxite derives its name from Baux, near Arles, in France, where it is largely mined as an ore of aluminium. The only other large producer is the

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* Holland regards bauxite as an intimate mixture of two minerals—viz., gibbsite, having the formula $Al_2O_3.3H_2O$; and diaspore, with the formula $Al_2O_3.H_2O$ ("Rec. Geol. Surv. India," vol. xxxii., p. 176).

United States, where the ore is mined in Alabama, Arkansas, Georgia, and Tennessee.

**Cryolite.**—A fluoride of aluminium and sodium: $Al_2F_6.6NaF$ (aluminium 12·85 per cent., sodium 32·79 per cent., and fluorine 54·36 per cent.). Crystallizes in the monoclinic system. It forms tabular crystals or occurs massive. Colourless to greyish-white, yellow, or brown. Streak, white. Lustre, vitreous. Transparent to translucent. Index of refraction low ($\beta = 1·36$). Double refraction, weak. Cleavage, basal and prismatic, perfect, the cleavage appearing nearly cubical on account of the close approximation to 90° of the angle between the two prism faces and between the latter and the basal plane. Fracture, uneven. Brittle. Hardness, 2·5. Density, 2·97. Fusibility, 1·5. Decomposed by sulphuric acid.

Cryolite occurs as a large bed or vein in gneiss at Ivigtut in Arksukjord (West Greenland).

## APPENDIX TO THE ORES.

### THE VEINSTONES OR GANGUE MINERALS.

The ores are accompanied in their lodes and veins by a number of minerals, which, from an economic point of view, are either intrinsically worthless, or are regarded as valueless in comparison with the ore for which the particular vein is exploited. The commonest veinstones are *quartz* and its congeners—*jasper, opal, chalcedony;* the carbonates of calcium—*calcite* and *aragonite;* the double carbonate of calcium and magnesium—*dolomite;* the carbonate of iron—*chalybite;* the sulphate of barium—*barytes;* the sulphates of calcium—*anhydrite* and *gypsum;* the iron-oxides—*magnetite, hæmatite* and *limonite;* the oxides of manganese—*wad, etc.;* the sulphides of iron—*pyrites, marcasite,* and *pyrrhotite;* the arsenosulphide of iron—*mispickel;* and many other sulphides, which under more favourable circumstances are themselves regarded as ores—*e.g., blende, galena, stibnite* and *molybdenite.* Veins of pneumatolytic origin are characterized by the presence of *tourmaline, fluorspar* and *topaz.* Many rock-forming minerals also occur as veinstones: examples are, the felspars—*orthoclase* and *albite;* the *hornblendes, pyroxenes* and *micas* and their decomposition products—*chlorite, serpentine, sericite* and *talc;* the zeolites, such as *analcime, laumontite* and *prehnite;* lastly, the so-called accessory rock-forming minerals, such as *garnet, apatite,* and *sphene.* Descriptions of all these minerals are given in their appropriate chapters.

# CHAPTER III

## THE SALTS AND USEFUL MINERALS OTHER THAN ORES

ALTHOUGH every combination of an acid with a base may be termed a salt, only the carbonates, sulphates, nitrates, chlorides, phosphates and borates of the alkalies and alkaline earths are included here.*

These substances occur frequently as beds that have been deposited from the waters of a former lake or inland sea; but many of them are found also as veins, either alone or forming the gangue material of ores of the heavy metals. Nitrates are formed by the decomposition of organic matter in saliferous and rainless districts; while phosphatic deposits have in part been produced by the accumulation of bones or of the coprolites of fishes.

An appendix to the chapter contains a description of the non-metallic elements sulphur and carbon.

### CARBONATES.

A great number of carbonates occur as natural salts. Some of them—namely, the carbonates of the heavy

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* The compounds formed by the union of some of the acids with the heavier metallic bases have been already referred to among the ores.

metals—have been mentioned among the ores. The carbonates now to be described are the following: *calcite, aragonite, dolomite, magnesite, witherite, strontianite, natron*, and *trona*.

**Calcite.**—Carbonate of lime: $CaCO_3$ (lime 56, carbon dioxide 44, per cent.). Crystallizes in the hexagonal system, with rhombohedral hemihedrism. Common forms are flat or acute rhombohedra; sharp-pointed scalenohedra (*dog-tooth spar*); prisms, terminated either by the basal plane or by rhombohedral faces; and flat tables with dominant basal plane. There are several types of twinning: that in which the twin-plane

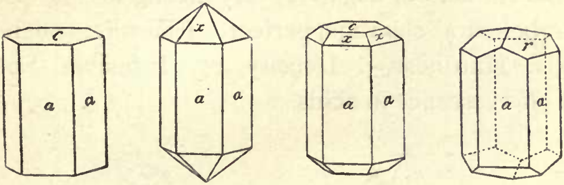

FIG. 95.—CALCITE: PRISMATIC FORMS.
*c*, Basal plane; *x*, pyramid; *r*, rhombohedron; *a*, prism.

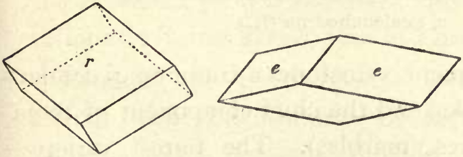

FIG. 96.—CALCITE: RHOMBOHEDRAL FORMS.
*r*, Rhombohedron (R); *e*, a more obtuse rhombohedron ($-\frac{1}{2}$ R).

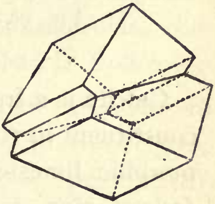

FIG. 97.—CALCITE.
Twinned crystal, the twin-plane being a face of the rhombohedron, *e* ($-\frac{1}{2}$ R).

is the obtuse rhombohedron (*e*), is the commonest, and is responsible for the polysynthetic lamellation characteristic of calcite when viewed in thin sections under the microscope. Colourless to white, yellow, red, and brown. Transparent to opaque. Lustre, vitreous. Streak, white. Index of refraction, moderate ($\omega = 1{\cdot}658$). Double refraction, negative, very strong ($\omega - \epsilon = 0{\cdot}172$). Rhombohedral cleavage, perfect. Fracture, conchoidal. Brittle. Hardness, 3. Density, 2·7. Infusible. Soluble, with effervescence in acids.

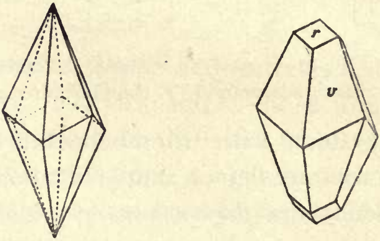

FIG. 98.—CALCITE: SCALENOHEDRAL FORMS.
*v*, Scalenohedron ($R_3$).

Calcite is a frequent veinstone, a common secondary constituent in rocks, and the chief component of metamorphic limestones (marbles). The purest variety—*Iceland spar*—is used in the manufacture of optical instruments.

**Aragonite.**—Carbonate of calcium: $CaCO_3$ (lime 56, carbon dioxide 44, per cent.). Crystallizes in the rhombic system, in tabular and prismatic forms; its frequent pseudo-hexagonal habit is due to repeated twinning on the prism (*m*). Occurs also as fibrous aggregates. Colourless. Transparent. Lustre, vitreous. Index of refraction high ($\beta = 1{\cdot}682$). Double refraction, negative, very strong ($\gamma - \alpha = 0{\cdot}156$). Brachypinacoidal and prismatic cleavages, imperfect. Fracture, subconchoidal. Brittle. Hardness, 3·5. Density, 2·9. Infusible. Soluble in acids, with effervescence.

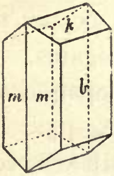

FIG. 99.—ARAGONITE.
*b*, Brachypinacoid; *m*, prism; *k*, brachydome.

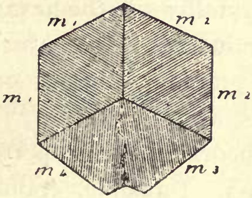

FIG. 100.—DIAGRAM ILLUSTRATING THE MODE OF TWINNING IN ARAGONITE: FOUR INDIVIDUALS TWINNED ON A FACE OF THE PRISM.
The striation indicates the direction of the brachydiagonal.

Aragonite occurs as a gangue material of ore deposits; also as stalactitic incrustations, and as spheroidal concretions as in the *Sprudelstein* of Carlsbad in Bohemia.

**Dolomite,** or pearl spar. — Double carbonate of calcium and magnesium: $CaMg(CO_3)_2$ (lime 30·4, magnesia 21·7, carbon dioxide 47·9, per cent.). Crystallizes in the hexagonal system, with rhombohedral hemihedrism. Saddle-shaped crystals with curved faces are characteristic. Colourless to white. Transparent. Lustre, vitreous. Streak, white. Index of refraction high ($\omega = 1{\cdot}682$). Double refraction, negative, very strong ($\omega - \epsilon = 0{\cdot}179$). Rhombohedral cleavage, perfect. Fracture, subconchoidal. Brittle. Hardness, 3·5. Density, 2·85. Infusible. Soluble with effervescence in warm acids.

Dolomite occurs as a veinstone in association with ores, and massive in magnesian limestones.

**Magnesite.** — Carbonate of magnesium: $MgCO_3$ (magnesia 47·62, carbon dioxide 52·38, per cent.). Crystallizes in the hexagonal system, with rhombohedral symmetry. More usually, however, it occurs massive, in granular, fibrous, or compact aggregates. Colourless, white, or yellow. Transparent to opaque. Rhombohedral cleavage, perfect. Hardness, 4-4·5. Density, 2·9-3. Infusible. Soluble in acids, with effervescence, when in the state of powder and warmed.

Magnesite occurs as a decomposition product of ferromagnesian silicates, and is found associated with serpentine, which is of similar origin. It is exploited for the manufacture of the sulphate of magnesia (Epsom salt).

**Witherite.**—Carbonate of barium: $BaCO_3$ (oxide of barium 77·7, carbon dioxide 22·3, per cent.). Crystallizes in the rhombic system. Habit, pseudohexagonal and bipyramidal (see Fig. 101). Twinning on the prism. Also found massive or in botryoidal or kidney-shaped aggregates. Colourless to white, grey or yellowish-grey. Transparent. Lustre, vitreous.

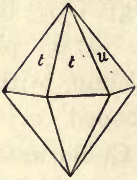

FIG. 101.—WITHERITE.
Pseudo-hexagonal bipyramid composed of—*t*, pyramid; *u*, brachydome.

Streak, white. Index of refraction, moderate ($\beta = 1{\cdot}531$). Double refraction, negative, weak. Brachypinacoidal and prismatic cleavages, imperfect. Fracture, uneven. Brittle. Hardness, 3-3·5. Density, 4·2-4·3. Fusibility, 2. Colours the flame green. Soluble in hydrochloric acid.

Witherite accompanies certain ore deposits as a veinstone, and is exploited to a small extent for use in the manufacture of plate-glass.

**Strontianite.**—Carbonate of strontium: $SrCO_3$ (oxide of strontium, 70·17, carbon dioxide 29·83, per cent.). Crystallizes in the rhombic system, in varieties of habit resembling aragonite, but usually found in fibrous aggregations. Colourless to white, grey, yellow, brown, or green. Transparent. Lustre, vitreous. Streak, white. Prismatic cleavage, imperfect. Fracture, uneven. Hardness, 3·5-4. Density, 3·6-3·8. Infusible. Colours the flame red. Strontianite occurs as a veinstone, and is exploited for use in the refining of sugar.

**Natron.**—Hydrated carbonate of sodium: $Na_2CO_3 . 10H_2O$. Crystallizes in the monoclinic system, but usually found massive or as an earthy incrustation. Colourless to grey or white. Lustre, vitreous. Streak, white. Basal cleavage, imperfect. Hardness, 1-1·5. Density, 1·4-1·45. Fusibility, 1. Colours the flame yellow. Soluble in water.

Natron occurs as an evaporation product of the so-called soda-lakes in Africa and America, and is exploited for the manufacture of soda salts.

**Trona.**—Hydrated carbonate of sodium: $Na_2CO_3.HNaCO_3.2H_2O$. Crystallizes in the monoclinic system, but usually occurs massive or as earthy incrustations. Colourless to white or grey. Transparent. Lustre, vitreous. Orthopinacoidal cleavage, perfect. Fracture, uneven. Hardness, 2·5-3. Density, 2·1-2·15. Fusibility, 1·5. Colours the flame yellow. Soluble in water.

Trona occurs as an incrustation from the evaporation of lakes; *e.g.*, at Borax Lake, San Bernardino Co., California.

## SULPHATES.

Several important sulphates occur as natural salts. Of these, the sulphates of the heavy metals have been referred to among the ores; but the following sulphates of the alkalies and alkaline earths are treated here: *anhydrite*, *gypsum*, *barytes*, *celestite*, *mirabilite*, *epsomite*, *alum*, and *alunite*.

**Anhydrite.**—Sulphate of lime: $CaSO_4$ (lime 41·16, sulphur trioxide 58·84, per cent.). Crystallizes in the rhombic system, in thick tabular crystals; but more often found massive, in coarsely crystalline aggregates resembling marble. Colourless, white, or bluish-white. Transparent to opaque. Pinacoidal cleavages, perfect. Fracture, uneven. Brittle. Hardness, 3-3·5. Density, 2·8-3. Fusibility, 3. Soluble in hydrochloric acid.

Anhydrite occurs in beds associated with gypsum and rock-salt, as, for example, in the New Red Marl of this country, and in the Stassfurt salt deposits of Central Germany.

**Gypsum**, or selenite.— Hydrated sulphate of lime: $CaSO_4.2H_2O$ (lime 32·5, sulphur trioxide 46·6, water 20·9, per cent.). Crystallizes in the monoclinic system, usually in stout or slender prisms, but also in flat rhomboid tables, that owe their shape to the dominance of the clinopinacoid. Occasionally the crystals are lenticular, with curved faces. Also occurs in fibrous masses (*satin spar*); or granular (*alabaster*). Twinning on the orthopinacoid is common, producing a swallow tailed form. Usually colourless and water-clear, but also white or tinted. Streak, white. Lustre, vitreous. Transparent. Index of refraction, 1·522. Double refraction, moderate ($\gamma - a = 0·01$). Clinopinacoidal cleavage, perfect. Sectile. Flexible. Hardness, 2. Density, 2·2-2·4. Fusibility, 3. Soluble in hydrochloric acid.

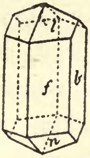

FIG. 102.—GYPSUM.

*l*, Negative hemi-pyramid; *n*, positive hemi-pyramid; *f*, prism; *b*, clinopinacoid.

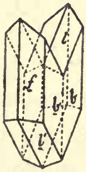

FIG. 103.—GYPSUM: CRYSTAL TWINNED ON THE ORTHOPINACOID.

Gypsum is a very common mineral occurring in beds and veins in marls and clays in the New Red Marl, Oxford Clay, Purbeck Beds, Gault, London Clay, etc. It is used to improve soils or to make plaster of Paris. The compact granular variety (*alabaster*) is in request for vases, statuary, etc.

**Barytes**, or heavy spar.—Sulphate of barium: $BaSO_4$ (oxide of barium 65·7, sulphur trioxide 34·3, per cent.). Crystallizes in the rhombic system, with tabular or prismatic habit, the former being due to the dominance of the basal plane (*c*) in combination with the prism (*m*), the latter to elongation either along the *b*-axis with dominant macrodome (*d*), or along the *a*-axis with dominant brachydome (*o*). Also compact, granular, or fibrous. Colourless to reddish-white, grey, or yellow. Lustre, vitreous. Transparent. Streak, white. Index of refraction, high ($\beta = 1{\cdot}637$). Double refraction, positive, moderate ($\gamma - a = 0{\cdot}012$). Basal and prismatic cleavage, perfect. Fracture, uneven. Brittle. Fusibility, 3. Colours the flame green. Not decomposed by acids.

Barytes often forms the gangue material of ores; but it also occurs alone in veins, and is exploited for mixing with white lead.

**Celestite**, or celestine. — Sulphate of strontium: $SrSO_4$ (oxide of strontium 56·52, sulphur trioxide 43·48, per cent.). Crystallizes in the rhombic system, being isomorphous with barytes. Habit, prismatic, due to elongation along the *b*-axis, with dominant macrodome; or tabular, with dominant basal plane. Colourless to bluish-white or grey. Transparent. Lustre, vitreous.

Streak, white. Index of refraction, high ($\beta = 1·624$). Double refraction, positive, moderate ($\gamma - \alpha = 0·009$). Basal cleavage, perfect; prismatic, good. Fracture, uneven. Hardness, 3-3·5. Density, 3·9-4. Fusible. Colours the flame red. Insoluble in acids.

Celestite is exploited for the preparation of strontium compounds, which are used for fireworks.

**Mirabilite**, or Glauber's salt.—Hydrated sulphate of soda: $Na_2SO_4 10H_2O$ (soda 19·3, sulphur trioxide 24·8, water 55·9, per cent.). Crystallizes in the monoclinic system, but occurs in Nature mostly in the form of an efflorescent incrustation. Colourless to white. Lustre, vitreous. Transparent. Streak, white. Pinacoidal cleavage, perfect. Hardness, 1·5-2. Density, 1·48. Fusibility, 1·5. Colours the flame yellow. Soluble in water.

Occurs in the so-called soda-lakes of Wyoming and in Salt Lake, Utah.

**Epsomite**, or Epsom salt.—Sulphate of magnesium: $MgSO_4.7H_2O$ (magnesia 16·26, sulphur trioxide 32·52, water 51·22 per cent.). Crystallizes in the rhombic system, with dominant prism (*m*) and brachydome (*z*), but occurs in Nature mostly as a fibrous efflorescence. Colourless to white. Transparent. Lustre, vitreous. Cleavage, brachypinacoidal. Fracture, conchoidal. Hardness,

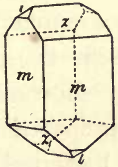

FIG. 104.—ARTIFICIAL CRYSTAL OF EPSOMITE.

2-2·5. Density, 1·7-1·8. Fusibility, 1. Soluble in water, to which it imparts a bitter taste.

It occurs on the steppes of Siberia, in Catalonia, and as a deposit from the soda-lakes of Wyoming in the United States. It also exists in solution, as in the springs at Epsom and in sea water.

**Alums.**—The alums constitute an isomorphous group of sulphates of alumina and of the alkalies, magnesia, iron, and manganese, each member of which crystallizes in the regular system, with twenty-four molecules of water. Some of the more important members of the group are the following:

Kalinite or potash-alum:
$K_2SO_4 + Al_2(SO_4)_3 + 24H_2O$.
Mendozite or soda-alum:
$Na_2SO_4 + Al_2(SO_4)_3 + 24H_2O$.
Tschermigite or ammonia-alum:
$(NH_4)_2SO_4 + Al_2(SO_4)_3 + 24H_2O$.

These salts are easily soluble in water, and have a sweetish astringent taste.

Although the alums exist in small quantities as natural efflorescences, the alum of commerce is chiefly prepared from the mineral *alunite*, or *alum-stone*, a hydrated sulphate of alumina and potash: $(K_2O.3Al_2O_3.4SO_3.6H_2O)$, and from aluminous shales containing pyrites, the latter mineral supplying the sulphuric acid.

## NITRATES.

The important nitrates occurring as natural salts are those of the alkalies, potash, and soda—viz., *nitre* and *nitratine*. They are used in the manufacture of nitric acid and of gunpowder, and are also of great value as artificial manures.

**Nitre**, or saltpetre.—Nitrate of potash: $KNO_3$ (potash 46·58, nitrogen peroxide 53·42 per cent.). Crystallizes in the rhombic system, in silky needle-shaped prisms, but also occurs as an incrustation. Colourless, white, or grey. Lustre, vitreous. Transparent. Cleavage, prismatic. Fracture, conchoidal. Hardness, 2. Density, 1·9-2·1. Fusibility, 1. Easily soluble in water. Like all potash salts, imparts a violet coloration to the flame of a spirit-lamp or Bunsen burner.

Nitre is found as an efflorescent crust, or mixed with the soil of certain rainless districts—in Spain, Algeria, India, Quito—and is used principally for the preparation of gunpowder.

**Nitratine**, soda-nitre, or Chili saltpetre.—Nitrate of soda: $NaNO_3$ (soda 36·49, nitrogen peroxide 63·51, per cent.). Crystallizes in the hexagonal system, with rhombohedral hemimorphism; but is usually found as an efflorescent incrustation. Colourless, but also white or grey. Lustre, vitreous. Transparent. Rhombohedral cleavage, perfect. Fracture, conchoidal. Hardness, 1·5-2. Density, 2·1-2·2. Deliquescent and easily soluble in water. Fusibility, 1. In common with all soda salts, it colours the flame yellow.

Nitratine is found mixed with clay and sand (*caliche*), on the rainless pampas of Chili (Tarapaca and Antofagasta) and Peru, and is exploited for the preparation of nitric acid and of nitre, and as a manure, being too deliquescent for the direct manufacture of gunpowder.

## CHLORIDES AND FLUORIDES.

There are a great number of naturally-occurring chlorides. The following only are selected for description : *rock-salt, sylvite, sal ammoniac, carnallite,* and the fluoride, *fluorspar.*

**Rock-Salt**, or halite.—Chloride of sodium: $NaCl$ (sodium 39·3, chlorine 60·7, per cent.). Crystallizes in the regular system, usually in cubes, but also occurs in granular masses and in fibrous aggregates. When pure, colourless or white, but often tinted yellow, red, blue, etc., by the presence of a small quantity of some impurity. Transparent to opaque. Lustre, vitreous. Streak, white. Cubic cleavage, perfect. Fracture, conchoidal. Brittle. Hardness, 2-2·5. Density, 2·1-2·3. Fusibility, 1·5. Soluble in water, and easily recognizable by its saline taste.

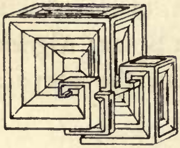

FIG. 105.—ROCK-SALT. Skeleton-cubes.

Rock-salt is widely distributed among lacustrine deposits. Thus it occurs with gypsum in the Trias of Cheshire and Worcestershire; and there are thick deposits at Sperenberg near Berlin, at Wieliczka, in Austrian Poland, and at Parajd in Transylvania. In the Permian of Stassfurt, in Central Germany, it occurs in association with gypsum and numerous sulphates and chlorides of potassium and magnesium, the exploitation of which constitutes an important industry. Salt is also found as an efflorescence in the rainless districts of Chili and Africa, and as a deposit from brine in the "salt pans" of the Northern Transvaal.

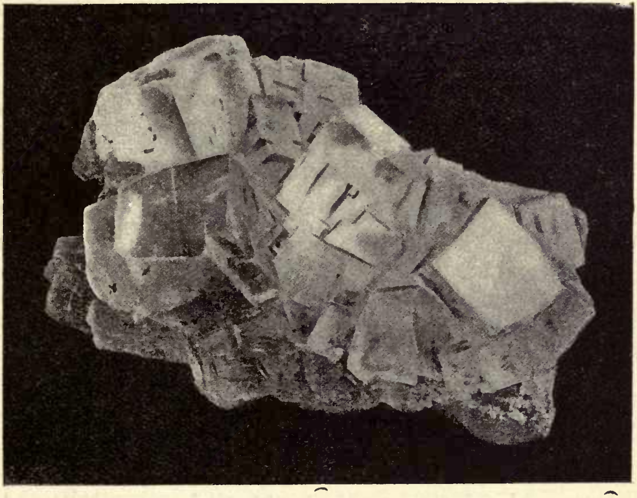

Fig. 106.—Rock-Salt Crystals from Stassfurt (after G. P. Merrill).

**Sylvite**, or sylvine.—Chloride of potassium: $KCl$ (potassium 52·4, chlorine 47·6, per cent.). Crystallizes in the regular system, with cubic habit. Colourless. Lustre, vitreous. Transparent. Streak, white. Cubic cleavage, perfect. Brittle. Fracture, uneven. Hardness, 2. Density, 1·9. Fusibility, 1·5. Soluble in water, to which it imparts a saline, bitter taste.

Sylvite occurs with rock-salt at Stassfurt in Central Germany, and at Kalusz in Galicia.

**Sal Ammoniac.**—Chloride of ammonium: $NH_4Cl$ (chlorine 66·26, nitrogen 26·25, hydrogen 7·49, per cent.). Crystallizes in the regular system, but usually in stalactitic aggregations or as an incrustation. When pure, colourless or white, but often stained yellow by chloride of iron. Hardness, 1·5-2. Density, 1·52. Soluble in water, to which it imparts a pungent saline taste.

Sal Ammoniac occurs as an incrustation on lava at Vesuvius, Etna, and in other volcanic districts.

**Carnallite.**—Double chloride of magnesium and potash: $MgCl_2.KCl+6H_2O$ ($MgCl_2$, 34·2, $KCl$, 26·8, $H_2O$ 39, per cent.). Crystallizes in the rhombic system. Colourless to white or red. Transparent. Lustre, vitreous. Fracture, conchoidal. Hardness, 1. Density, 1·6. Fusibility, 1-1·5. Soluble in water, and deliquesces when exposed to air.

Carnallite occurs at Stassfurt in Central Germany.

**Fluorspar** or fluorite.—Fluoride of calcium: $CaF_2$ (fluorine 48·72, calcium 51·28, per cent.) Crystallizes in the regular system, occurring in cubes and octahedra, sometimes in combination with the rhombic dodecahedron and icositetrahedron. Interpenetration twins common. The crystals are transparent, and have a glassy lustre. Colour, blue, violet, green, and yellow.

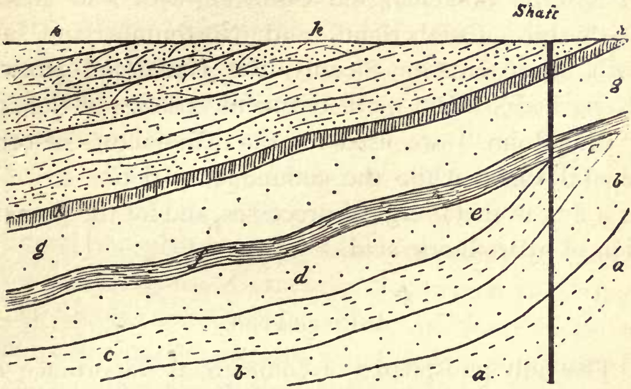

FIG. 107.—THE STASSFURT DEPOSITS.

*a*, Rock-salt; *b*, polyhalite; *c*, kieserite; *d*, carnallite; *e*, kainite; *f*, impervious clay; *g*, anhydrite; *h*, gypsum; *k*, sandstone.

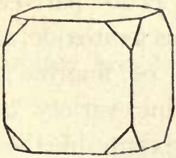

FIG. 108.—FLUORSPAR: CUBE WITH OCTAHEDRON.

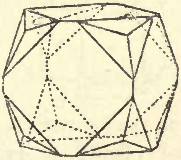

FIG. 109.—FLUORSPAR: CUBE WITH ICOSITETRAHEDRON.

Transparent. Lustre, vitreous. Streak, white. Index of refraction, low ($\mu = 1{\cdot}43$). Octahedral cleavage, perfect. Fracture, subconchoidal. Hardness, 4.

Density, 3·2. Fusibility, 3. Phosphorescent when heated. Decomposed by sulphuric acid.

As a veinstone, fluorspar is associated with tin ore in Saxony, Bohemia, and Cornwall, with lead ores in Derbyshire, Cumberland, and Northumberland, and with silver ores in Saxony, the Harz, and Norway (Kongsberg). The more beautiful varieties of the spar ("Blue John") are used for the manufacture of ornamental vases, while the commoner varieties are used as a flux in metallurgical processes, and for the preparation of hydrofluoric acid.

## PHOSPHATES.

The only phosphates of commercial importance are those of lime, known variously as *apatite*, *phosphorite*, *coprolites*, and *guano*.

**Apatite.**—Chlorophosphate of calcium, $3Ca_3(PO_4)_2.CaCl_2$, or fluorophosphate of calcium, $3Ca_3(PO_4)_2.CaF_2$. The fluorine variety contains 42·26 per cent. of phosphorus pentoxide, and 3·77 per cent. of fluorine; while the chlorine variety contains 40·92 per cent. of the oxide, and 6·82 per cent. of chlorine. Crystallizes in the hexagonal system. Habit, short prismatic or thick tabular. The smaller crystals are composed of numerous pyramid and prism faces, usually terminated by the basal

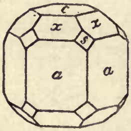

FIG. 110.—APATITE.

*c*, Basal plane; *x*, proto-pyramid; *s*, deutero-pyramid; *a*, proto-prism.

plane. Large opaque crystals and compact or fibrous nodular masses (*phosphorite*) also occur. Colourless to white, but usually tinted green, blue, violet, or red. Lustre, vitreous to resinous. Transparent to opaque. Streak, white. Refractive index, moderately high ($\omega = 1{\cdot}646$). Double refraction, negative, weak ($\omega - \epsilon = 0{\cdot}004$). Basal and prismatic cleavages, imperfect. Fracture, conchoidal. Brittle. Hardness, 5. Density, 3·16-3·22. Fusibility, 5. Decomposed by hydrochloric acid.

Mineral phosphates are exploited for use as fertilizers in Cornwall, Spain, Germany, Norway, Russia, the United States, and Canada. Many of these deposits occur as nodular concretions which have been formed by the concentration of phosphatic material of organic origin. *Guano* is a phosphatic deposit of recent organic origin, occurring in regions where abundant animal life and small rainfall combine to assist its accumulation, as in Chili, Peru, Bolivia and Africa.

## BORATES.

Two borates are here described — viz., *borax* and *boracite.*

**Borax.**—Hydrated borate of sodium: $Na_2O.2B_2O_3.10H_2O$ (soda 16·23, boron trioxide 36·65, water 47·12, per cent.). Crystallizes in the monoclinic system, but usually occurs massive (*tinkal*). Colourless to white. Transparent. Lustre, vitreous. Streak, white. Index of refraction, low ($\beta = 1{\cdot}47$). Double refraction, negative, weak ($\gamma - \alpha = 0{\cdot}004$). Orthopinacoidal cleavage, perfect; prismatic cleavage, good. Fracture, conchoidal. Brittle. Hardness, 2-2·5. Density, 1·7. Fusibility, 1-1·5. Soluble in water, to which it imparts a sweetish alkaline taste.

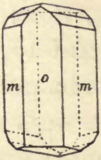

FIG. 111.—BORAX.
*o*, Orthopinacoid; *m*, prism.

Borax is found as a chemical deposit on the shores of lakes in Thibet, California, and Nevada, and is exploited for its antiseptic properties.

**Boracite.** — Chloroborate of magnesium: $6MgO.2B_2O_3.MgCl_2$ (magnesia 26·9, boron trioxide 62·5, chloride of magnesium 10·6, per cent.). Crystallizes apparently in the regular system, with tetrahedral development. According to a recent view, the crystals are considered to be compound twins of rhombic or of monoclinic individuals. Colourless to white. Lustre, vitreous. Transparent to translucent. Streak, white. Index of refraction, moderate ($\beta = 1{\cdot}667$). Double refraction, moderate ($\gamma - \alpha = 0{\cdot}011$). Tetrahedral cleavage, imperfect. Fracture, conchoidal. Brittle. Hardness, 7. Density, 2·9-3. Fusibility, 3. Soluble in hydrochloric acid.

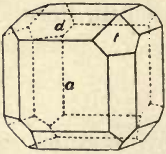

FIG. 112.—BORACITE.
*a*, Cube; *d*, rhombic dodecahedron; *t*, tetrahedron.

Boracite is found enclosed in gypsum and anhydrite at Lüneburg and Segeberg, and in carnallite at Stassfurt in Germany.

# APPENDIX.

## OTHER USEFUL MINERALS.

**Sulphur**, S.—Crystallizes in the rhombic system, with bipyramidal habit. Also occurs in nodular, kidney-shaped or stalactitic masses or as a mealy deposit or incrustation. Colour, pale yellow to dark brown. Lustre, resinous to adamantine. Transparent. Streak, white. Index of refraction, high ($\beta = 2{\cdot}04$). Double refraction, very strong ($\gamma - a = 0{\cdot}290$). Basal and prismatic cleavage, very imperfect. Fracture, conchoidal. Brittle. Hardness, 1·5-2·5. Density, 1·9. Easily fusible. Volatile and combustible. Insoluble in acids.

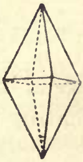

FIG. 113.—SULPHUR; RHOMBIC PYRAMID.

Sulphur is produced by sublimation in volcanic districts, by deposition from sulphurous springs, or by the alteration of beds of gypsum. It occurs in deposits of industrial importance in Sicily and Japan.

**Graphite**, Carbon, C.—Crystallizes probably in the monoclinic system, although its six-sided crystals have a decidedly hexagonal habit. Most frequently it occurs massive or in scales disseminated through rocks. Colour, black. Lustre, metallic. Streak, grey. Opaque. Unctuous to the feel, soiling the fingers. Pliable. Hardness, 0·5-1. Density, 1·9-2·3. Infusible. Insoluble in acid.

Graphite occurs in scales disseminated through limestone, slate, gneiss, mica-schist, or in larger pocket-like deposits and veins, and it is exploited for "black-lead" or plumbago. It is found in deposits of industrial importance in Borrowdale, near Keswick, in the Lake District, in Finland and Siberia, in Austria, in India and Ceylon, and in the United States and Canada.

*Coal*, *mineral pitch* (*asphaltum*), *bitumen*, *mineral oil* (*petroleum*), *mineral wax* (*ozokerite*), *mineral resin* (*amber*), are other mineral substances of which the chief constituent is carbon. They are not, however, properly speaking, mineral species, since they have neither an unvarying chemical composition nor definite physical properties. Petroleum consists of an homologous series of hydrocarbons of the general formula $CH_4+nCH_2$, which in Nature occur mixed in all proportions. By fractional distillation it can be separated into heavy lubricating oils, light oils, spirits (petrol, benzol, etc.).

# CHAPTER IV

## GEMS

UNDER the head of gems are included certain rather rare minerals which are used for the purpose of ornamentation and personal adornment.

The two chief physical features in a precious stone are *hardness* and *brilliancy*. While a sufficient degree of the former insures durability by preventing deterioration under wear, it is the latter which determines the beauty of the gem-stone. But brilliancy is produced by a combination of properties which may be variously developed in a stone. These properties are the *pellucidity*, *colour*, *refractive index*, *dispersive power*, and *pleochroism*.

The pure and delicate colours possessed by gems are a great feature of their beauty; and in many cases the jeweller's names are founded entirely on differences in colour. Thus the ruby and the sapphire are red and blue varieties respectively of the mineral *corundum*, and the emerald and the aquamarine are green and blue varieties of *beryl*. Although most gems are perfectly limpid, a few are only translucent or opaque (opal, turquoise, etc.). The dispersive power (see p. 47) imparts the quality of emitting brilliant flashes of variously coloured light, which determines the "fire" of a gem. Many gems possess in greater or less degree the property of transmitting differently coloured light when viewed in different directions. This is a phenomenon of pleochroism (see p. 54).

Among the minerals mentioned in this chapter will be found several that have been described in other parts of the book. Thus some varieties of quartz, felspar, and olivine, which are among the commonest rock-forming minerals, are used as gem-stones.

**Diamond**, Carbon, C.—Crystallizes in the regular system, the usual habit being the octahedron alone, or this form in combination with the rhombic dodecahedron and other regular forms. The faces are generally curved, producing rounded crystals. Twinning on the octahedron. Colourless; but also yellow, straw-coloured, or brown, and very occasionally green and blue. Transparent. Lustre, adamantine. Index of refraction, very high ($\mu = 2{\cdot}417$). Dispersion, very strong. Octahedral cleavage, perfect. Fracture, conchoidal. Brittle. Hardness, 10. Density, 3·52. Infusible. Insoluble in acid. Burnt in oxygen, yields carbon dioxide.

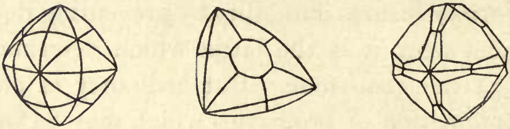
FIG. 114.—CRYSTALS OF DIAMOND.

Diamonds are found in alluvial sands, in association with other precious stones, and with gold and platinum —in the Deccan of India, Brazil (Minas Geraes), Borneo, Sumatra, and Australia. The chief source of the present supply is at Kimberley, in South Africa, where stones of the first water and of good size are found imbedded in a dark-coloured ultrabasic volcanic breccia (kimberlite), filling volcanic vents or "pipes."


FIG. 115.—THE CULLINAN DIAMOND.
Half natural size.

**Corundum.**—Oxide of aluminium, $Al_2O_3$ (aluminium 52·9 per cent.). Crystallizes in the hexagonal system, with rhombohedral symmetry. Habit, tabular, prismatic, or pyramidal, the first-named being determined by the dominance of the basal plane. Horizontal striation on pyramid and prism faces. Also occurs in rounded crystals and as rolled pebbles and grains in the so-called "gem-sands." Colourless when pure. Generally coloured: blue (*sapphire*), red (*ruby*), yellow (*oriental topaz*), grey, purple (*oriental amethyst*), or green (*oriental emerald*). Streak, colourless. Lustre, vitreous to adamantine or resinous. Transparent to translucent. Index of refraction high ($\omega = 1·768$). Double refraction, negative, moderate ($\omega - \epsilon = 0·008$). No true cleavage. Separation (due to twinning) parallel to the basal plane and to the rhombohedron $r$ $(10\bar{1}1)$. Fracture, conchoidal. Brittle. Hardness, 9. Density, 3·9-4·1.

Corundum occurs as an accessory constituent in igneous rocks rich in alumina, both as an allogenic and as an autogenic product. It also occurs in granite contact zones, especially in argillaceous limestones. The dark granular variety, known as *emery*, occurs in admixture with iron ores (magnetite and hæmatite) in association with schists and gneiss on the island of Naxos. A massive variety of red corundum is exploited for use as a polishing material at Salem in Madras.

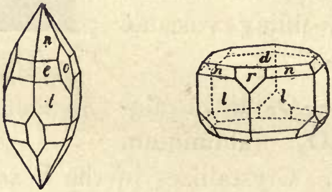

FIG. 116.—CORUNDUM: CHARACTERISTIC CRYSTALS.

*d*, Basal plane; *r*, rhombohedron (R); *o*, rhombohedron ($-2$R); *n*, deutero-pyramid ($\frac{4}{3}$P2); *e*, deutero-pyramid ($\frac{8}{3}$P2); *l*, deutero-prism.

Rubies occurring in a matrix of limestone are worked in Burmah. Many of the best gems are found loose in gravels and sands, as in Ceylon (rubies), Siam (sapphires and rubies), Montana (sapphires).

**Spinel.**—A double oxide of aluminium and magnesium: $MgO,Al_2O_3$ (magnesia 28·2, alumina 71·8, per cent.). Crystallizes in the regular system. Habit, octahedral. Twinned on the octahedron. Colour, red. Streak, white. Lustre, vitreous. Transparent. Index of refraction, high ($\mu = 1{\cdot}715$). Octahedral cleavage, imperfect. Fracture, conchoidal. Brittle. Hardness, 8.

Density, 3·5. Infusible. Soluble with difficulty in sulphuric acid.

Spinel occurs in crystalline limestones and dolomites, also in igneous and metamorphic rocks. It is of frequent occurrence in sands—*e.g.*, the so-called "gem sands" of Ceylon.

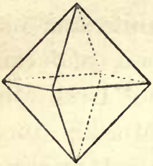

FIG. 117.—SPINEL: OCTAHEDRON.

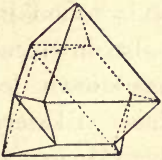

FIG. 118.—SPINEL: CRYSTAL TWINNED ON AN OCTAHEDRAL FACE.

**Beryl.**—Metasilicate of beryllium and aluminium: $3BeO.Al_2O_3.6SiO_2$ (oxide of beryllium 14, alumina 19, silica 67, per cent.). Crystallizes in the hexagonal system, forming long six-sided prisms, terminated by the basal plane. In addition pyramidal faces are sometimes developed. The prismatic planes usually show a vertical striation. Colourless to white, yellowish or greenish white, pale pink, honey-yellow, and various shades of green and blue. The emerald-green to apple-green varieties are known as *emerald*, while the blue or sea-green varieties are distinguished as *aquamarine*. Lustre, vitreous. Transparent to translucent.

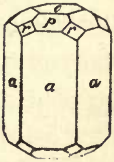

FIG. 119.—BERYL. *c*, Basal plane; *P*, pyramid; *a*, prism; *r*, deutero-pyramid (2P2).

Streak, white. Index of refraction, moderate ($\omega = 1{\cdot}584$). Double refraction, negative, weak ($\omega - \epsilon = 0{\cdot}006$). Basal cleavage, distinct. Fracture, conchoidal to uneven. Brittle. Hardness, 7·5-8. Density, 2·6-2·8. Fusibility, 5·5. Insoluble in acids.

Beryl is found imbedded in granite and pegmatite veins; also in mica-schist, limestone, and clay slate. The best-known localities are the Ural Mountains (Mursinka, Ekaterinburg, and Miask), the Altai, Colombia (Muzo, Cosquez and Somondoco mines), and New South Wales (Emmaville).

**Garnet.**—The garnets are silicates of aluminium, iron, manganese, chromium, calcium, and magnesium, having the general formula $3MO.R_2O_3.3SiO_2$, in which M stands for metals like calcium, magnesium, etc., forming protoxides, and R for metals like aluminium and chromium, forming sesquioxides. According to the variation of MO and $R_2O_3$, the following varieties may be distinguished:

| Name. | Constituent Bases. | | Colour. | Density. | Index of Refraction. |
|---|---|---|---|---|---|
| | MO. | $R_2O_3$. | | | |
| Grossularia | CaO | $Al_2O_3$ | Pale green | 3·4–3·6 | 1·747 |
| Almandine | FeO | $Al_2O_3$ | Claret | 3·9–4·3 | 1·807 |
| Pyrope | FeO, MgO, CaO | $Al_2O_3$, $Cr_2O_3$ | Blood red | 3·7–3·8 | 1·745 |
| Melanite | CaO | $Fe_2O_3$ | Blackish-brown | 3·6–4·3 | 1·856 |
| Spessartine | MnO | $Al_2O_3$ | Light reddish | 4·0–4·3 | 1·810 |
| Uvarovite | CaO | $Cr_2O_3$ | Green | 3·4–3·5 | 1·838 |

Other existing varieties are isomorphous mixtures of these. They crystallize in the regular system, the most common habit being the rhombic dodecahedron, with edges sometimes truncated by icositetrahedral faces. Colour, as above. Streak, white. Lustre, vitreous to resinous. Transparent to opaque. Index of refraction, as above. Rhombic dodecahedral cleavage, imperfect. Fracture, uneven. Hardness, 6·5-7. Density, as above. Brittle. Fusibility, 3 for all varieties except uvarovite, which has a fusibility of 6. Attacked with difficulty by hydrochloric acid.

The garnets are frequent accessory constituents of igneous rocks, such as granite, microgranite, aplite, trachyte, and andesite. They are also found in gneisses and other crystalline schists, and in ultrabasic rocks, such as peridotites, eclogite, serpentine, kimberlite, etc. They are a frequent constituent of the so-called "gem sands." It would serve no purpose to give localities for so common a mineral; but the occurrence of pyrope in Bohemia, of melanite at Frascati, near Rome, and uvarovite in the Ural Mountains, may be mentioned.

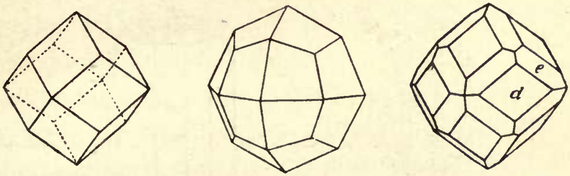

FIG. 120.—GARNET: COMMON FORMS, RHOMBIC DODECAHEDRON, ICOSITETRAHEDRON, ALONE AND IN COMBINATION.

**Topaz.**—Fluorsilicate of aluminium: $Al(F.OH)_2.AlSiO_4$ (alumina 55·44, $SiO_2$ 32·61, fluorine 20·65, per cent.). Crystallizes in the rhombic system. Habit, prismatic, terminated by the basal plane alone or together with faces of various brachydomes, and those of the proto-pyramid. One end alone shows perfect development, the faces constituting the opposite termination being usually rudimentary. The prisms show a vertical striation. Colourless, wine-yellow, brown, or tinted blue, red, or green. Lustre, vitreous. Transparent to translucent. Index of refraction, 1·62. Double refraction, moderate $(\gamma - \alpha = 0{\cdot}009)$. Basal cleavage, perfect. Hardness, 8. Density, 3·4-3·6. Infusible and unattacked by acids.

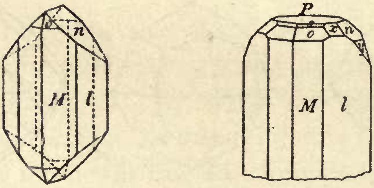

FIG. 121.—TOPAZ.

*P*, Basal plane ; *s* and *o*, pyramids ; *x*, brachypyramid ; *M*, prism ; *l*, brachyprism ; *n* and *y*, brachydomes.

Topaz occurs in drusy cavities of granitic rocks or as loose and rolled pebbles. Well-known localities are—St. Michael's Mount in Cornwall, the Mourne Mountains in Ireland, Saxony (Schneckenstein), Brazil (Minas Geraes), United States, Siberia, Ceylon.

**Tourmaline.** — Hydrated borosilicate of sodium, magnesium, and aluminium. According to Clarke, the tourmaline series consists of salts of an acid which may be represented by the formula $Al_5(SiO_4)_6(BO_2)_2.BO_3H_2.H_{12}$. Crystallizes in the hexagonal system, with rhombohedral symmetry and hemimorphic development. Habit, prismatic, with rhombohedral terminations, and the prisms vertically striated. Also occurs in fibrous veins and stellate aggregates. Colour, usually black or dark brown, but various tints of red, blue, and green, are common, and even colourless crystals are known. Transparent to translucent. Lustre, vitreous. Index of refraction, fairly high ($\omega = 1{\cdot}64$). Double refraction, negative, strong ($\omega - \epsilon = 0{\cdot}017$). Strongly dichroic, with marked absorption of the ordinary ray. Rhombohedral and prismatic cleavages, imperfect. Fracture, subconchoidal. Brittle. Hardness, 7. Density, 3-3·2. Fusibility, 3-5. Insoluble in acids.

Tourmaline occurs in the contact zones of granite and in pegmatites. It is also a frequent constituent of sands and sandstones. The best gems come from Brazil, Ceylon, Siberia, and North America.

**Zircon.**—Silicate of zirconium: $ZrO_2.SiO_2$ ($ZrO_2$ 67·2, $SiO_2$ 32·8, per cent.). Crystallizes in the tetragonal system, being isomorphous with cassiterite and rutile. Habit, prismatic or pyramidal. The prisms are of both orders; the pyramid, of the first order only. Colour, usually dark brown, also orange, yellow, red (*jacinth*), pale green, and grey (*jargoon*). Streak, colourless. Lustre, adamantine. Transparent to opaque. Index of refrac-

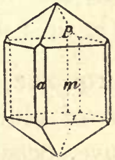

FIG. 122.—ZIRCON.
*P*, Pyramid; *m*, prism; *a*, deutero-prism.

tion, high ($\omega = 1{\cdot}93$). Double refraction, positive, very strong ($\epsilon - \omega = 0{\cdot}062$). Dispersion, strong. Pyramidal and prismatic cleavages, imperfect. Fracture, conchoidal. Brittle. Hardness, 7·5. Density, 4·7. Infusible. Only attacked with difficulty by hot sulphuric acid.

Zircon is a constituent of most granites, syenites, etc., and of the sands derived from them. The gems are derived from Ceylon, New South Wales, and Queensland.

**Sphene,** or titanite. — Titanosilicate of calcium: $CaO.TiO_2.SiO_2$ (oxide of titanium 40·8, oxide of calcium 28·6, silica 30·6, per cent.). Crystallizes in the monoclinic system. Habit, cuneate. Colour, olive-brown. Transparent. Lustre, adamantine. Streak, white. Index of refraction, high ($\beta = 1{\cdot}894$). Double refraction, positive, very strong ($\gamma - \alpha = 0{\cdot}121$). Dispersion, very strong. Prismatic cleavage, distinct. Fracture, subconchoidal. Hardness, 5. Density, 3·5. Fusibility, 3. Decomposed with difficulty by hydrochloric acid.

Sphene occurs in many igneous rocks and crystalline schists, also in limestones. Its inferior hardness militates against its employment as a gem.

**Turquoise**, or callaite.—A hydrated and basic phosphate of alumina: $Al_2(OH)_3PO_4.H_2O$. Only known massive, occurring as veins and nodules in igneous rocks. Colour, cerulean or peacock blue. Opaque. Lustre, resinous. Fracture, conchoidal. Hardness, 6. Density, 2·7.

The turquoise used in jewellery is found near Nishâpûr in Persia, and in the Burro and Jarilal mountains in New Mexico.

**Chrysoberyl.**—A double oxide of beryllium and aluminium, $BeO.Al_2O_3$ (oxide of beryllium 19·8, alumina 80·2, per cent.). Crystallizes in the rhombic system, in forms similar to those of olivine. Often in twins and triplets, the latter termed *alexandrite*, which was once considered to be a distinct mineral. Habit, short prismatic or thick tabular, with vertical striations.

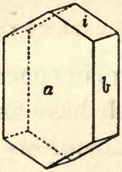

FIG. 123.—CHRYSOBERYL.
*a*, Macropinacoid ; *b*, brachypinacoid ; *i*, brachydome.

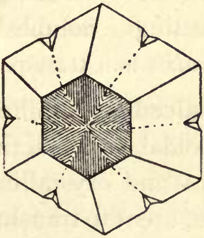

FIG. 124.—COMPOUND TWINNED CRYSTAL (ALEXANDRITE).

Colour, yellowish-green to olive-green. Lustre, vitreous. Transparent. Streak, colourless. Index of refraction, high ($\beta = 1\cdot75$). Double refraction, positive, moderate ($\gamma - a = 0\cdot009$). Pleochroic. Cleavage, imperfect. Fracture, conchoidal. Brittle. Hardness, 8·5. Density, 3·7. Infusible. Insoluble in acids.

Chrysoberyl is known to the jewellers under the name of the *cat's-eye* (*cymophane*) and *oriental chrysolite*, and is chiefly found in Brazil, Ceylon, Ural Mountains, and in Connecticut in the United States.

**Peridot.** — A beautiful transparent, deep olive-green variety of olivine (see p. 106), is used as a gem-stone.

**Opal.**—Hydrated silica: $SiO_2 + nH_2O$. Amorphous, occurring in botryoidal or stalactitic masses. Colour, bluish, yellowish, or milk white. Translucent. Streak, white. Lustre, vitreous or resinous. Index of refraction, low ($\mu = 1{\cdot}455$). The "fire" of "precious opal" is the result of reflection and diffraction of light from internal surfaces. Fracture, conchoidal. Brittle. Hardness, 6. Density, 2·1. Infusible, but yields water on heating. Soluble in potash.

*Hyalite* is a transparent, colourless variety of opal.

**Chalcedony.**—Silica: $SiO_2$. Occurs in concretionary, botryoidal, or stalactitic masses which have an internal fibrous and crystalline structure. Colourless to white. Transparent to translucent. Lustre, resinous. Fracture, uneven to splintery. Hardness, 7. Density, 2·6-2·64.

*Carnelian* is a red variety of chalcedony; *Sard*, a brownish-red variety; *Plasma*, a leek-green variety; *Chrysoprase*, an apple-green variety; *Agate* and *Onyx* are banded and variegated varieties which occur as the infilling of amygdaloidal cavities in certain basic lavas; *Sardonyx* is a variety of onyx which contains layers of carnelian or sard.

**Quartz.**—Certain coloured varieties of quartz (see p. 84) are used for decorative purposes.

*Jasper* is an opaque red-coloured variety in which there is much admixed iron oxide; *Amethyst* is a violet-coloured quartz often used as a gem-stone; *Smoky Quartz*, *Cairngorm*, *Rose Quartz*, are smoke-coloured yellow and pink varieties of quartz; *Tiger's Eye* is a golden-yellow replacement by quartz of fibrous crocidolite.

**Felspar.**—Some varieties of felspar (see p. 86) are used as gem-stones.

*Moonstone* is an opalescent variety of orthoclase found in Ceylon; *Amazon-stone* is a green variety of microcline; *Labrador Spar* is an iridescent variety of labradorite, which when polished exhibits a magnificent play of colours. The iridescence is due to interference produced by a lamellar structure.

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