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GEMS AND GEM MATERIALS

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GEMS
AND
GEM MATERIALS

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PREFACE

Man has always been keenly interested in minerals suitable for personal adornment and ornamentation, but mineralogists generally have made few attempts to give systematic instruction in this phase of their science at our institutions of higher learning. The need for reliable information on the part of the lover of and the dealer in gems and gem materials has increased greatly in modern times. This is the result of: first, a more general use of natural gems, and second, the introduction upon the market of large quantities of manufactured material of pleasing qualities. To meet to some extent this demand for more knowledge of precious stones, a regular course of lectures dealing with this extremely fascinating branch of mineralogy was organized a decade ago at the University of Michigan. The course has annually attracted a sizable group of students. The aim of the course is to give information about some of those things in the admiration and esteem of which credulity and sentiment, rather than accurate knowledge, are generally the dominant factors. To make the content of these lectures available to a wider circle, especially to those engaged in the sale of gem materials, this text has been prepared.

In Part One those properties which are necessary for an appreciative understanding of gems are discussed. An attempt has been made to present this phase of the subject in as non-technical a manner as possible, for it is hoped that the text may prove of service to those who have had no previous training in mineralogy. Descriptions of the various minerals and materials used as gems are given in Part Two. There are also numerous tables in which gem materials are classified according to properties. Those desiring epitomized information will find it conveniently arranged in the last table designated as a Summary of the Properties of Gem Materials.

Most of the illustrations are either new or are taken from Kraus and Hunt's Mineralogy. For the use of the others we are indebted to the American Museum of Natural History, Stern

Brothers and Company, and Fera and Kadison of New York City, and to the National Geographic Magazine of Washington. From time to time aid, suggestions, and the permission to use material have been received from various sources, but especial acknowledgments are due Mr. Henri Polak, of Amsterdam, Holland; and Mr. Andries Meyer and Mr. Sidney H. Ball, of New York City.

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UNIVERSITY OF MICHIGAN.
July, 1925.

On August 5, 1925, Edward Fuller Holden, the junior author, was drowned at North Deer Isle, Maine. A young life already rich in achievement and full of promise for a notable scientific career was thus tragically ended. May this book serve as one of the monuments to his memory.

E. H. K.

August 14, 1925.

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GEMS AND GEM MATERIALS

CHAPTER I

INTRODUCTION

Man and Minerals.—From the earliest times down to the present minerals have played an exceedingly important part in the development and progress of the human race. Primitive man made his first rude weapons and utensils from stone, such as flint and other compact varieties of quartz which were easily chipped into rough shape. These artifacts are largely the material upon which the archaeologist builds his concept of the human kind in the early paleolithic age, called the old or rough-stone age. As man became more adept in the art of working stones into a required shape, he was able to smooth them, and sometimes to give them a crude polish. With this knowledge he emerged into the neolithic age, that is, the new or smooth-stone age.

With the development of the art of recovering metals from their ores, man passed successively through the copper, bronze, and iron ages, in which minerals were even more important than in the stone age. Then came the discovery of the fact that coal would burn, and the coal age was inaugurated. The present time is often called the motor age. The motor is an assemblage of metals, and, accordingly, man's dependency upon minerals is today greater than ever before.

When the study of the substances upon the earth was first begun, they were divided into three kingdoms: the animal, the vegetable, and the mineral kingdoms. All animal life of the land, sea, and air was referred to the first kingdom. With a more intensive study of that group of organisms, zoölogy was developed, and with it such allied sciences as anatomy, physiology, animal breeding, and paleozoölogy. The vegetable kingdom included all the plants, from fungi and lichens to trees and flowers. Botany, and such related sciences as agriculture, forestry, and paleobotany, are the outgrowth of study of the vegetable kingdom. The early naturalists assigned to the mineral kingdom the entire residue of naturally occurring substances: minerals, the rocks, the soils, the air, the seas, lakes, and rivers. From the investigation of this kingdom a large number of modern sciences have developed, including mineralogy, geology, chemistry, physics, meteorology, and oceanography.

Gems and Precious Stones.—The rôle that minerals and metals have played in the progress of civilization has just been briefly discussed. Besides their employment in the manufacture of articles essential to the comfort and welfare of man, minerals have long been used, on account of their beauty, for personal adornment. Minerals especially suited to that purpose are known as *gems* or *precious stones*. The cutting and carving of gems was probably first carried on in Babylonia, several thousand years before the birth of Christ. In those times and until quite recently engraved gems were much used as seals. The medicinal and magical powers which were generally ascribed to gems in former days added to their popularity.[1] Now gems are worn primarily because of their beauty.

Definition of a Mineral.—Since gems are minerals, it is well to state the meaning of the term "mineral." A mineral may be defined as *a substance occurring in nature with a characteristic chemical composition, and usually possessing a definite crystalline structure, which is sometimes expressed in external geometrical forms or outlines.* Many of the artificially prepared compounds of the laboratory correspond to naturally occurring minerals. For example, $CaSO_4$, called calcium sulphate by the chemist, occurs in nature as the mineral anhydrite. Scientists are able to produce many minerals by chemical processes, but even though these artificial compounds are like the natural substances in every respect aside from occurrence, they are not minerals.

The composition of a mineral is nearly constant, though small variations often occur, due to impurities or to the replacement of one element by another closely related to it. A formula may usually be given which expresses the composition of the mineral, as SiO_2, silicon dioxide, for quartz.

The phrase "usually possessing a definite crystalline structure" means that the structural units of a mineral, which are atoms or

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[1] See, KUNZ, "The Curious Lore of Precious Stones," and "Magic of Jewels and Charms."

groups of atoms, are generally arranged in an orderly and definite way, characteristic of the particular mineral. Most gem minerals as found in nature exhibit external geometrical forms or outlines. These forms are known as crystals, and they are more fully discussed in Chapter II.

In some definitions of minerals the term "inorganic" is incorporated, in order to restrict the use of the term "mineral" to substances which are lifeless and which are not the result of organic processes. Such definitions would exclude pearls, amber, coral, and jet, which are discussed in this text, from consideration as true minerals.

Qualifications of Gem Minerals.—Minerals, in order to be suitable for use as gems, must possess as many as possible of the following qualifications: (1) *splendor* or *beauty*, (2) *durability;* (3) *rarity;* and (4) *fashion.* Rarely are all of these qualifications possessed by a single gem. The diamond, however, has each of these properties to a marked degree, and, accordingly, is the most generally esteemed gem.

Splendor or beauty in a gem depends upon its transparency, brilliancy, luster, fire, and color. These properties are defined and discussed in Chapter III. A colored diamond is almost alone among gems in having all of these desirable qualities. Even white diamonds fall short because of lack of color. Rubies and emeralds have very desirable colors, but their brilliancy and fire are not exceptional. The opal is attractive mainly because of its play of colors. Turquois makes its appeal by color alone, for it is dull and opaque. Many other illustrations might be given.

It often happens that beautiful minerals are too soft to wear well, except in brooches or pins, where they are not so much exposed to abrasion as are gems mounted in rings. Such minerals lack durability and are very easily scratched. The satin spar variety of gypsum, with its attractive sheen and silky luster, is much too soft to be of value as a gem. A precious stone should be harder than the dust particles in the air, which are largely composed of a rather hard mineral, quartz. For this reason the most valuable stones are those which are decidedly harder than quartz: diamond, ruby, sapphire, and emerald. Durability is further discussed under hardness (p. 24).

Rarity is a valued attribute in gems. It is natural to esteem most highly things which are scarce, even though they may not be superior in their intrinsic qualities to many commoner substances. On this account some gems which are beautiful and durable but not rare make little appeal. Garnets are an illustration. Though often very attractive, they are generally worth little more than the cost of cutting. The common mineral beryl occurs in many colors, blue-green, golden-yellow, pink, and emerald-green. The green variety known as emerald is the rarest and most valuable, even though it is scarcely more beautiful than some of the others.

The last factor in determining the suitability of a mineral for gem purposes is fashion or vogue. The effect of fashion upon the value of gems is enormous. A gem may be very popular at some period—perhaps it has been worn by royalty or leaders of fashion—only to fall back into its former unimportance at a later date. For instance, a short time ago news items stated that emeralds were greatly in vogue in England because Princess Mary chose that gem for her engagement ring. Some colors are always popular, such as reds, blues, and greens, while yellow is not commonly in demand. Certain gems are invariably fashionable, especially the diamond, ruby, sapphire, and emerald.

A number of gems are locally popular in the district in which they occur. This constitutes another phase of the influence of fashion on the wearing of gems. Examples of these locally used gems are: californite, a variety of vesuvianite, in California; chlorastrolite, thomsonite, and datolite in northern Michigan; tourmaline in Maine; malachite in Russia.

During recent years the number of gem minerals has somewhat increased. The new stones include beautiful and previously unknown varieties of familiar minerals as well as some newly discovered minerals. In the first group perhaps the best example is kunzite, the rose-colored, transparent variety of spodumene, a mineral which is usually white and opaque. Among the recently discovered minerals the sapphire-blue benitoite has found a rather limited use as a gem.

Mineralogy and Gems.—The word *gemmology* has been proposed to designate that branch of mineralogy which deals with the use of minerals for personal adornment or ornamentation. On account of the remarkable advances which have been made in the manufacture of artificial and imitation gems, gemmology should include a discussion of such material. The term "gemmology" is not widely used.

Some knowledge of the science of mineralogy is necessary for the fullest appreciation and understanding of gems and their properties. Mineralogy teaches that ruby and sapphire are both varieties of one mineral, corundum; that the emerald differs from aquamarine only in color; and, further, that the trade names applied to gems are often not unintentionally deceptive. Moreover, some knowledge of mineralogy and chemistry is necessary for the understanding of the processes by which artificial gems are manufactured.

The first part of this text consists of an elementary presentation of those portions of mineralogy cognate to the study of gems. It is designed to furnish the reader with the general scientific background necessary to a full understanding of the second portion of the text, in which the individual gem minerals are described.

PART I

CHAPTER II

CRYSTAL FORMS

Crystals.—When a mineral, or a chemical compound prepared by man, is bounded by regularly arranged natural plane surfaces, giving the specimen a definite geometrical form or outline, the substance is said to be a *crystal*. Gem minerals occur almost universally in well-formed crystals. For that reason an elementary study of crystallography is of value to those interested in precious stones, especially since a knowledge of the more common crystal forms is of material assistance in the identification of uncut gems.

(*Photo by courtesy of the United States Geological Survey.*)

FIG. 1.—Gigantic crystal of spodumene, Etta Mine, South Dakota.

Constancy of Crystal Angles.—Practically every mineral is found in crystals of a definite and unique type. Measured at the same temperature, similar angles on crystals of the same substance remain constant regardless of their size or shape (Steno's law). That is, while the sizes and shapes of the faces of a crystal may have been distorted by irregular growth, the angles between given faces are constant for all crystals of a given substance.

Size of Crystals.—Crystals vary in size from those of microscopic dimensions to crystals weighing many tons. Crystals of spodumene have been found at the Etta mine, South Dakota, 36, 40, 42, and 47 feet long, weighing in the neighborhood of 37 tons (Fig. 1). Beryl crystals have been obtained from Acworth and Grafton, New Hampshire, which weighed several tons.

Crystal Systems.—All crystals fall naturally into six groups, defined by the lengths and angular relationships of imaginary lines, *crystal axes,* passed through the center of the crystal. These six groups are known as the *crystal systems.*

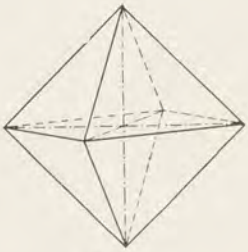

FIG. 2.

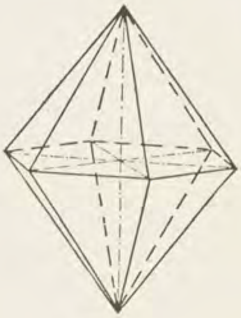

FIG. 3.

1. *Cubic System.*—Crystals in this system have three equal and perpendicular axes. Figure 2 represents a cubic crystal and its axes. Diamond, spinel, and garnet belong to this system.

2. *Hexagonal System.*—Hexagonal crystals have four axes. Three of these are equal, horizontal, and intersect at 60 degrees. The fourth axis is perpendicular to these and therefore vertical. It is longer or shorter than the horizontal axes (Fig. 3). Beryl, including emerald, and ruby and sapphire, which are varieties of corundum, as well as quartz and tourmaline are all representatives of the hexagonal system.

3. *Tetragonal System.*—Crystals of this system have three axes which intersect at right angles. The vertical axis is longer or shorter than the two equal horizontal axes (Fig. 4). Zircon and vesuvianite are tetragonal gem minerals.

4. *Orthorhombic System.*—This system is characterized by three perpendicular but unequal axes (Fig. 5). To this system belong topaz and olivine.

5. *Monoclinic System.*—In the monoclinic system all the axes are unequal. Two intersect at right angles, while the third is inclined to them (Fig. 6). Epidote, spodumene, and titanite crystallize in the monoclinic system.

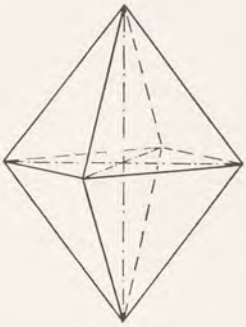

FIG. 4.

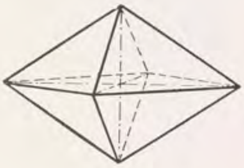

FIG. 5.

6. *Triclinic System.*—Triclinic crystals have three axes, all unequal, and all inclined (Fig. 7). To this system belong labradorite and some moonstones.

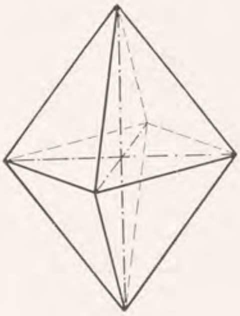

FIG. 6.

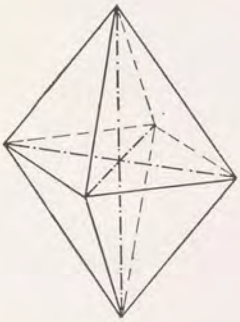

FIG. 7.

Certain relationships between the systems may now be pointed out. The morphological classification of crystals into systems is by no means artificial. The optical properties form another natural basis for the classification. Both the crystal form and the optical characteristics depend upon the arrangement of the very small particles which build up a mineral. While the optical properties will be later discussed in more detail (p. 46) it may be indicated here that by them crystals may be divided into three groups: (1) cubic crystals; (2) hexagonal and tetragonal crystals; and (3) orthorhombic, monoclinic, and triclinic crystals.

Light passes through crystals of the cubic system without being resolved into two rays, that is, such minerals are *singly refractive* (Fig. 8). They are also called optically *isotropic* because light travels through them with the same velocity in all directions. Amorphous substances, those which do not crystallize, are also singly refractive and isotropic.

All other substances are in general *doubly refractive;* that is, a ray of light, in passing through them, is resolved into two rays (Fig. 9). These minerals are optically *anisotropic,* for light travels through them with different velocities in different directions. Hexagonal and tetragonal substances show single refraction in one direction, parallel to the vertical axis. This isotropic direction is called the *optic axis.* Since minerals of these systems have only one such direction, they are called *uniaxial.*

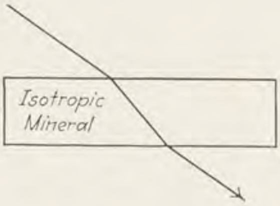

FIG. 8.

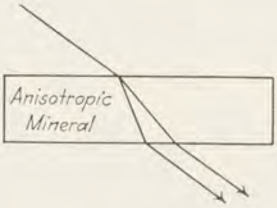

FIG. 9.

Substances crystallizing in the orthorhombic, monoclinic, and triclinic systems have two isotropic directions or optical axes, and are therefore called *biaxial.* Other distinctions serve to differentiate the systems within these groups. A tabular presentation of the classification of substances with respect to their optical properties may be found on page 47.

Crystal Forms.—All those faces of a crystal which intersect the several axes in the same way belong to a single *form,* or assemblage of corresponding faces. For instance, each face of an octahedron (Fig. 10) cuts all three crystal axes at the same distances from the center of the crystal. A crystal may consist of one form only, or of two or more forms. The latter case is termed a *combination* of forms (Fig. 11): *h*, cube; *o*, octahedron (see cubic system below). The forms and combinations of forms which occur most frequently on gem minerals will now be considered.

Cubic System.—In the cubic system the following are the more common forms:

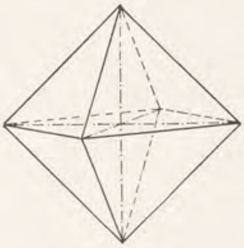

Fig. 10.

Fig. 11.

Octahedron.—This form has eight faces, which are triangular when the octahedron is uncombined with other forms (Fig. 12).[1]

Cube or Hexahedron.—The cube has six square faces, and is exactly like the geometrical cube (Fig. 13).

Dodecahedron.—This form has twelve diamond-shaped or rhombic faces (Fig. 14).

Fig. 12.

Fig. 13.

Fig. 14.

Tetragonal Trisoctahedron.—The apparently unwieldy name of this form is in reality an abbreviated definition of its character. The term *tetragonal,* from a Greek word meaning four-angled, indicates that the faces are four-sided, while the word *trisoctahedron* means that the form has three times eight or twenty-four faces (Fig. 15).

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[1] The illustrations in this chapter are principally photographs of idealized wooden models of natural crystals.

Tetrahedron.—This is a form with but four triangular faces. It is identical with the tetrahedron of geometry, which is the solid with the smallest possible number of faces (Fig. 16).

As indicated above, these forms may occur simultaneously upon a single crystal, which is then called a combination of forms.

FIG. 15.

FIG. 16.

Figures 17, 18, and 19 illustrate combinations of the cubic forms: *h*, hexahedron; *o*, octahedron; *d*, dodecahedron; and *i*, tetragonal trisoctahedron. The combination illustrated by Fig. 17 is frequently observed on spinel; that by Fig. 19 on garnet.

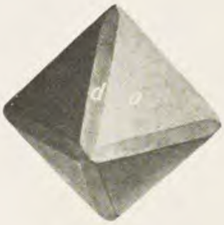

FIG. 17.

FIG. 18.

FIG. 19.

Hexagonal System.—The forms in the hexagonal system generally have faces in numbers which are multiples of six.

Hexagonal Prisms.—The prisms of this system have either six or twelve faces arranged parallel to the vertical axis (Figs. 20 and 21). A prism alone cannot enclose space, but resembles an open tube. Other forms must be present in combination with a prism. For this reason a prism is called an *open form.*

Hexagonal Bipyramids.—As the name indicates, these are forms which resemble two pyramids placed base to base. The complete forms have twelve or twenty-four faces (Figs. 22 and 23). Bipyramids enclose space, and are called *closed forms.*

Basal Pinacoid.—This is an open form, consisting of two parallel faces which are perpendicular to the vertical axis. In Figs. 20 and 21 the top and bottom faces constitute the basal pinacoid.

Fig. 20.

Fig. 21.

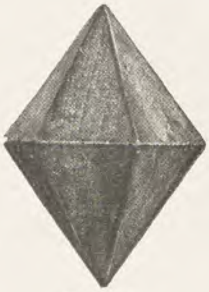

Fig. 22.

Fig. 23..

Rhombohedron.—The rhombohedron has six rhombic or diamond-shaped faces, and may be considered a distorted cube (Fig. 24).

Scalenohedron.—This form is bounded by twelve faces which are scalene triangles, hence the name (Fig. 25). Both the rhombohedron and the scalenohedron are characterized by having equatorial edges which run alternately up and down.

Fig. 24

Fig. 25.

Fig. 26.

Fig. 27.

Combinations of prisms (*a* and *m*), bipyramids (*p* and *s*), and the basal pinacoid (*c*) are frequently observed on beryl, as illustrated by Fig. 26. A combination of the rhombohedron (*r*) and prism (*m*) as it occurs on quartz is illustrated by Fig. 27.

Tetragonal System.—The forms of this system are closely related to those of the hexagonal system.

Fig. 28.

Fig. 29.

Tetragonal Prisms.—The prisms have four or eight faces, and are parallel to the vertical axis (Figs. 28 and 29).

Fig. 30.

Fig. 31.

Tetragonal Bipyramids.—These forms are like hexagonal bipyramids, but have eight or sixteen faces, instead of twelve or twenty-four (Figs. 30 and 31).

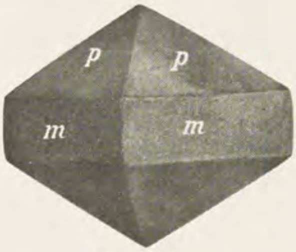

Fig. 32.

Fig. 33.

Fig. 34.

Basal Pinacoid.—This form is similar to the pinacoid of the hexagonal system (top and bottom faces, Figs. 28 and 29).

Combinations of the above forms are observed on crystals of zircon (Figs. 32 and 33) and vesuvianite (Fig. 34): prisms, *a* and *m*; bipyramid, *p*; and basal pinacoid, *c*.

Orthorhombic, Monoclinic, and Triclinic Systems.—The crystal forms of these three systems are so much alike that they may be readily discussed together. The corresponding forms in these systems can perhaps be most easily distinguished by the number of faces they possess.

Fig. 35.

Fig. 36.

Prisms.—These are forms with faces parallel to the vertical axis (Fig. 35).

Fig. 37.

Fig. 38.

Domes.—Domes are often called horizontal prisms. These forms are like prisms in shape but are parallel to a horizontal rather than to a vertical axis (Fig. 36).

Bipyramids.—These forms are similar to the bipyramids previously described, but have fewer faces (Fig. 37).

Pinacoids.—In these three systems a crystal may have as many as three sets of pinacoids, each set consisting of two parallel faces. Each face cuts one of the axes and is parallel to the other two. Figure 38 is a combination of the three pinacoid forms.

The following table shows the variations in the numbers of faces of the above forms, as they occur in these three systems:

Form	Orthorhombic system	Monoclinic system	Triclinic system
Prism	4	4	2
Dome	4	2 or 4	2
Bipyramid	8	4	2
Pinacoid	2	2	2

In the triclinic system, due to peculiar conditions, forms can have no more than two parallel faces.

Some combinations of forms in these systems are represented by: Fig. 39, topaz, orthorhombic; Fig. 40, orthoclase, monoclinic; and Fig. 41, albite, triclinic. Prisms are designated by the letters *m*, *M* and *l*; domes by *y*; bipyramids by *i*, *o*, and *u*; pinacoids by *b* and *c*.

Fig. 39.

Fig. 40.

Fig. 41.

Compound Crystals.—Thus far crystals have been described as single individuals. Crystals consisting of several individuals may also occur. These are known as *compound crystals,* which may be of two types: *parallel groups* and *twin crystals.* In a parallel group two or more crystals of the same substance have so intergrown that the crystallographic axes of one individual are parallel to those of the others. Occasionally crystals of different substances may be grouped in this way.

In twin crystals the individuals have intergrown in a definite manner, or as it is termed, according to a definite law. Parallelism of the separate individuals is not essential. There are two types of twins: *contact twins* and *penetration twins*. As the name implies, contact twins are those in which two crystals are in contact one with another. The two parts of such a twin have grown side by side, and are so related that one part may be considered to be one-half of a whole crystal, rotated through 180 degrees about an axis known as the *twinning axis*. Figure 42 illustrates a contact twin of spinel. Penetration twins are those in which two individual crystals are so intergrown that they penetrate one another. The mineral staurolite well illustrates this type of twin (Fig. 43). Its twins often resemble crosses, and are sometimes called "fairy stones." Reentrant angles are characteristic of twinned crystals.

FIG. 42.

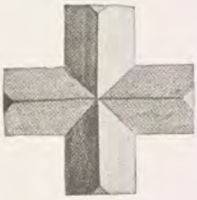

FIG. 43.

FIG. 44.

FIG. 45.

In crystallography the word "twin" is used in a broad sense. A twin may consist of more than two individuals. This is the result of repeated twinning. *Cyclic* and *polysynthetic twins* are formed in this way (Figs. 44 and 45 respectively). Polysynthetic twinning frequently gives rise to characteristic fine, parallel lines, called *twinning striations*, on the surface of the specimen. These represent the boundaries between individual crystals. In some instances, however, this type of twinning can only be observed in polarized light under the microscope.

Pseudomorphs.—The term *pseudomorph* has the meaning "false form." When one mineral alters to another in such a way that the structure or crystal form of the original mineral is retained, the specimen is called a pseudomorph. A typical example is the alteration by oxidation and hydration of pyrite (FeS_2), cubic, to limonite ($Fe_2O_3.H_2O$), amorphous. The limonite then has the external form of the pyrite crystals, but the inner crystalline structure of pyrite is entirely lacking. Thus limonite has assumed a false form (Fig. 46). Pseudomorphs are only rarely used as gem material.

FIG. 46.—Limonite pseudomorphs after pyrite. Hartz Mountains, Germany.

CHAPTER III

PHYSICAL PROPERTIES

In this chapter those physical properties which are easily determined will be defined and discussed. Optical properties, the determination of which involves the use of the polarizing microscope or other optical instruments, will be treated in the next chapter.

Structure.—With respect to structure minerals may be classified as follows:

Amorphous Minerals.—These have no definite structure or arrangement of particles. Opal is the most important amorphous gem. Glass is another typical amorphous substance. The substances known as colloids and gels are invariably amorphous. Opal is a gel.

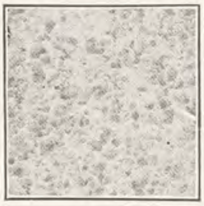

Fig. 47.—Marble.

Fig. 48.—Calcite (scalenohedron). Joplin, Missouri.

Crystalline Aggregates.—These are composed of intergrown grains, each of which has a definite internal structure. The whole mass of a crystalline aggregate, however, shows no regular external form. Coarse marble illustrates this type of structure (Fig. 47).

Crystals and Crystal Aggregates.—In crystals the definite internal structure finds expression in the presence of natural plane surfaces which bound the substance (Fig. 48). A crystal aggregate is a group of distinct crystals, partially intergrown (Fig. 49).

When substances occur in well-developed crystals their growth has been slower than is the case with crystalline aggregates. Crystals are, therefore, likely to be more pure than crystalline aggregates, more transparent, and of better color. For this reason they are of greater value for use as gems than minerals of other structures.

Masses which appear to the unaided eye to be amorphous, but which are revealed by the microscope to be crystalline, are called *cryptocrystalline*. Some forms of quartz, such as agate and flint, possess this structure.

Crystalline aggregates, crystals, crystal aggregates, and cryptocrystalline substances are collectively known as *crystalloids*.

Many more or less self-explanatory terms are often used in describing the various types of aggregates and amorphous masses. These are of little importance here, since the minerals serviceable as gems usually occur in distinct crystals.

Fig. 49.—Calcite. Cumberland, England.

Hardness.—Hardness is defined as the resistance which a substance offers to abrasion or scratching. It is of the utmost importance in connection with gems, for durability, a cardinal virtue in gem minerals, is largely dependent upon hardness. Hardness is a property of great assistance in the identification of minerals.

The Mohs scale is commonly used as a measure of the hardness of minerals. It consists of ten minerals arranged in order of increasing hardness, as follows:

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

Frequently beryl, with a hardness of 7½ to 8, is substituted for topaz, because of its greater abundance. The values assigned to the members of this scale show simply the *relative* hardness.

To supplement the Mohs scale, the finger nail, a copper coin, the knife blade, a piece of glass, and a steel file may be used. They have the following values:

Finger nail, hardness up to 2½
Copper coin, hardness up to 3
Knife blade, hardness up to 5½
Window glass, hardness 5½
Steel file, hardness 6 to 7

The hardness of a substance is determined by finding which mineral in the Mohs scale will just scratch the material in question. If a mineral is scratched by quartz (7) and not by feldspar (6), it is said to have a hardness of 6½. Two substances with the same hardness will scratch each other equally well. Care should be taken to distinguish between an actual scratch and a chalk mark. The latter is the mark left on the harder mineral and consists of the powder of the mineral which is the softer. This powder is easily removed by rubbing the specimen with the finger.

In determining the hardness of a gem the scratch should be as short as possible, perhaps 1/32 inch. On cut gems the scratch should never be made on the table or other prominently exposed facet, but rather near the equatorial edge of the stone, known as the girdle (p. 76). A small hand lens is frequently of service in detecting whether or not a gem has been scratched. A scratch on the girdle can be easily concealed by the setting of the stone.

Many jewelers use a very fine steel file to test hardness. If the file "bites" the tested material, its hardness is below 7. The file will not "bite" stones harder than 7, but will slide over the edge being tested, often leaving a steel streak. Since many imitations, especially those of glass, have a hardness less than 7, while the really precious gems are much harder, the file can generally be used to distinguish between them.

It might be inferred that the hardness of a substance is a constant quantity. This, however, is not correct, for the hardness varies with the crystallographic direction. Ordinarily the variation is so slight as not to be readily detected by the usual methods. But in some minerals this variation is quite marked. Cyanite, which occurs in elongated crystals, has a hardness of 4 to 5 parallel to the length of the crystals, while the value at right angles to the elongation is much higher, 6 to 7. Further, specimens of one and the same mineral from different localities may vary in hardness. Diamond cutters well know that the stones from Borneo and New South Wales are in general harder than those from South Africa. Diamonds are frequently harder on the surface of the natural stone than in the interior, and the hardness on cube faces of a diamond crystal is greater than that on the octahedron faces. Stones from wet diggings are usually harder than those from dry diggings.

The hardness of a mineral determines to a very great extent its durability. One of the ever-present substances which tend to abrade gems, to materially dull the polish and consequently the brilliancy and splendor of the stone, is dust, which consists essentially of finely divided particles of quartz. For this reason, in order to wear well and remain beautiful for any considerable length of time, a gem should have a hardness greater than that of quartz. The *precious* stones, diamond, ruby, sapphire, and emerald, are all decidedly harder than quartz. The softer stones are generally regarded as *semi-precious*.

In the table given on page 187 gem minerals are arranged according to their hardness.

Cleavage.—Many minerals readily split or separate along definite planes. This property is called *cleavage*. It is frequently conspicuous and highly characteristic. A mineral can be cleaved either by striking it a properly directed blow or by pressing upon it in a definite direction with the edge of a knife blade. The planes along which the separation takes place are called *cleavage planes*, while the resultant surfaces are known as *cleavage faces*. These planes are parallel to possible crystal faces, after which they are named. For instance, the diamond and fluorite have perfect cleavage parallel to the faces of an octahedron, and accordingly are said to possess *octahedral* cleavage (Fig. 50). Topaz cleaves easily parallel to the basal pinacoid, and its cleavage is called *basal*. Other important cleavages are the *cubical* and *rhombohedral*. The manner and ease with which cleavages are obtained are indicated by such terms as *perfect, imperfect, distinct, easy,* and so forth. The presence of cleavage is frequently to be recognized by the observation of cleavage cracks within a crystal, or by the irregular character of the surfaces, which may be made up of a number of small, parallel cleavage planes.

Cleavage is a property of great importance in the cutting of gem stones. It is constantly employed, especially in the case of the diamond, to give to the uncut material the proper form for efficient cutting and to remove flaws (see p. 79 for further reference to cleaving in the cutting of the diamond). In some instances a considerable blow is necessary to cleave a mineral, while in others a sudden shock or even dropping it to the floor may be enough to cause cleavage cracks. Gem stones possessing easy cleavage must accordingly be handled cautiously when being cut or polished in order to avoid the development of cleavage cracks. Also in the setting of gems great care must be exercised, for if the prongs press with unequal pressure upon stones with easy cleavages, cracks are apt to be formed.

FIG. 50.—Fluorite (octahedral cleavage). Near Rosiclare, Illinois.

In gems cleavage may sometimes be recognized by an examination, with a hand lens, of the stone near the prongs. If very minute portions have been broken off along the girdle by the pressure of the prongs the resulting surface is very likely to show whatever type of cleavage the stone may possess. In this way one may distinguish between diamond with its perfect octahedral cleavage, and glass imitations which have no cleavage, but instead show a shell-like fracture.

Cleavage is independent of hardness and is possessed alike by minerals which are extremely soft and by those which are very hard. It depends rather upon the internal structure, and is characteristic of those substances which occur in well-developed crystals or crystalline masses. Amorphous substances do not possess cleavage.

Parting.—Parting is a separation somewhat similar to cleavage, and is sometimes called "false cleavage." It is most often the result of polysynthetic twinning, or may be due to pressure applied in definite directions. Corundum has basal, rhombohedral, and prismatic partings.

Fracture.—The fracture refers to the character of the surface obtained when a substance is broken in a direction parallel to which there is no cleavage or parting. Since amorphous substances have no cleavage, they always show a fractured surface when broken. When the fractured surfaces are curved and shell-like the substance is said to have *conchoidal* fracture. This type of fracture is quite common among gems. Quartz and opal are good examples of conchoidal fracture. In minerals with an *even* fracture the surfaces are smooth and even; with *uneven* fracture they are rougher. Minerals which are more or less fibrous break with a *splintery* fracture. Splintery fracture is well illustrated in jadeite.

Specific Gravity.—The ratio between the weight of a substance and the weight of an equal volume of water is called its *specific gravity*, commonly abbreviated *sp. gr.* Since the value of the specific gravity can be obtained without in any way injuring the stone, its determination is a valuable aid in the identification of gems. Thus quartz may be readily distinguished from the diamond, for the former has a specific gravity of 2.65, the latter, 3.52.

When a solid is suspended in a liquid, its weight is decreased by an amount exactly equal to the weight of the displaced liquid. The majority of methods for determining the specific gravity of solids are based upon this fact. The solid is weighed first in air, then in water. Its loss of weight in water is equal to the weight of an amount of water of the same volume as the solid. Therefore, the specific gravity of the solid is equal to its weight in air divided by the loss of weight in water.

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

There are several methods for the determination of the specific gravity of solids. These involve the use of:

1. The chemical balance.
2. The pycnometer.
3. Heavy liquids and the Westphal balance.
4. The Jolly balance.

1. In using the *chemical balance* for the determination of the specific gravity of a gem, the stone is suspended by a fine thread or wire. It is weighed first in air, and again when suspended in a beaker of water. The beaker is supported over the scale pan in such a way that it will not interfere with the weighing. If

W = weight of the gem in air, and
W' = weight of gem in water, then
$W - W'$ = loss of weight of gem when in water.

The *specific gravity* of the gem, therefore $= \dfrac{W}{W - W'}$.

While this method, sometimes called the *hydrostatic method,* is very accurate, it is time consuming. It is applicable to fairly large gems and fragments.

2. The method which makes use of the *pycnometer* or *specific gravity flask* is also accurate but slow. The pycnometer in its simplest form consists of a small glass flask (Fig. 51) fitted with a ground-glass stopper, which is pierced lengthwise by a capillary opening. The flask is first weighed empty (A), and then when filled with distilled water (B). It is then emptied, and after being thoroughly dried, the gem is placed within the bottle, and the whole is weighed (C). The pycnometer, still containing the gem, is again filled with water, and a fourth weighing made (D). The specific gravity can then be calculated from the following formula:

$$\text{Specific gravity} = \frac{C - A}{B + C - A - D}$$

Fig. 51.—Pycnometer.

Care must be exercised to remove all air bubbles. This can usually be done by boiling the water and allowing it to cool. When this method is carefully carried out, very accurate results may be obtained. It is well adapted to the determination of the specific gravity of small fragments or gems.

3. The *Westphal balance* is an instrument for determining the specific gravity of liquids. For use with this balance there are available heavy liquids which may be diluted to give solutions of any given specific gravity, within certain wide limits. From the end of a graduated beam (Fig. 52), a thermometer body or sinker is suspended in a cylindrical vessel containing the liquid. Weights are placed along the beam until the sinker neither rises nor falls in the liquid. The specific gravity of the liquid can then be read directly from the position of the various weights on the beam.

To determine the specific gravity of a gem by means of the Westphal balance, one of the heavy liquids is suitably diluted until the immersed gem remains suspended midway, without motion up or down. For this reason this method is sometimes called the *suspension method*. Having thus matched the specific gravity of the liquid and the gem, it is a simple matter to determine the specific gravity of the liquid, with the Westphal balance. The value determined for the liquid is obviously also the specific gravity of the gem. This method combines accuracy with reasonable rapidity. It is used principally for small gems.

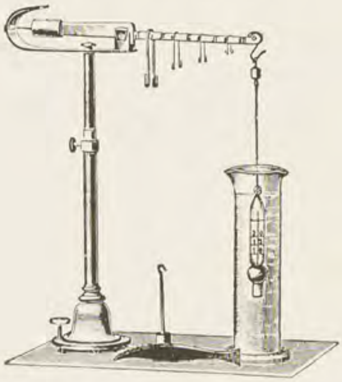

FIG. 52.—Westphal balance.

The heavy liquids listed below are suitable for use with this method. Their maximum specific gravity is given, which of course may be lowered by dilution.

	SPECIFIC GRAVITY
Methylene iodide	3.31
Potassium mercuric iodide (Thoulet's solution)	3.196
Cadmium borotungstate (Klein's solution)	3.284
Barium mercuric iodide (Rohrbach's solution)	3.58
Thallium silver nitrate (Penfield's or Rector's solution)	5.0

At ordinary temperatures the last compound is a solid, but it melts to a liquid at 70°C. and may then be used.

4. The most rapid determination of the specific gravity of a gem can be made with the *Jolly balance* or *spiral spring balance*.[1] While this method is not quite as accurate as the three first described, the results obtained are more than sufficient for the identification of gems. This balance (Fig. 53) consists of a

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[1] This balance is manufactured by the Eberbach and Son Company, Ann Arbor, Michigan.

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

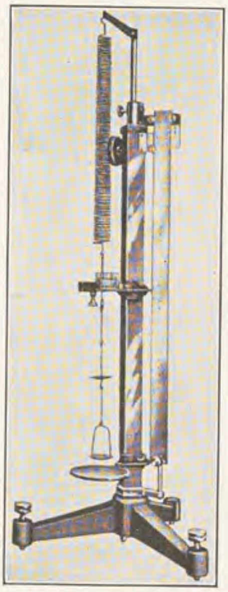
FIG. 53.—Jolly balance.

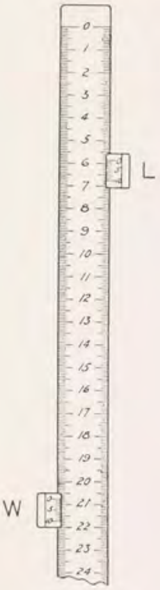

FIG. 54.

In using the balance it is necessary that the graduated scale, the two verniers, and the index, which is attached to the spiral spring, all be at zero, the lower scale pan being immersed in water. This is accomplished by approximately adjusting, by hand, the length of the rod carrying the spring and then introducing the necessary correction by means of the micrometer screw shown directly below the spring in the cut (Fig. 53). The gem stone is then placed on the upper scale pan and by turning the large milled-head the round tube, graduated scale, and outer vernier are all carried upward until the index on the spring is again at zero. The fixed inner vernier W (Fig. 54) now records the elongation of the spring due to the weight of the gem in air. The scale is then clamped by means of the screw at its lower end (Fig. 53). The stone is now transferred to the lower scale pan, immersed in water, and the round tube lowered by the large milled-head until the index again reads zero. During this operation the outer vernier moves downward on the graduated scale and its position may now be indicated by L (Fig. 54). This is obviously the decrease in the elongation of the spring due to the immersion of the fragment in water. The readings at W and L are all the data necessary for the calculation of the specific gravity. For

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

It is also obvious that these readings are recorded so that they may be checked, if necessary, after the operations and calculation are completed. A determination can be made with this instrument in about two minutes. This method can be used to best advantage with fairly large specimens.

Table III (p. 188) gives a list of the gem mineralsa rranged according to their specific gravity.

Color.—The beauty and splendor of gems depend to a large extent upon their color. Indeed some gems depend solely on color for their charm and appeal. Turquois might be cited as an example.

With respect to color, minerals are divided into two classes, *idiochromatic* and *allochromatic* minerals. The color is an inherent property in idiochromatic minerals, some essential constituent of the mineral being the pigmenting agent. The gems containing copper as an important constituent belong to this group. These include the green minerals malachite, dioptase, and chrysocolla, and the blue azurite. Gem minerals with a metallic luster, such as pyrite and hematite, are also idiochromatic. In idiochromatic minerals the color is constant, and therefore is a property which is of assistance in their identification.

Allochromatic minerals are perfectly colorless or white when pure. Due to the presence of a pigment they are often colored. The pigmenting impurity may be present either in submicroscopic particles or as inclusions of another colored mineral. It is evident that allochromatic minerals may therefore show a great variety of colors, and color is but a poor aid in their determination. For example, quartz is entirely colorless when pure, but it is more often colored, and among its varieties practically every hue is represented. Some of the colored varieties are the purple amethyst, the brown to black smoky quartz, the pink rose quartz, and the golden citrine. The majority of gem minerals are allochromatic.

It frequently happens that the pigment of allochromatic minerals is unevenly distributed. The color may occur in irregular blotches, as is often the case with amethyst. On the other hand it may be distributed in regular and sharply bounded zones or bands. For example, tourmaline often exhibits a zonal arrangement of colors. Crystals of that mineral are usually long, with a spherical triangular outline in cross-section. The crystals may be banded in horizontal layers across the length, or in concentric zones parallel to the spherical triangular outline (see Fig. 55). These zonings are very striking and attractive, combinations in pink and green being especially common. The variety of quartz known as agate also is banded with different colors.

FIG. 55.—Tourmaline showing zonal distribution of color and spherical triangular outline. San Diego County, California.

Coloring by inclusions is illustrated by moss agate, which contains tree-like or *dendritic* inclusions of manganese oxide.

FIG. 56.—Andalusite: variety, chiastolite. Lancaster, Massachusetts.

In other stones inclusions may be arranged in a definite manner, as is the case with chiastolite, which is a variety of andalusite containing cross-shaped groups of inclusions of a black, carbonaceous material (Fig. 56). Rutilated quartz, also called Thetis or Venus hairstone, is rendered attractive by long and slender inclusions of rutile (Fig. 201, p. 148). The beauty of sunstone is due to golden inclusions of iron oxide.

A list of gem minerals grouped according to their color is given on page 189.

Streak.—The streak of a mineral is the color of its powder, as determined by rubbing the specimen over a piece of white unglazed porcelain. Gems rarely have colored streaks.

Play of Color.—Many white opals exhibit a great variety of internal hues, forming a brilliant and beautiful patchwork of color. As the stone is turned, or as it is observed from another direction, the color of each individual patch changes. This phenomenon is known as *play of colors*. Labradorite shows the same effect, except that the patches of uniform color are larger than in the opal. The beauty of these minerals is almost entirely due to their play of color. The cause of the phenomenon is the interference offered to light by minute cracks or inclusions within the mineral. This is quite similar to the color effect observed in thin oil films and in soap bubbles. Play of color must not be confused with fire (see p. 38).

Chatoyancy.—The wavy, changeable, silky sheen shown by fibrous minerals, such as satin spar (Fig. 250, p. 178) or tiger's eye (Fig. 202, p. 149), is known as *chatoyancy*. Chatoyant gems are best cut cabochon (p. 74).

Opalescence.—This consists of milky or pearly reflections from the interior of a substance. It is usually observed to best advantage on gems cut with rounded surfaces, that is, on cabochon cuts, described on page 74. Opal and moonstone have this property.

FIG. 57.—Asterism shown by muscovite from South Burgess, Canada. (*After Hauswaldt*).

Asterism.—Minerals show asterism if on being held in strong reflected or transmitted light they exhibit a star-like light effect. In many cases this is due to regularly arranged inclusions of minute size. Rubies and sapphires, particularly those from Ceylon, frequently show asterism in strong, reflected light, when cut with a rounded convex surface. They are then known as star sapphires and rubies, and are highly prized. Mica often shows pronounced asterism in transmitted light (Fig. 57).

Luster.—The appearance of the surface of a mineral in reflected light is its luster. Luster is a function of the transparency, refractivity, and structure of a mineral. It is in no way related to hardness. There are two principal types of luster, *metallic* and *non-metallic.*

Metallic luster is that of metals and minerals of a metallic appearance. All substances with metallic luster are opaque. But few gems possess this luster. Pyrite and hematite are examples.

All other types of luster are collectively referred to as non-metallic. Various kinds of non-metallic luster are:

Adamantine.—The splendent luster typical of the diamond, and possessed only by minerals with high indices of refraction.

Vitreous.—The luster of glass or quartz.

Resinous.—The luster of resin.

Greasy.—With the appearance of an oily surface.

Pearly.—This is the luster of mother-of-pearl, usually shown by minerals with a platy structure.

Silky.—The luster of fibrous minerals, such as the satin spar variety of gypsum.

Dull.—As the name indicates, the surfaces of minerals with this luster are not at all bright or shiny.

Transparency or Diaphaneity.—Transparency is the ability of a substance to transmit light. Light passes freely through a *transparent* mineral, and objects can be easily and distinctly seen through such a substance. Rock crystal is an example of a transparent substance (Fig. 58). Light is feebly transmitted through a *translucent* mineral, and no objects can be distinguished on looking through them. In thin layers jade is translucent. No light can pass through *opaque* objects, which include all metallic minerals. *Sub-* or *semi-transparent* and *sub-* or *semi-translucent* are terms used to denominate intermediate stages of diaphaneity. The majority of gem minerals are transparent. This is especially the case with the more precious stones.

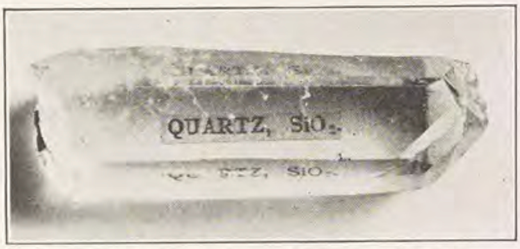

FIG. 58.—Transparent quartz from Dauphiné, France.

Phosphorescence and Fluorescence.—Some minerals glow when they are heated in the dark. If the glow continues after the heat or other cause of excitation is removed, the phenomenon is referred to as *phosphorescence*. It is designated as *fluorescence* if the substance glows only during the period of excitation. Fluorite exhibits both phosphorescence and fluorescence. The term *luminescence* is used collectively for both effects. Excitation with ultra-violet rays, which are conveniently produced by the iron arc, X-rays, radiations from radium preparations, or even with sunlight, may produce luminescence. The diamond and kunzite markedly show this phenomenon.

In discussing the effect of radiations it should be mentioned that they may cause a change in the color of minerals. Diamonds exposed to the action of radium become green. In the same way colorless quartz becomes smoky. Furthermore, such radiations may be used to improve artificially the color of a stone. It has been suggested that many allochromatic minerals may owe their color to radium radiations from neighboring minerals or solutions. This hypothesis, however, has not yet been substantiated.

FIG. 59.—X-Ray photograph of diamond (right) and of a glass limitation (left).

It may also be noted that diamonds are transparent to X-rays, while imitations made of lead glass are opaque to the same radiations. An X-ray photograph will serve to distinguish the genuine diamond from glass imitations (Fig. 59).

Electrical Properties.—Some gem minerals may be electrified by vigorous rubbing. They will then attract bits of paper. Diamond, tourmaline, and topaz may be positively electrified by friction with a cloth. On the other hand, amber becomes negatively charged.

Tourmaline is the notable example of *pyroelectric* minerals. If crystals of tourmaline are subjected to a marked change in temperature, positive and negative charges of electricity develop on opposite ends. This is due to the polar development of tourmaline, whereby forms occurring at opposite ends of the vertical axis are different (Fig. 60). This phenomenon is known as *pyroelectricity*. It is easily detected by Kundt's method. The crystal to be tested is gently heated, and allowed to cool on an insulated support. It is then sprinkled with a finely powdered mixture of red lead and sulphur, the particles of which are electrified by friction in their passage through a fine sieve in the nozzle of the bellows containing the powder. The red lead, having been positively electrified, collects at the negative end of the crystal, and the negatively electrified sulphur is attracted to the positive end. That is, the negative end of the crystal becomes red in color, the positive end yellow. On account of the polar development of its horizontal axes quartz also may exhibit pyroelectricity.

Fig. 60.

CHAPTER IV

OPTICAL PROPERTIES

In the preceding chapter those physical properties have been treated which may be determined without the use of specially designed optical instruments. The properties, the determination of which necessitates the use of the polarizing microscope and other optical instruments, will now be discussed. The recognition of these properties is of the greatest value in the positive identification of gem minerals. Some of the essential properties of light will be reviewed before the polarizing microscope and its uses are described.

Reflection of Light.—When a ray of light falls upon a mirror or other polished surface, it is reflected in such a way that *the angle of reflection is equal to the angle of incidence, and the reflected and incident rays lie in the same plane.* This is illustrated by Fig. 61. A ray of light EX from the candle at E strikes the reflecting surface AB at X, with the angle of incidence EXO or i. It is reflected to the eye at D, and DXO or r is the angle of reflection. To the eye the object E appears to be at E'. The angle r is equal to the angle i, as the law of reflection states.

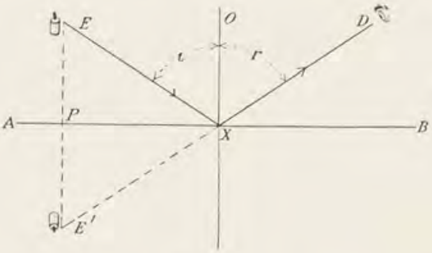

FIG. 61.

Refraction of Light.—In the case of gems reflected light is not generally as important in producing a pleasing effect as is the light which enters the gem, that is, the refracted light. When light passes obliquely from one medium to another, as from air into water, the path of the ray is bent, or the ray is *refracted.*

The bent appearance of a stick thrust into a pond is due to this fact. Figure 62 illustrates the refraction of light. A ray of light Dx, in air, strikes the surface of the water, AB, at x. Instead of continuing in the same direction after entering the water, the ray is refracted into the direction xE, that is, toward OM, the normal to the surface of contact. Whenever light passes from a rare to a denser medium, as in this case, the ray is bent toward the normal. The reverse takes place when light passes from a dense to a rarer medium. It is then bent away from the normal. In Figure 62 the angle of incidence DxO may be designated as i, and the angle of refraction, MxE as r. The law of refraction then is: *the incident and refracted rays lie in the same plane, and the ratio between the velocities of light in the two media, V and V', and the ratio between the sines of the angles of incidence and refraction, i and r, are equal and constant for the media concerned.* In the case of air and water:

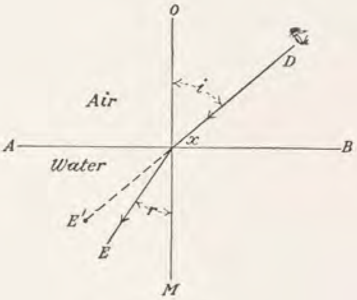

FIG. 62.

$$n \text{ (index of refraction)} = \frac{V \text{ (air)}}{V' \text{ (water)}} = \frac{\text{sine } i}{\text{sine } r} = 1.333.$$

The constant n is the *index of refraction*, the velocity of light in air being taken as unity. For water, n is always 1.333, and for the diamond, 2.42. The velocity of light in a substance is proportional to the reciprocal of its index of refraction. It is evident that a gem may usually be identified by determination of the value n. Methods for the determination of this important constant are given later (p. 40).

Dispersion.—A common experiment in elementary physics is the resolution of white light into its component colors, by passing sunlight through a glass prism (Fig. 63). Of the component colors which together make up white light, red is refracted least and violet most, while the other colors—orange, yellow, green, and blue—occupy intermediate positions in the band of colors, known as the *spectrum*. In other words the velocity of red light is the greatest, and that of violet light the least. That is, *dispersion* of light has taken place. For this reason indices of refraction can be accurately determined only with light of a definite color (*monochromatic light*).

The difference in the velocities of red and violet light in passing through a substance indicates the strength of the dispersion of that substance. This is numerically expressed by the difference in the indices of refraction for violet and red lights.

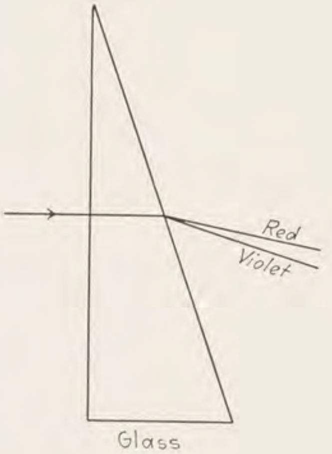

FIG. 63.

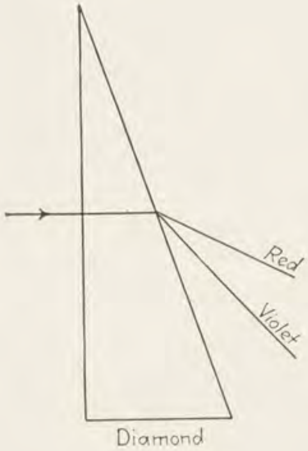

FIG. 64.

The diamond is characterized by a very high dispersion, about three times that of glass, as shown by the following data giving the values of n for various colors of light.

	(wave length)	
n, red light	$687\mu\mu$	2.407
yellow	589	2.417
green	527	2.427
violet	397	2.465

Dispersion = $2.465 - 2.407 = 0.058$

The high dispersion of the diamond is the important factor in producing the *fire* so characteristic of that gem. This highly prized attribute is due to the fact that the component colors of white light in passing through the diamond are widely dispersed (Fig. 64) and on emergence under favorable conditions, practically pure colors may be observed. That is, when a diamond is viewed in one direction a flash of yellow may appear, while slight turns of the stone may produce red or blue flashes. Substances like quartz or glass, which have a low dispersion (Fig. 63) show little or no fire.

Total Reflection and the Critical Angle.—If light passes from a dense to a rarer medium, the ray is bent away from the normal (Fig. 65). The angle of incidence I is smaller than the angle of refraction R. For a definite angle of incidence i, r will equal 90 degrees, and the ray of light will just graze the surface between the media. If I be further increased, as in the case of I', the light ray cannot emerge, but is reflected back into the dense medium according to the law of reflection, making R' equal to I'. This is the phenomenon of *total reflection.* All light impinging at the surface AB with an angle of incidence greater than i will suffer total reflection.

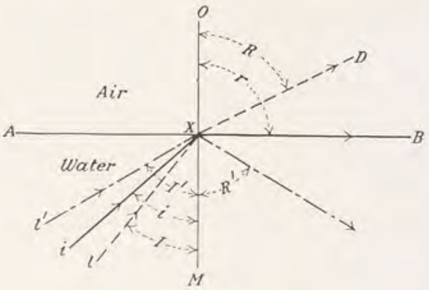

FIG. 65.

The value of the critical angle may be expressed by

$$\text{sine } i = \frac{1}{n}$$

in which n is the ordinary index of refraction, and i is the critical angle, light being totally reflected if it impinges at the surface with a greater angle. From this formula it follows that the higher the value of n, the smaller will be the critical angle i, and light will be more readily totally reflected within the substance. In the diamond, for an intermediate color, n is 2.42, and i, 24° 26′; for water, n is 1.333, i, 48° 36′. The low value of the critical angle in the diamond permits total reflection to take place rather easily. All the light exterior to a small cone, the surface of which makes an angle of 24° with its axis, can be totally reflected in the diamond (Fig. 66). Because of repeated total reflections, the brilliancy is very much enhanced. The dispersion of light within the diamond is also greatly increased, aiding in the production of its fire. On the other hand, total reflection of light does not take place as readily in water as in the diamond because the critical angle is twice as large, namely 48° 36′ (Fig. 67).

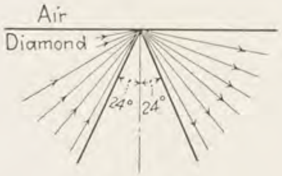

FIG. 66.

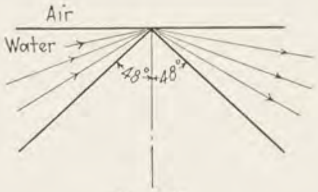

FIG. 67.

Determination of Indices of Refraction.—The determination of the index of refraction is one of the most accurate and readily applied means of identifying precious stones. There are several methods for doing this:

1. Prism methods.
   a. Minimum deviation method.
   b. Perpendicular incidence method.
2. Approximate immersion method.
3. Smith's total reflectometer method.
4. Becke's method.

Of these methods the most accurate are those employing prisms. However, these require the use of an instrument not always available, known as the goniometer. The approximate immersion and Becke methods are more rapid, but not so applicable to cut or mounted stones as is the Smith reflectometer method. With Smith's instrument a determination of sufficient accuracy for the identification of a gem may be made in one or two minutes.

As indicated previously, monochromatic light should be used in determining the index of refraction of a substance. The usual source of such light is a non-luminous gas flame colored by salts of one of the following elements:

Lithium, gives a red flame, of wave length $670\mu\mu$
Sodium, gives a yellow flame, of wave length $589\mu\mu$
Thallium, gives a green flame, of wave length $535\mu\mu$

Since the value of the index of refraction often varies markedly with direction, many gems have not merely one index of refraction, but two or even three principal indices. In such cases all indices may be determined by the use of properly oriented prisms or sections. The determination of any one index, however, will generally be sufficient for purposes of identification.

Prism Methods. *Minimum Deviation.*—As noted above there are two prism methods for the determination of indices of refraction. In both a prism is cut from the mineral, and mounted at the center of an instrument known as a *goniometer* (Fig. 68), which is provided with a telescope, collimator, and graduated scale for the measurement of angles. A ray of light is allowed to pass from the collimator through the prism. By means of the telescope the position is found at which the ray is least deviated in its passage through the substance. Having measured this angle of least deviation (δ) and the angle between the faces of the prism (α), the index of refraction is easily calculated, as follows:

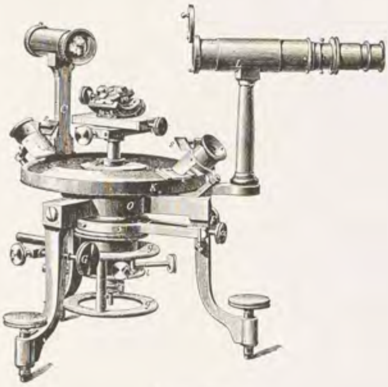

FIG. 68.

$$n = \frac{\text{sine}\,\dfrac{\alpha + \delta}{2}}{\text{sine}\,\dfrac{\alpha}{2}}$$

Perpendicular Incidence.—In this method a ray of monochromatic light is allowed to fall perpendicularly upon the face of a prism mounted as before upon the goniometer. The angle between the faces of the prism must be smaller than the critical angle, in order that the ray will not be totally reflected within the mineral. From the measured values of α, the angle between the prism faces, and δ, the angle of deviation, n may be calculated as follows:

$$n = \frac{\text{sine } (\alpha + \delta)}{\text{sine } \alpha}$$

These methods are readily applicable to cut gems, which may be so mounted that oppositely placed facets form the necessary prisms.

Approximate Immersion Method.—This method depends upon the fact that a transparent solid becomes practically invisible when placed in a liquid with the same color and the same index of refraction. The solid and the liquid form a continuous medium for the passage of light so that the boundaries of the solid tend to disappear. By using a series of liquids with different indices of refraction the approximate index of most minerals may be found. The stone is immersed in one liquid after another, until that liquid is found in which it most completely disappears. The stone then has approximately the index of that liquid. Figure 69 shows the appearance of a glass imitation immersed in a liquid with approximately the same index. The greater the difference in refractivity between the liquid and the solid, the greater will be the *relief* of the solid, that is, the more plainly will it be visible. This method may be applied to colored as well as colorless stones, though in the case of the former it is not quite so easy to use. It is more difficult to tell when the relief is least, for the color of the stone aids in indicating its outline. The approximate immersion method is much used with fragments under the microscope, but that application is of little importance here. The following liquids may profitably be used in the approximate immersion method:

Water	$n = 1.33$
Petroleum	1.45
Turpentine	1.47
Xylol, meta	1.50
Clove oil	1.54
Cinnamon oil	1.60
α monobromnaphthalene	1.65
Methylene iodide	1.74
Sulphur in methylene iodide	1.79

By mixing these liquids in the proper proportions, solutions with intermediate indices of refraction are easily obtained. It is common practice to prepare a series of such liquids, the individual members of which have indices of refraction varying by one unit in the second decimal place. The mixtures generally used are: petroleum and turpentine; turpentine and clove oil; clove oil and α monobromnaphthalene; α monobromnaphthalene and methylene iodide; methylene iodide and sulphur. There is no liquid with an index as high as that of the diamond (2.42), but the range of the liquids given above includes the indices of refraction of nearly all of the other gems, as well as those of the usual imitations of the diamond. Figure 69 shows the diamond (n 2.42) and glass immersed in cinnamon oil (n 1.60). It is quite obvious that the index of refraction of the glass imitation, as indicated by the low relief, is approximately the same as that of the cinnamon oil.

FIG. 69.—Diamond (left) and glass (right) immersed in cinnamon oil.

Smith's Total Reflectometer Method.—The convenient hand-size instrument known as the Smith total reflectometer is illustrated in Fig. 70. It makes use of the principle of total reflection (p. 39). The most essential part is a polished hemisphere of glass with a very high index of refraction, exceeding that of most minerals. Light enters through an opening at the left. The mounted or unmounted stone to be tested is placed upon the polished flat surface of the glass hemisphere. However, a drop of liquid of high index, such as methylene iodide, must be first placed upon the glass in order to displace the film of air which would otherwise be present between the stone and the

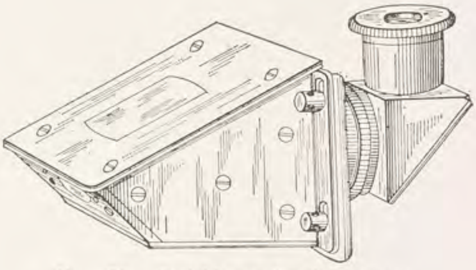

FIG. 70.—Smith's total reflectometer.

glass. A broad beam of light enters the instrument through the opening at the left, and passes up to the lower surface of the stone, which must be flat and smooth.

The light thus passes from a dense to a rarer medium. Part of the broad beams falls upon the stone at an angle less than the critical angle and continues through the stone and into the air. But some of the light impinges upon the stone at an angle which exceeds the critical angle. This light is therefore totally reflected back into the glass. The totally reflected light falls upon a graduated scale, which is viewed through the eyepiece at the right. It is obvious that part of the scale will be illuminated by that portion of light which is totally reflected, while the rest of the scale will be somewhat darker. This is because some of the light has escaped from the instrument. The position of the boundary between the lighter and darker portions of the scale is a function of the critical angle of the stone with reference to the dense glass. This angle, of course, depends upon the relative indices of refraction of the gem and the glass. Since the index for the glass is known, the scale may be so graduated that the position of the boundary of the illuminated area will indicate the index of refraction of the stone. Thus the index of the gem may be read directly from the scale. The divisions of the scale correspond to 0.01, but the index may be estimated to 0.001. The range of the instrument extends nearly to an index of 1.80.

Making use of this method, the index of refraction of a mineral may quickly be determined. Where great accuracy is desired, monochromatic light should be used. Ordinarily, however, the determination can be made with white light or sunlight, in which case one observes a fringe of colors, instead of a sharp boundary to the illuminated area. The colored bands indicate the indices of the stone for the various colors of light. In most stones the dispersion is such that this effect is not very noticeable. If the stone has more than one index of refraction (p. 46) two boundaries may be observed, each for a different index.

The index of refraction of a gem, in connection with the color and other easily noted properties, is usually sufficient for identification. On page 192 is a list giving the indices of the more common gem minerals.

Becke's Method.—The method devised by Becke makes use of the polarizing microscope (p. 47). This method, like the one previously described, depends upon the total reflection of light.

Let A and B (Fig. 71) be two substances in contact, B having a higher index than A. If the microscope be focused upon the contact, a band of light will be observed at SO which will move toward B when the tube of the microscope is raised; on lowering the tube it moves toward A. This band is caused by the concentration of light on one side of the contact, for all rays of light in A which strike on the contact will pass into B irrespective of the angle of incidence i. Thus, the ray x will emerge as OM. But when light passing through B impinges upon the contact, the size of the angle of incidence is of great importance, for now the passage is from a dense to a rarer medium. In all such cases total reflection will take place if the angle of incidence i is larger than the critical angle. For instance, the ray R will emerge as ST. As before mentioned, the raising of the microscope tube will displace the band of light, due to this concentration of rays, toward the substance with the higher index. Whether or not the index of the gem or mineral being investigated is higher or lower than that of a known substance can thus be easily determined.

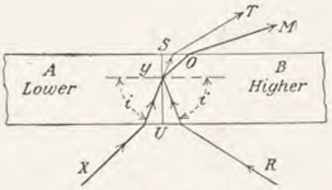

FIG. 71.

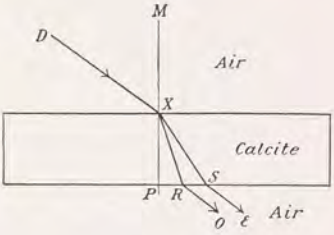

FIG. 72.

The indices of refraction of cut gems or gem fragments can be determined by immersing them in liquids with known indices (p. 42) and noting the movement of the band of light. The operation is repeated until a liquid is found whose index matches that of the gem mineral.

Double Refraction.—When a ray of light passes into a cubic or amorphous mineral it continues in the mineral as a single, refracted ray. This is designated as *single refraction*. In general, light passing obliquely through minerals of the other five crystal systems is not only refracted, but also resolved into two rays which travel with different velocities. This is called *double refraction*. It is illustrated by Fig. 72, which represents a section of calcite. Calcite is a mineral with exceedingly strong double refraction, so strong indeed as to be readily detected by the eye. Figure 73 shows the apparent doubling of print as seen through a cleavage piece of calcite.

In Fig. 72 the ray *DX* strikes the section of calcite at *X*, and is resolved into two rays, *o* and *e*. The velocity of the *o* ray is the same in all directions through the crystal, and this ray is called the *ordinary ray*. But since the velocity of the *e* ray varies according to the direction in which it passes through the crystal, it is called the *extraordinary ray*. In calcite *o* is the slower ray, and it is refracted more than the faster ray *e*. However, in other substances this relationship may be reversed.

Fig. 73.—Calcite: variety, Iceland spar, showing double refraction. Big Timber, Montana.

Optical Groups.—As indicated on page 12 the crystal systems may be classified into optical groups. Cubic and amorphous minerals are *singly refractive* and *isotropic*. Light travels through such minerals with the same velocity in all directions. They have but one index of refraction, usually designated n. Examples of this group are: diamond (cubic), $n = 2.42$; garnet (cubic), $n = 1.75$; opal (amorphous), $n = 1.45$.

All other minerals are *anisotropic*, that is to say the velocity of light varies with the direction in which it passes through them. However, these substances may have either one or two isotropic directions, known as the directions of the *optic axes*. Those substances with one isotropic direction are called *uniaxial*, those with two such directions, *biaxial*.

Hexagonal and tetragonal crystals have one isotropic direction which is parallel to the vertical crystal axis and they are therefore uniaxial. Minerals of this group are subdivided into two classes according to the relative values of the indices for the *o* and *e* rays. The index of refraction for the ordinary ray is designated by the Greek letter ω (omega), that for the extraordinary ray by ϵ (epsilon). If the value for ω is greater than that for ϵ, the crystal is said to be optically negative; and it is called positive if ϵ exceeds ω. Calcite is negative, $\omega = 1.65$, $\epsilon = 1.48$; zircon, positive, $\omega = 1.924$, $\epsilon = 1.968$. The difference between the values for ϵ and ω is called the strength of the *double refraction* or *birefringence*. For calcite the birefringence is 0.17 ($1.65 - 1.48$); for quartz it is only 0.009 ($1.553 - 1.544$).

The other group of anisotropic crystals contains those which have two isotropic directions or optic axes, and are spoken of as *biaxial*. To this group belong all orthorhombic, monoclinic, and triclinic crystals. They possess three principal optical directions, at right angles one to another. For each such direction there is a principal index of refraction, these three indices being: α (alpha), the smallest; β (beta), the intermediate; γ (gamma), the largest. Examples are: topaz (orthorhombic), $\alpha = 1.607$, $\beta = 1.610$, $\gamma = 1.618$; epidote (monoclinic), $\alpha = 1.730$, $\beta = 1.754$, $\gamma = 1.768$; albite or moonstone (triclinic), $\alpha = 1.531$, $\beta = 1.534$, $\gamma = 1.540$. If the value of β is nearer to α than to γ, as with topaz, the mineral is optically *positive;* if β lies nearer to γ (epidote), it is optically *negative*. The double refraction or birefringence is equal to $\gamma - \alpha$; for topaz it is 0.011 ($1.618 - 1.607$). In the table below the optical properties are briefly summarized.

Singly refractive or isotropic	Amorphous substances and cubic crystals		One index of refraction, n
Doubly refractive or anisotropic	Hexagonal Tetragonal	Uniaxial	Two indices of refraction, ω and ϵ Positive, $\omega < \epsilon$ Negative, $\epsilon < \omega$
	Orthorhombic Monoclinic Triclinic	Biaxial	Three indices of refraction, α, β, and γ Positive, $\alpha\beta$, γ Negative, α, $\beta\gamma$

Polarizing Microscope.—The polarizing microscope, as used by mineralogists, differs materially from the ordinary biological instrument. It is illustrated in Fig. 74, and a cross-section is shown in Fig. 75. The stage rotates in a horizontal plane, adding greatly to the usefulness of the instrument. The essential difference, however, lies in the fact that polarized light may be used, instead of ordinary light. This kind of light is produced by two nicol prisms (see p. 50) *P* and *A* in the figure (75), the polarizer and analyzer respectively. Both nicols may usually be rotated.

An instrument known as the *epidiascope* is frequently used for the projection upon a screen of observations made with the microscope.

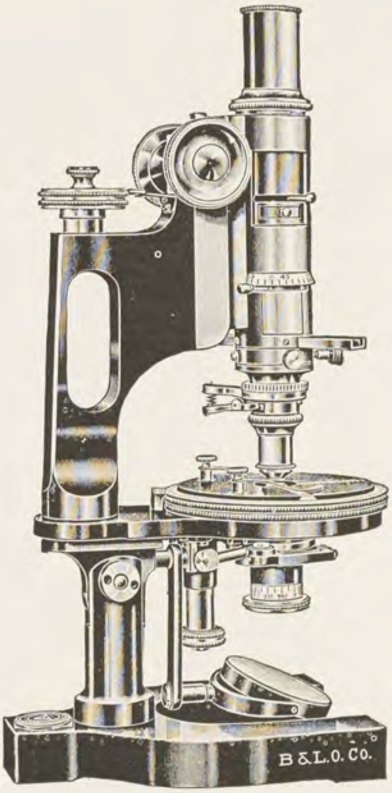

Fig. 74.

Polarized Light.—According to the usually accepted undulatory theory, light is considered to be a form of energy transmitted by waves in the ether which is everywhere present. Light travels with the great velocity of approximately 186,000 miles or 300,000 meters per second. It is propagated by the vibration of ether particles in a direction perpendicular to that in which the light travels.

With ordinary light the ether particles vibrate in a plane at right angles to the direction of propagation of the light, but the vibration direction in this plane is continually changing. If in Fig. 76 a ray of light is considered as traveling in a direction perpendicular to the plane of the page, then the vibration of the ether particles is successively in the direction AA', BB', CC' and so forth. In Fig. 77 this is shown in perspective.

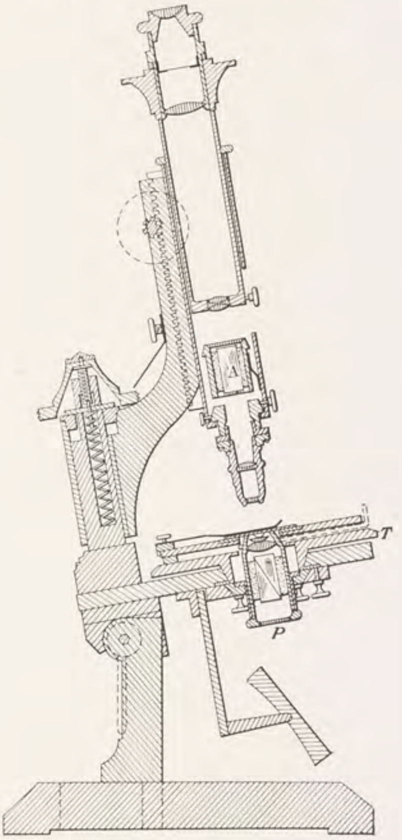

FIG. 75.

In *plane polarized* light, which is ordinarily designated simply as *polarized* light, the vibrations of the ether particles are still in a plane at right angles to the direction in which the light is propagated, but they take place in only one definite direction in that plane. This type of light may be produced: (1) by reflection from glass plates or other surfaces; (2) by the partial absorption of ordinary light in passing through certain crystals; and (3) by means of refraction, as is the case with nicol prisms. The last is the method usually employed in the polarizing microscope and other optical instruments.

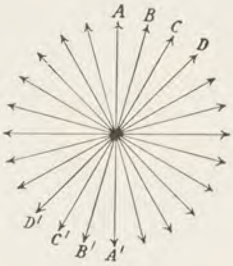

Fig. 76.

Nicol Prism.—A nicol prism is represented in Fig. 78. It consists of a clear cleavage piece of calcite or Iceland spar. The dotted outline at *A* and *F* represents the original outline of the cleavage piece. The angles at these points, originally 71 degrees, are ground down to 68 degrees, producing the outline represented by *BCED*. The piece of calcite is then cut along the plane *CD* into two parts. The cut faces are polished, and then the two parts are cemented together in their original position by means of a thin layer of Canada balsam, which has an index of refraction of about 1.54.

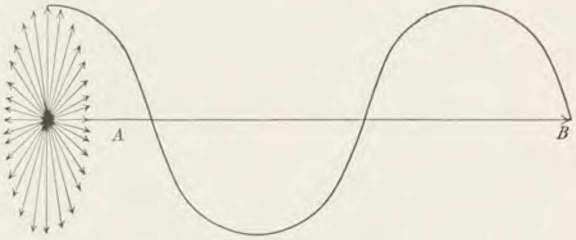

Fig. 77.

A ray of ordinary light, *MN*, falling upon *DE*, is resolved into two rays *NR* and *NS* by the doubly refracting calcite. Each of these rays is plane polarized in this operation. The ordinary ray *o* has a constant index of refraction of 1.658. This ray strikes the film of balsam at *S* with an angle of incidence greater than the critical angle, and is therefore totally reflected in the direction *ST*.

It is absorbed by the side of the case containing the nicol and does not emerge at the upper end.

The index for the extraordinary ray *e* of calcite varies with its direction through the mineral, namely from 1.486 to 1.658. In the direction *NR* its index is practically the same as that of the balsam, hence the light passes through with little or no deviation along *RW*, and emerges from the nicol as a plane polarized ray.

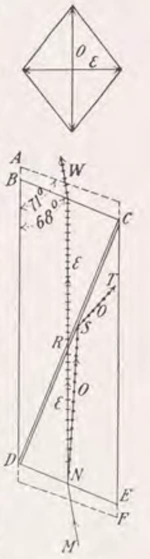

Fig. 78.

Nicol prisms find extensive use in polarizing microscopes and all other optical instruments in which plane polarized light is employed. In the microscope one nicol prism, called the *polarizer*, is placed below the stage, and a second, the *analyzer*, is mounted in the tube above the objective (Fig. 75). Both nicols may be rotated. Observations are made with the vibration directions of the two nicols either *parallel* or *crossed*. The nicols are crossed when their vibration directions are at right angles to each other.

Parallel and Convergent Polarized Light.—Polarized light may be either parallel or convergent. In the first case the rays of light pass through the substance under examination in a direction parallel to the axis of the microscope tube. Convergent polarized light is produced by placing a condensing lens above the polarizer. This causes the rays to converge in the substance (Fig. 79). The use of the polarizing microscope in the identification of gem minerals will now be discussed.

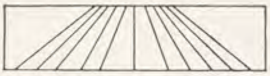

Fig. 79.

Behavior of Isotropic Substances.—If the analyzer is removed from the tube of the microscope, and an isotropic substance, either cubic or amorphous, be viewed in parallel polarized light, the field will be illuminated, and will remain illuminated in all positions of the stage. However, when the analyzer is replaced, the field is dark in all positions of the stage, provided the vibration directions of the upper and lower nicols are crossed. This latter observation is characteristic of isotropic substances, and serves to distinguish them from those which are anisotropic. Also in convergent light, with crossed nicols, an isotropic substance is always dark, exactly the same as with parallel polarized light.

Behavior of Uniaxial Substances.—With parallel polarized light and the analyzer removed, uniaxial substances are illuminated in all positions of the stage, provided the section has been cut perpendicular to the optic axis. With crossed nicols such sections are always dark. Sections cut in any other direction behave very differently. With crossed nicols such sections, that is, those parallel or inclined to the optic axis, are four times light and four times dark during a complete rotation of the stage. In daylight or artificial white light an *interference color* is observed in the four positions of illumination, while with monochromatic light some shade of the color employed is seen in those positions. The positions of greatest darkness are known as those of *extinction*. The cross hairs of the microscope are parallel to the vibration directions of the nicols, and are used in the determination of the extinction or vibration directions of the section or crystal. If extinction takes place when the cross hairs are parallel or perpendicular to the crystal edges or cleavage cracks in the specimen (Fig. 80), the substance is said to have *parallel extinction*. Uniaxial substances may also possess *symmetrical extinction* (Fig. 81).

Fig. 80.

Fig. 81.

Fig. 82.

Fig. 83.

Sections of uniaxial minerals cut perpendicular to the optic axis exhibit a characteristic uniaxial *interference figure* (Fig. 82) with crossed nicols in convergent polarized light. In monochromatic light this figure consists of a dark cross superimposed upon a series of light and dark rings. In white light the rings are of different colors. The figure remains stationary when the stage is rotated. If the section is inclined to the optic axis the interference figure is eccentric, as in Fig. 83. The greater the departure of the section from perpendicularity to the optic axis, the more eccentric will the figure be. When the stage is rotated the arms of the dark cross in eccentric figures move across the field parallel to the cross hairs, and in the same direction as the movement of the stage. This observation is of great importance in distinguishing uniaxial from certain biaxial figures. Whether a mineral is optically positive or negative may be determined from the effect of test plates on the interference figure.

FIG. 84.

Behavior of Biaxial Substances.—With crossed nicols and in parallel polarized light biaxial minerals are in general four times dark and four times light during a complete rotation of the stage.

FIG. 85.

FIG. 86.

However, sections cut perpendicular to an optic axis remain uniformly illuminated during the rotation. In orthorhombic substances extinction is either parallel or symmetrical. Monoclinic substances may show either parallel, symmetrical, or *inclined* extinction. When the cross hairs of the microscope are at an angle to the crystal edges of a substance in the position of extinction, that substance is said to possess inclined extinction (Fig. 84). Triclinic substances always have inclined extinction.

These facts enable one to differentiate the crystal systems among biaxial substances.

The interference figures observed in biaxial crystals, in convergent light with crossed nicols, are quite different from those seen in uniaxial substances. Biaxial figures vary markedly according to the direction in which the section is cut. Figure 85 illustrates, in the normal position, the biaxial figure observed when the section of the substance is perpendicular to the line bisecting the angle between the two optic axes. When the section has been rotated 45 degrees on the stage of the microscope, or to the diagonal position, the interference figure appears as illustrated in Fig. 86. The two "eyes," indicating the emergence of the optic axes, the oval curves, and the hyperbolic brushes are to be noted in these figures. If the section be cut perpendicular to an optic axis the interference figure will resemble those illus-

Fig. 87.

Fig. 88.

Fig. 89.

trated in Figs. 87 and 88, the normal and diagonal positions, respectively. In these figures one axis and one brush are visible. Figure 89 represents the figure observed, if the orientation of the section is intermediate between the two positions just described. As already indicated, these figures do not remain stationary when the stage is rotated, and the brushes move in a direction opposite to that of the stage. With test plates it can be determined whether a biaxial substance possesses positive or negative optical character.

From the foregoing brief treatment of the optical properties of crystals it is evident that by means of the microscope much important optical data may be obtained. In most cases the crystal system can be determined as well. Such an examination is of great value in the identification of minerals, especially if they happen to be poorly crystallized or in fragments or powder. In the following table are summarized the criteria by which the determinations may be made:

All sections remain dark through 360 degrees.	Isotropic	(*a*) No regular outline, structure, or cleavage.	Amorphous
		(*b*) Regular outline, structure, and cleavage.	Cubic
Not all sections remain dark through 360 degrees. Some are four times light and four times dark, others remain uniformly light.	Anisotropic	(*a*) Isotropic and doubly refractive sections. The first show a uniaxial interference figure in convergent light.	Hexagonal. Isotropic sections trigonal or hexagonal in outline. Tetragonal. Isotropic sections 4- or 8-sided.
		(*b*) Sections either extinguish regularly or remain uniformly light. The latter show the emergence of an optic axis in convergent light.	Orthorhombic. All sections show parallel or symmetrical extinction. Monoclinic. Sections show parallel, symmetrical, or inclined extinction. Triclinic. All sections show inclined extinction.

Enantiomorphism and Circular Polarization.—Right- and left-handed crystals of substances are found, which bear the same relationship to each other as do the right and left hand. The crystals are exactly similar but cannot be superimposed one upon the other, just as one's hands are exactly alike but cannot be made to fit over each other, palm to back, thumb over thumb. Figures 90 and 91, respectively, show right- and left-handed crystals of quartz. This phenomenon is the result of a peculiar arrangement of the units from which the crystals are built up. It is as if with the same kind, size, and shape of building stones, in one case a spiral stairway were built winding up to the right, in another, winding up to the left. This condition has its effect on the optical properties. *Enantiomorphous crystals*, as these are called, exhibit *circular polarization*, that is, they rotate the plane of polarization of light. Quartz is the best-known example of such minerals, and the interference figures to be observed on quartz because of its ability to polarize light circularly are illustrated by Fig. 92. This differs somewhat from the normal uniaxial figure, espe-

FIG. 90.

FIG. 91.

FIG 92.

FIG. 93.

FIG. 94.

cially in that the arms of the dark cross do not extend in to the center of the figure. By the use of test plates the right- or left-handed character of the crystals may be determined. This can also be done by superimposing a section of a right-handed over one of a left-handed crystal (Fig. 93) or *vice versa* (Fig. 94).

Pleochroism.—The color of a mineral is due to the absorption of certain portions of white light in its passage through the mineral. This is known as *selective absorption*. The remainder of the white light, namely that which is not absorbed in the mineral, blends to produce the color seen. In isotropic minerals light is equally absorbed irrespective of the direction in which it travels. But in anisotropic minerals the absorption of light varies with the direction, as is also the case with the velocity of light. This variation in absorption is the cause of the phenomenon of *pleochroism*.

The ruby well illustrates pleochroism. When looked at in a direction parallel to the vertical axis, a ruby has a much deeper red color than when viewed in a direction perpendicular to the axis. For this reason rubies are usually cut with the table (p. 76) parallel to the basal pinacoid, thus producing the best possible color. Light traveling parallel to the vertical axis is much more strongly absorbed than that traveling in the perpendicular direction. The paler color seen in the latter direction is a compound hue made by the blending of two colors. One of these is the same deep red observed parallel to the vertical axis, the other is pink. The former is the color for the ordinary ray, the latter that for the extraordinary ray. As both rays are seen simultaneously the eye strikes an average, and an intermediate color is observed.

Uniaxial minerals, of which the ruby is an example, have two principal colors and are designated as *dichroic*. This property is called *dichroism*. Biaxial minerals have three principal colors, one usually corresponding to each of the three principal optical directions. These minerals are sometimes called *trichroic*. Pleochroism is the general term covering both dichroism and trichroism. Many minerals, like the ruby, are pleochroic in two shades of the same color. In others, however, the colors may be entirely unlike when the substance is viewed in different directions. Thus cordierite, sometimes called dichroite, shows three principal colors, yellow, light blue, and dark blue.

In order to separate the combined colors as seen by the eye, a simple instrument called the *dichroscope* (Fig. 95) is used. This consists of a rhombohedren of calcite or Iceland spar, *C*, mounted in a cylindrical case. At one end is a small square opening, *O*, and at the other end an eyepiece, *L*. Glass prisms are sometimes placed at either end of the rhombohedron of calcite. Another and very convenient form of this instrument is shown in Fig. 96.

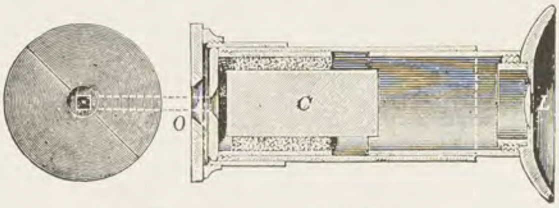

Fig. 95.—Cross-secton of dichroscope.

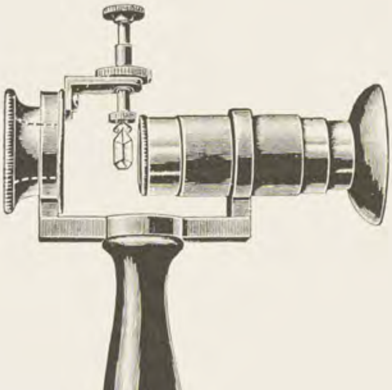

Fig. 96.—Dichroscope with mounted crystal.

If a pleochroic mineral be held before the square opening, and light be transmitted through the mineral into the dichroscope, two differently colored squares will be seen at the eyepiece. The colors of the squares correspond to the colors transmitted by the two rays in the mineral. For example, if the ruby is observed in a direction perpendicular to the vertical axis, one square is pink, the other deep red. By means of its double refraction the calcite separates the two rays emerging from the mineral and the eye sees a patch of color for each ray. In biaxial substances there are three directions in which the absorption is different, but the dichroscope reveals only two of these colors with the specimen in a given position. The specimen must therefore be turned into another position in order to observe the third color.

Pleochroism may also be observed with the microscope, using plane polarized light with the analyzer out. In rotating a pleochroic substance first one color and then another will be seen at intervals of 90 degrees. But in this case it is necessary to carry in mind one of the colors for comparison with the other. However, in the dichroscope the colors are to be seen side by side, and very slight variations in tints are thus more easily recognized.

The property of pleochroism is another aid in the determination of gems. In many cases the character of the pleochroism is decisive in making an identification. For example, red garnet and spinel have been used to imitate the ruby, but on account of their total lack of pleochroism these stones are easily distinguished from the ruby.

Absorption Spectra.—The color of a mineral is the result of the blending of all the portions of white light not absorbed. Two minerals may absorb light in entirely different ways, and yet show the same color. By means of the spectroscope, an instrument described in all standard texts on physics, exactly what particular portions of white light are absorbed by any substance may be determined. The unabsorbed light is dispersed (p. 37) in its passage through the spectroscope, forming a band of colors known as an *absorption spectrum.* Dark zones crossing the spectrum represent the light which has been absorbed. Certain gems have typical and unique absorption spectra, and the determination of these spectra is often of value in the differentiation of precious stones. For example, ruby absorbs almost all of the green and yellow light (Fig. 97). On the other hand, zircon shows sharp and distinct absorption bands distributed through the entire spectrum. Other gem minerals showing strong absorption spectra are almandite, sapphire, and amethyst (Fig. 97). In the

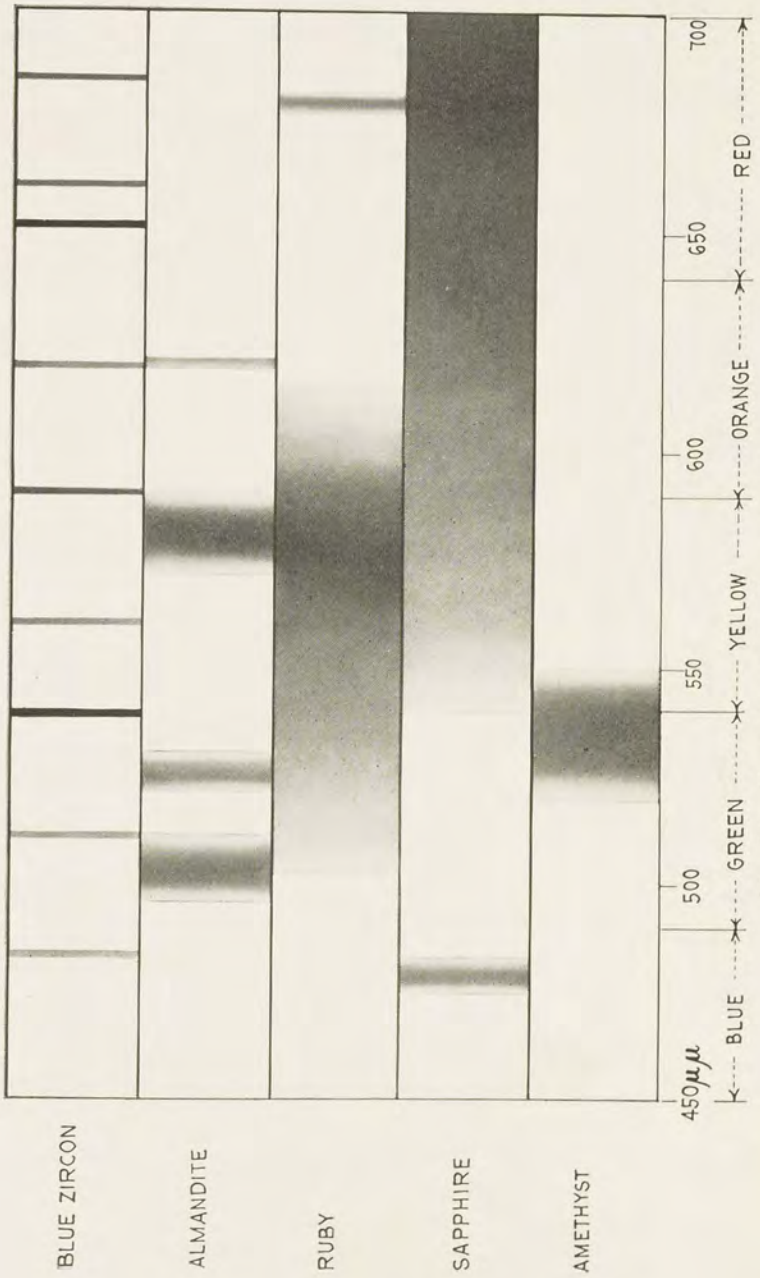

FIG. 97.—Absorption spectra of some gem minerals.

case of an allochromatic mineral (p. 30) the character of the absorption spectrum may offer a clue as to the nature of the pigmenting impurity, which might not be detected in any other way. The *pocket spectroscope* and *microspectroscope* may be conveniently used for the rapid and approximate determination of absorption spectra.

CHAPTER V

CHEMICAL PROPERTIES

Every mineral has a characteristic chemical composition, and may be either, an element or a chemical compound. With regard to their chemical composition minerals are classified under the following divisions. Minerals used as gems are given as examples for each group. The elements, oxides, aluminates, and silicates are the groups which contain most of the important gem minerals.

1. *Elements*	
Diamond	C
2. *Sulphides*	
Pyrite	FeS_2
3. *Oxides and Hydroxides*	
Corundum (ruby and sapphire)	Al_2O_3
Quartz	SiO_2
Opal	$SiO_2 + xH_2O$
4. *Carbonates*	
Smithsonite	$ZnCO_3$
Malachite	$CuCO_3.Cu(OH)_2$
5. *Sulphates*	
Gypsum (satin spar)	$CaSO_4.2H_2O$
6. *Aluminates*	
Spinel	$Mg(AlO_2)_2$
Chrysoberyl	$Be(AlO_2)_2$
7. *Phosphates*	
Turquois	$H_5[Al(OH)_2]_6Cu(OH)(PO_4)_4$
Apatite	$Ca_5(F, Cl)(PO_4)_3$
8. *Silicates*	
Beryl (emerald)	$Be_3Al_2(SiO_3)_6$
Orthoclase (moonstone)	$KAlSi_3O_8$
Garnet	$M_3''M_2'''(SiO_4)_3$ (M'' = Mg, Ca, Fe, or Mn; M''' = Al, Fe, or Cr).

The above are all of inorganic character. Certain substances, which are used to some extent as gems, such as jet, amber, pearl, and coral, are of organic nature, having been formed through the agency of live organisms.

CHAPTER VI

FORMATION AND OCCURRENCE OF GEM MINERALS

Formation of Gem Minerals.—There are three important modes of formation of precious stones. These are: (1) formation from solution; (2) from fusion; and (3) by metamorphic processes.

Formation from Solution.—This is illustrated by the crystallization of salt due to the evaporation of sea water. The loss of gases acting as solvents also causes the deposition of minerals from solutions. An example is the precipitation of calcite, $CaCO_3$, by the loss of CO_2 from calcium bicarbonate solutions. Still other ways in which minerals may be formed from solution are: changes in the temperature of the solution or in the pressure to which it is subjected, *e.g.*, vein quartz; interaction of two or more solutions, *e.g.*, calcite formed by the interaction of calcium sulphate and sodium carbonate solutions; interaction of solutions and solids, *e.g.*, smithsonite ($ZnCO_3$), formed by the interaction of zinc sulphate solutions with limestone: and interaction of gases with solutions, *e.g.*, pyrite (FeS_2) formed by the action of hydrogen sulphide on iron-bearing solutions. Furthermore, certain organisms are able to secrete mineral substances or to precipitate them from solution. Calcite and some forms of quartz are deposited in this way. Examples of gem minerals derived from solutions in one or another of the ways mentioned above are gypsum, malachite, quartz, and opal.

Formation from Fusion.—Igneous rocks (p. 66) are formed by the solidification of molten magmas of rather complex composition. During the solidification of the magma various minerals separate out one after another. In general, the slower the cooling of the mass the larger are the crystals which are formed. *Mineralizers*, which include water vapor and other gases, are also important in influencing the size and character of the crystals formed. Gem minerals are usually only minor constituents of igneous rocks. Among the precious stones formed as the result of fusion are diamond, emerald, sapphire, topaz, and tourmaline.

Formation by Metamorphic Processes.—The action of heat, pressure, and moisture upon rocks produces marked changes in their character and mineral composition. The intrusion of igneous masses often causes profound changes in the surrounding rocks, due to the action of the heat and gases emanating from the igneous body. This is called *contact metamorphism.* Shales and limestones are especially susceptible to alteration by this type of metamorphism. Emerald, cyanite, andalusite, spinel, and staurolite are commonly the result of contact metamorphism. Mountain-making processes, largely dependent for their effectiveness upon pressure, cause the metamorphism of very large areas of rocks. This is known as *regional metamorphism.* Among gems formed in this way are epidote, garnet, and vesuvianite.

Fig. 98.—Beryl: variety, emerald. Bogota, Colombia.

Fig. 99.—Titanite. Arendal, Norway

Fig. 100.—Attached crystal of diopside. Ala, Italy.

Occurrence of Gems.—Gem minerals may either be *disseminated* through other minerals or rocks (Figs. 98 and 99) or they may be found as *attached crystals* (Fig. 100). Disseminated minerals sometimes are well crystallized, though more often they are of irregular shape. Garnet, beryl, and diamond are commonly found disseminated. Attached crystals are usually *singly terminated* (Fig. 100), while the disseminated crystals may be *doubly terminated*, having well-developed faces at both ends of the crystal (Fig. 99).

FIG. 101.—Vein of serpentine.

FIG. 102.—Banded vein of sphalerite (dark), fluorite, and calcite.

A *vein* is a crack or crevice filled with mineral matter (Fig. 101). A rock crevice becomes a vein by the gradual deposition within it of one or more minerals, usually from solutions. If the composition of the solution changes from time to time, different minerals may be deposited in the same vein, giving it a *banded* appearance (Fig. 102). Veins may be either *symmetrically* (Fig. 102) or *unsymmetrically* banded. In the former case the same minerals appear in the same relative positions on both sides of the vein. The valueless portions of veins are spoken of as the *gangue*, as, for example, the quartz in gold-bearing quartz veins. The solutions commonly involved in the filling of veins may be either *descending* solutions, which have obtained their mineral matter by leaching out the more soluble constituents of the overlying rocks; or hot *ascending* solutions, whose mineral content has come from igneous masses or other deeply buried rocks. Mineralization by solutions which have traveled in a *lateral* direction may also occur.

Geodes are cavities lined with minerals, often well crystallized (Fig. 103). These cavities may be large enough to be called caves. They were once filled with a solution, from which the mineral matter slowly crystallized out. Quartz crystals, agate, and opal commonly form geodes.

The occurrences of gems are classified in still another way. If the minerals are found in the place in which they were originally formed, they are said to occur *in situ,* meaning "in place." Beryl and tourmaline in pegmatites are examples of the *in situ* type of occurrence. Quite often gems have been weathered out of the mother rock, and washed down into the valleys by rains. The streams carry them away, and by being constantly rolled about in the stream bed the stones become worn and rounded. When the load of material being transported by the stream exceeds its carrying power, the heavier minerals are naturally the first to be dropped. As gem minerals generally have a comparatively high specific gravity, they are unloaded by the stream along with gold, the ores of iron and tin, and other heavy minerals. In this way, by natural processes, the valuable gems are sorted out and segregated in heavy sands and gravels. The deposits so formed may often be profitably worked. They are known as *placer* or *secondary deposits.* The first South African diamonds were found in placers, that is, in the stream beds of the Vaal and Modder Rivers. Rubies and sapphires also frequently occur in such deposits.

FIG. 103.—Geode of calcite crystals.

Rocks.—The rocks of the earth's crust may be classified as: (1) igneous; (2) sedimentary; and (3) metamorphic rocks.

Igneous Rocks.—As mentioned previously (p. 63) igneous rocks are formed by the solidification of molten magmas, which are solutions of mineral matter with a complex composition. The melting point of these magmas is usually high. The minerals found in igneous rocks are of two types: *essential* minerals, which make up the larger part of the rock; and *accessory* or minor minerals, including gems and ores. Igneous rocks may reach the surface through volcanic vents. They are then called *volcanic* or *extrusive* rocks. Not many gems are found in these rocks. Having cooled rapidly on the surface of the earth, their texture is glassy, cellular, or very fine grained. Igneous bodies, which have solidified at depth, have cooled slowly, and are therefore coarse and fairly well crystallized. They are known as *plutonic* or *intrusive* rocks. Most of the gems found in igneous rocks occur in those which are plutonic.

Igneous rocks may be subdivided in another way, that is, on the basis of the mineral and chemical composition. One group is characterized by a high content of silica, and contains orthoclase feldspar, more or less quartz, and a small amount of some dark-colored mineral. Rocks of this group are generally light colored. They are referred to as *acid rocks.* Rocks of the other group contain less silica, with plagioclase feldspar, no quartz, and a large amount of dark minerals. These are usually dark in color, and are called *basic rocks.* It must be pointed out here that rocks intergrade gradually and completely. The distinctions between rocks are by no means as hard and fast as those between minerals.

The acid rocks include granites, syenites, and pegmatites, as well as other types of less importance. The very coarse and well-crystallized rocks known as pegmatites are important because of the gem minerals they frequently carry. Beryl, tourmaline, several forms of quartz (such as rock crystal, smoky and rose quartz, and amethyst), spodumene, topaz, and a great variety of other gems often occur in this kind of rock. Pegmatites are the segregations of the most soluble constituents of granites. Before solidification they contained large amounts of vapors and gases, which aided in the formation of the good crystals so characteristic of this type of rock. Pegmatites frequently occur in *dikes*, which are fissures filled with igneous intrusions.

The basic igneous rocks include diorite, gabbro, peridotite, and pyroxenite. Peridotites are extremely important as the original source of the diamond.

Sedimentary rocks are those which are characterized by a stratified or bedded structure, and have been laid down, generally by water. The materials of which they are composed have been derived from older igneous, metamorphic, or sedimentary rocks by the process of weathering and transportation. Sedimentary rocks are divided into: (1) mechanical; (2) chemical; and (3) organic sediments.

The *mechanical sediments* are those which have been deposited from bodies of water by settling due to gravity. The particles were not dissolved in the water, but were mechanically suspended. Some examples of mechanical sediments are: *shales*, composed of consolidated mud or silt; *sandstone*, made up of sand grains; and *conglomerates* and *breccias*, composed of rounded or angular fragments in a finer ground mass. *Chemical sediments* include some limestones, gypsum, and salt, all of which were deposited from solution by chemical means. The *organic sediments* are composed of the remains of animals or plants, and include limestones, dolomites, or magnesian limestones, and coal. Few gems are found in the sedimentary rocks, except occasionally in veins traversing them. In these veins such gem minerals as opal, quartz, gypsum, and emerald may be found.

Metamorphic rocks are formed from igneous or sedimentary rocks by the action of heat, pressure, and moisture, commonly at depths. As explained on page 64 there are two types of metamorphism, *regional* and *contact*. The more important metamorphic rocks are: *gneisses*, banded rocks derived from igneous rocks; *schists*, finely laminated, with a good cleavage, and made up chiefly of one mineral, such as mica, hornblende, talc, or chlorite; *quartzite*, a very firm and compact metamorphosed sandstone; *slate*, derived from shale, and possessing an excellent cleavage into large, flat sheets; *marble*, which is recrystallized limestone or dolomite; and *serpentine*, a soft, green rock, formed by the metamorphism of basic igneous rocks or impure dolomitic limestones. Metamorphic rocks are of little importance as gem bearers. Lapis lazuli, ruby, sapphire, and spinel occur in marbles. Schists and gneisses frequently contain chrysoberyl, emerald, garnet, jadeite, nephrite, tiger's eye, and others.

Statistics of Production and Occurrence.[1]—Normally about eighty million dollars worth of rough precious stones are mined yearly. Of this sum, 94 per cent represents the value of the uncut diamonds produced. The value of the annual production of the most popular precious stones is given in the table on page 69.

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[1] Adapted from Ball, S. H., "The Geologic and Geographic Occurrence of Precious Stones," *Economic Geology*, vol. 17, pp. 575–601, 1922.

Diamonds	$76,112,000
Sapphire	1,210,000
Amber	800,000
Emerald	550,000
Ruby	365,000
Jadeite	294,000
Turquois	290,000
Opal	209,000
Rock crystal	110,000
Beryl	100,000
Tourmaline	90,000
Other gems	566,000
Total	$80,696,000

Because it is the principal source of the diamond, South Africa yields seven-eighths of the world's gems, by value. Other gem-mining countries, in order of importance, are: Belgian Congo, Portugese West Africa, Brazil, Siam, Germany, Burma, and Colombia. In each country the value of the annual production exceeds $500,000. Figure 104 represents graphically the production by countries. The map (Fig. 105) on page 70 indicates the geographic sources of the more important gem minerals.

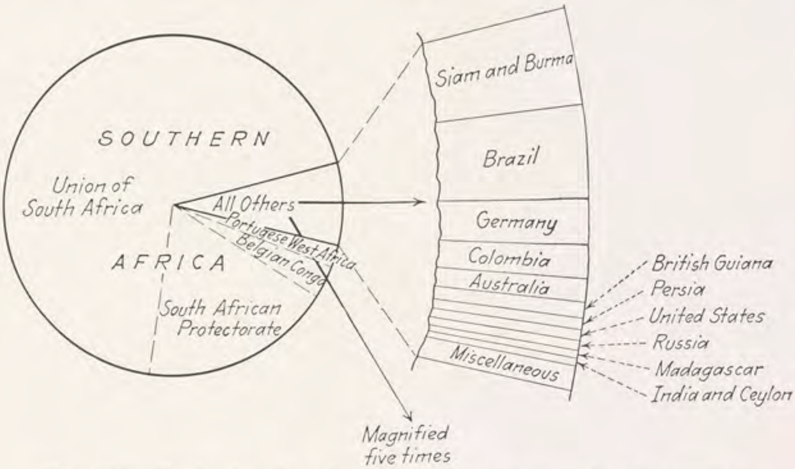

FIG. 104.—Production, by value, of gem minerals according to countries.

In the table on page 71 the production by continents is given (1) for all precious stones, and (2) for all gems other than the diamond:

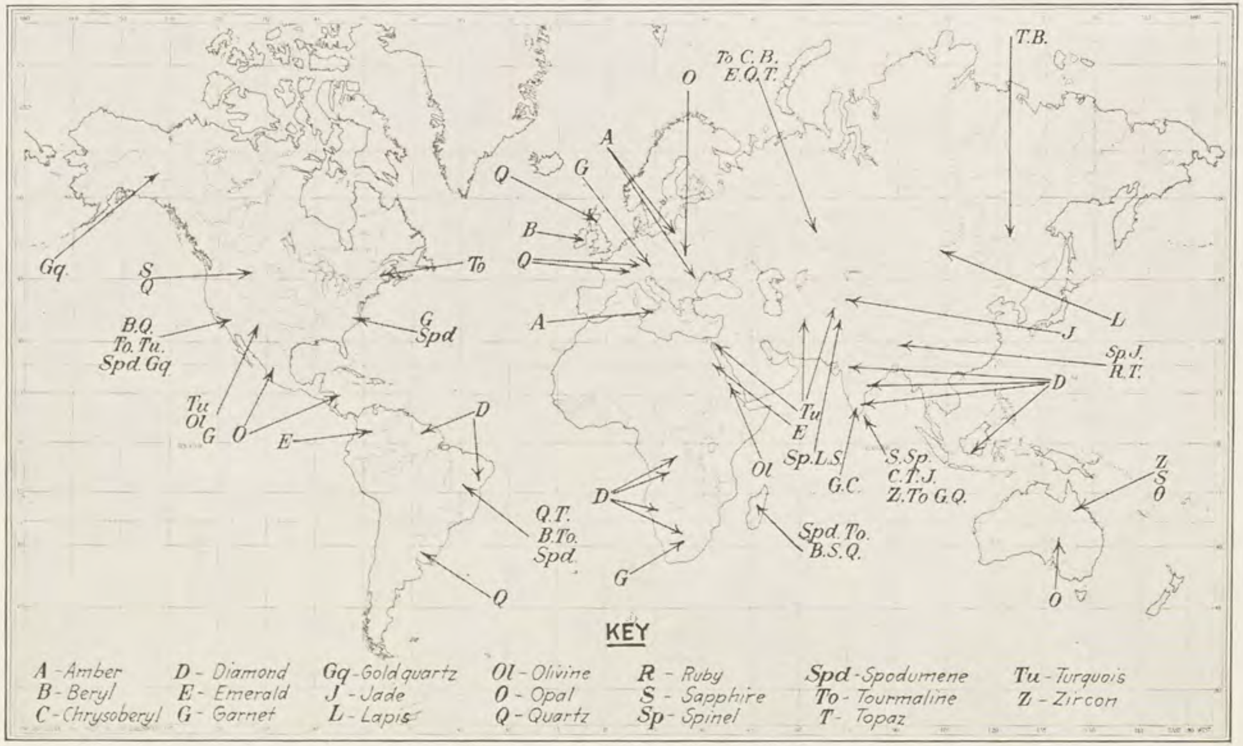

FIG. 105.—Geographical distribution of the more important gem minerals.

Production of Precious Stones by Continents

	Production of all precious stones		Production of precious stones exclusive of the diamond
Africa	$74,653,500 or	92.5 per cent	$ 196,500
South America	2,270,000	2.8	654,000
Asia	2,123,000	2.6	2,072,000
Europe	1,094,500	1.3	1,094,500
Australia	360,000	0.4	353,000
North America	195,000	0.3	192,500

According to Merrill,[1] in the United States approximately $169,000 worth of gems are mined per year. The annual production of the following stones in this country exceeds $10,000: corundum, quartz, turquois, and tourmaline. Other important gems are beryl, malachite, azurite, chrysocolla, diamond, garnet, opal, olivine, spodumene, topaz, variscite, and vesuvianite.

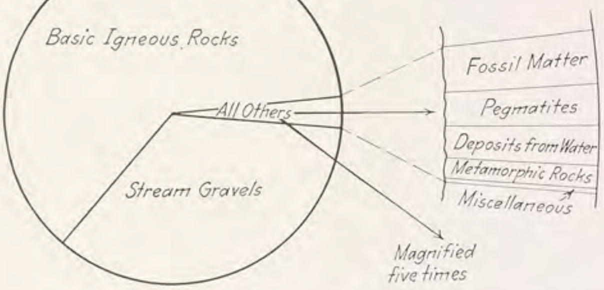

Fig. 106.—Relative importance of the various geological sources of gem minerals.

The table on page 72 and Fig. 106 show the comparative value of the gems obtained from the more important geologic sources. The great value of the diamond production makes the basic igneous rocks the principal source of gem minerals. Next in importance among the geologic sources are the stream gravels. This is due to several factors. One of these is the ease with which gem minerals may be recovered from placer deposits, with no danger of fracturing them by blasting. Furthermore, precious

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[1] Merrill, George P., *et al.* "Handbook of Gems and Precious Stones." *U. S. Nat. Museum Bull.* **118,** 1922.

stones obtained from gravels are usually of better quality than those recovered directly from the rocks in which they were formed. For, during their transportation by streams, such minerals are very likely to break along planes of weakness, which may be due to incipient fractures or to inclusions. The fragments thus formed are very apt to be free from flaws. South African river diamonds sometimes bring twice the price of those obtained directly from the peridotite. Pegmatites, especially those rich in sodium and lithium, are a third important source of gem minerals.

APPROXIMATE ANNUAL VALUE OF PRECIOUS STONES CONSIDERED AS TO GEOLOGIC SOURCE

Igneous rocks			$50,785,000
Basic rocks		$50,029,000	
Diamonds	$50,000,000		
Other gems	29,000		
Pegmatites		662,000	
Emerald	520,000		
Beryl	46,000		
Tourmaline	35,000		
Other gems	61,000		
Other Igneous rocks		94,000	
Secondary deposits			28,209,000
Stream gravels		28,199,300	
Diamond	26,112,500		
Sapphire	1,104,000		
Ruby	348,500		
Jadeite	144,000		
Rock crystal	88,000		
Tourmaline	54,000		
Beryl	54,000		
Agate	53,000		
Chrysoberyl	44,000		
Amethyst	40,000		
Other gems	157,300		
Beach and desert gravels, glacial deposits		9,700	
Fossil matter			825,000
Amber	800,000		
Other gems	25,000		
Deposits from water			595,000
Hot waters, principally ascending		289,000	
Opal	208,500		
Quartz	46,000		
Other gems	34,500		

Cold waters, principally descending		$306,000	
Turquois	$290,000		
Other gems	16,000		
Metamorphic rocks			$282,000
Contact metamorphosed limestones		56,500	
Lapis lazuli	37,500		
Other gems	19,000		
Contact metamorphosed schists and gneisses		175,500	
Jadeite	150,000		
Other gems	25,500		
Regionally metamorphosed schists and gneisses		50,000	
Nephrite	30,000		
Other gems	20,000		
Grand total			$80,696,000

CHAPTER VII

CUTTING AND POLISHING OF GEMS

Beautiful as some gems are in their natural form, they may all be much improved by judicious cutting and polishing. It frequently happens that only a small portion of the gem crystal is transparent, flawless, and of good color. Even if the entire crystal is of gem quality, its value may be greatly enhanced by the proper cutting of facets, so disposed as to bring out most effectively its color, fire, and brilliancy. At the same time an endeavor is made to produce a symmetrical stone, with an outline pleasing to the eye.

Cabochon Cuts.—Before the art of gem cutting was well developed, the naturally occurring gem minerals were smoothed or rounded off, and polished, by crude methods. Prismatic crystals of emerald were often drilled and suspended as drops. Perforated beads of gem minerals were fashioned at an early date. The old, rounded forms of cutting still survive in the various types of *cabochon* cuts. These include the double or convex cabochon, the lentil cut, high cabochon, simple, plain, or single cabochon, and hollow or concavo-convexo cabochon. The outline of gems cut in any of the above cabochon styles may be circular, elliptical, or oval, as one looks down upon the stone.


FIG. 107.


FIG. 108.


FIG. 109.

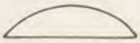
FIG. 110.

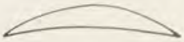
FIG. 111.

In the *double cabochon* cut (Fig. 107) both the upper and lower parts of the stone are convex, though the curvature of the upper side is the greater. If both sides have the same convexity the cut is known as the *lentil* (Fig. 108). The *high cabochon* (Fig. 109) is another modification of the double cabochon, with the upper portion very high. The *simple cabochon* style has a flat, lower surface, which is mounted as the under side of the stone (Fig. 110). In the *hollow cabochon* cut the lower surface is hollowed out, being concave, while the upper side is convex (Fig. 111).

The cabochon cuts are especially desirable for use with gems which have a sheen, such as tiger's eye; a play of colors, as in opal; opalescence, as in moonstone; or asterism, as shown by star rubies and sapphires. Stones whose charm depends upon their color or upon peculiar mottlings or markings are also cut in this way; garnet, turquois, tourmaline, chlorastrolite, and thomsonite being examples. Some stones, as for example the dark garnets, are so deeply colored that they appear almost black when cut in the ordinary way. For such gems the hollow cabochon cut may be used to considerable advantage, for the thickness of the stone is thereby so reduced that the true hue may be seen.

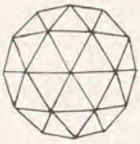
FIG. 112.

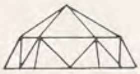
FIG. 113.

Faceted Cuts.—It is generally believed that Louis de Berquen of Bruges, whose name is variously given in different languages as Ludwig von Berquen or Ludwig van Berquen, first made use of faceted cuts in the latter part of the fifteenth century. The date is given by various authorities as between 1456 and 1476.

The original *table cut* was much used for the diamond. The upper and lower points of a natural octahedral crystal were smoothed off and polished; the upper facet, known as the *table*, being much wider than the lower facet, called the *culet*.

The *rose cut* was then developed, and was much employed in the cutting of the diamond. It is not used to any great extent at present except for small stones. The rose cut has a flat base, while triangular facets to the number of twelve to twenty-four, or even thirty-two, terminating in a point, are grouped about the upper part of the stone (Figs. 112 and 113). Stones cut with few facets (twelve or less) are called "roses d'Anvers" and are a specialty at Antwerp, while those with more facets are known as "roses couronnées." The outline of these stones may be circular, elliptical, or oval. Sometimes a *double-rose cut* is used. It consists of an upper and lower portion, each of which has the rose cut.

About the end of the seventeenth century the *brilliant cut* was developed. It is now almost always used for the diamond, since it brings out to the best advantage the remarkable fire and brilliancy of that gem. The octahedron, either natural or the result of cleavage, may be made the basis of this cut (Fig. 114). As indicated in the figure, five-eighteenths of the height of the stone is removed from the upper point, and one-eighteenth from the lower. This results in a form in which the portion above the girdle, *G* in Fig. 115, is half as thick as that below the girdle. The upper portion of the stone is called the *crown* or *bizet*, the lower part, the *pavilion* or *base*. The uppermost facet *T* is the *table*, and *C* is the *culet* (Figs. 115 and 116). Exclusive of the table and culet there are usually fifty-six facets, though in some cases the number is increased by groups of eight to sixty-four, seventy-two, or even eighty facets. All the facets of a brilliant have definite names. According to Andreis Meyer,[1] the fifty-eight facets of the usual brilliant (Fig. 115) include one table *T*; eight star facets *S*; four bezel or top main facets *B*; four top corner facets *TC*; sixteen top half or break facets *TH*; sixteen bottom half or break facets *BH*; four bottom corner facets *BC*; four pavilion or bottom main facets *P*; and one culet *C*.

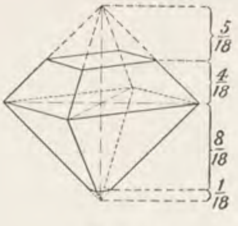

Fig. 114.

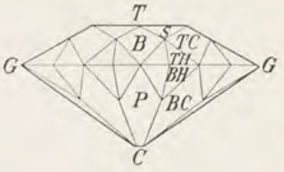

Fig. 115.

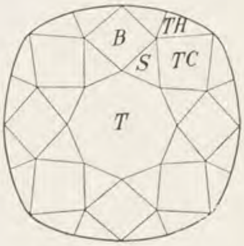

Fig. 116.

In order to exhibit the properties of the diamond to the best advantage certain definite proportions must be observed in the cutting of the stone. The width of the table should be four-ninths of the diameter of the stone at the girdle. Figure 117

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[1] President of the Diamond Workers' Protective Union of America, New York.

illustrates the course of rays of light in passing through a brilliant-cut diamond. If the proportions given above have been observed, and the facets have been cut with the proper angular relationships, the greatest brilliancy and fire will be produced. The light, which enters mostly through the table, will then strike the lower facets at an angle greater than the critical angle, which is about 24 degrees for the diamond (p. 40), and will repeatedly undergo total reflection. When this reflected light emerges from the stone through the inclined facets of the crown, the ever-changing flashes of color known as fire are to be observed, due to the strong dispersion of the mineral (p. 37).

There are several modifications of the brilliant cut. The *double brilliant* or *Lisbon cut* has seventy-four facets. The *half brilliant, old English,* or *single* cut is a simple form used for the smaller stones. The *trap brilliant,* or *split brilliant,* has forty-two facets. The *Portuguese cut* has two rows of rhomboidal and three of triangular facets on both crown and base. In the *star cut* there is an hexagonal table bordered by six facets in the shape of equilateral triangles, forming with the table a six-rayed star. The "*twentieth century*" *cut* has eighty or eighty-eight facets. Eight very low facets are substituted for the flat table of the other brilliant cuts.

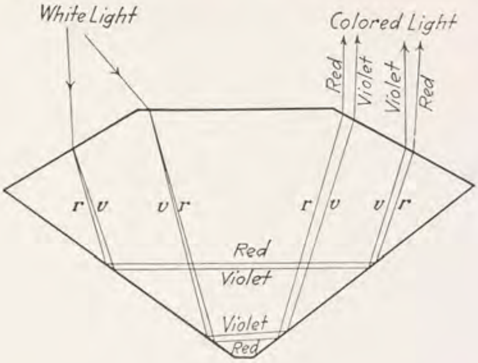

FIG. 117.

Large stones are frequently cut in unusual shapes, in order that as much of the stone as possibile may be retained. Symmetry and beauty of outline are never sacrificed for size, however. Rectangular, pear-shaped, oval, and drop-shaped cuts may be employed for the larger stones. The brilliant style is also used for stones other than the diamond, such as rubies, sapphires, and zircon. Brilliant cuts with a square girdle and relatively few facets are frequently employed for these stones.

The *step, trap*, or *cushion cut* (Figs. 118 and 119) is adapted to colored stones in which fire and brilliancy are unimportant, such as emerald, tourmaline, and so forth. The stone is cut rather flat, with one or more rows of facets arranged parallel to the girdle. A similar style, the *table cut*, differing somewhat from the older table cut (p. 75), has a very large table and culet, which join the girdle in beveled edges.

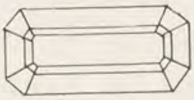

FIG. 118.

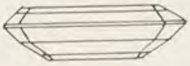

FIG. 119.

FIG. 120.

Cameo.—The term *cameo* is used to designate those stones generally composed of two differently colored layers, in one of which a raised figure or design has been cut, while the layer of the second color forms a background (Fig. 120). Cameos are cut principally from onyx, a variety of quartz having horizontal bands of different colors. Shells with a similarly banded structure are also employed. These are termed *shell cameos*. When a design is engraved in the surface of a gem, the stone is called an *intaglio* (Fig. 121).

FIG. 121.

Cutting of Gems.—Because of its superior hardness, the cutting of the diamond presents a difficult problem, and *diamond cutters* form an aristocracy of talent among those who cut precious stones. Men who fashion stones other than the diamond are called *lapidaries*. The principal diamond-cutting centers of the world, in order of importance, with the number of men employed in the industry under normal conditions, are as follows: Antwerp, Belgium, 11,000; Amsterdam, Holland, 10,000; Saint-Claude and surrounding towns, France, 1,500; New York, 500; Hanau, Germany, 400; Idar, Germany, 300; Erbach, Germany, 150; Paris, France, 200; Geneva, Switzerland, 100; Bienne, Switzerland, 80; London, England, 30. There are 70 shops in Antwerp, 50 in Amsterdam, and 30 in and near Saint-Claude. A few men are employed in Birmingham, England; Genoa, Italy; Cincinnati, Boston, and Chicago, United States; Rio de Janeiro, Brazil; Johannesburg and Pretoria, South Africa.[1]

Agates are cut and polished principally in Germany, at Idar and Oberstein, where there is abundant water power. Much fine lapidary work is done in Russia, largely in the fashioning of ornamental objects. In China and Japan crystal balls of quartz are laboriously cut and polished by hand. These are now produced by means of mechanical devices in other countries.

FIG. 122.—Diamond cleaver.[2]

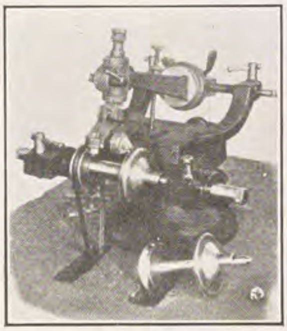

FIG. 123.—Diamond sawing machine.

Diamond Cutting.—The process of diamond cutting may be divided into three stages: (1) cleaving; (2) cutting; and (3) polishing.

The diamond possesses an excellent octahedral cleavage. By means of this cleavage flaws may be removed from the stone, which at the same time may be suitably shaped for advantageous cutting. Figure 122 is an illustration of a diamond cleaver at work. The direction of cleavage in the stone must be determined by careful examination. After it has been decided how the cleaving is to be done, the stone is notched at the proper

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[1] This information was kindly furnished by Henri Polak, of Amsterdam, Holland, president of the International Diamond Workers' Union.

[2] Figures 122 to 127, inclusive, are views taken in the diamond cutting works of Messrs. Stern Brothers and Company, New York.

point with another diamond. The diamond to be cleaved is then placed upon a support, and a dull steel or iron edge is inserted in the notch. The steel edge is struck a sharp blow, causing the stone to part. While this is apparently a simple process, cleaving in reality exacts the most careful workmanship, since a good diamond may easily be ruined by improper cleaving or careless handling.

Sawing is now largely used in the rough fashioning of the stone. The diamond is embedded in a metal cup-like holder by means of a solder. It is then held against the edge of a thin, rapidly revolving bronze disc, the margin of which is impregnated with diamond dust and oil (Figs. 123 and 124).

Fig. 124.—Diamond sawing room.

After the diamond has been cleaved into an approximately octahedral shape, the apexes of the octahedron must be removed. Formerly this was done by the method known as *bruting*. Two diamonds are mounted at the ends of sticks or holders, and are then rubbed together by hand over a box in which the powder is collected. This powder may later be used in the sawing and polishing processes. In this way facets are gradually ground upon the stone. Now sawing is often employed for this part of the work. It is much faster, and furthermore the removed portion of the stone may be used as a chip diamond, while it would have been ground to powder by bruting.

The facets are next ground upon the stone, either by bruting, or mechanically (Fig. 125). After the rough cutting has been performed, and the stone has begun to take its shape, the polishing, with further cutting, must be done (Figs. 126 and 127). A small, basin-like holder known as the *dop* is filled with an easily fused

FIG. 125.—Diamond cutters.

FIG. 126.—Diamond polisher.

alloy of tin and lead. This is melted, and while still hot, it is fashioned into a hemispherical mound over the dop. The diamond to be polished is mounted in the semi-molten metal near the summit of the mound, in which it is firmly held when the alloy has cooled. Only a few facets are exposed for polishing at one time, so that frequent remountings are necessary.

Diamonds are polished by being firmly held against a rapidly revolving horizontal wheel of porous cast iron known as the *skeif*. This makes about 2,500 revolutions per minute. Diamond dust mixed with olive oil is fed upon the wheel as the polishing medium. The dust is prepared from fragments of poor diamonds, known as *bortz,* together with diamond powder and chips from other operations. Usually four dops are handled on one skeif at a time. They must be frequently removed and plunged into cold water in order to prevent the alloy from melting and thus allowing the stone to be loosened. The facets must be precisely cut at a given angle, to obtain the best effect (p. 77). Gauges are used as an aid in estimating the proper inclination between the facets (Fig. 128).

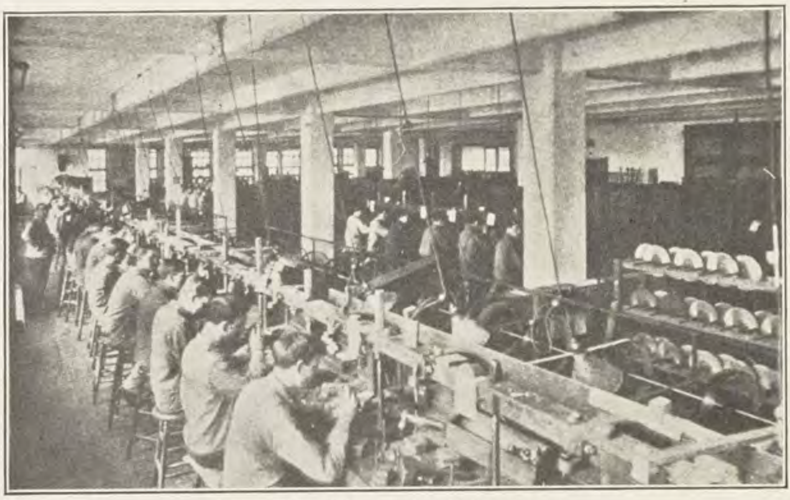

FIG. 127.—Diamond polishing room.

Semi-automatic machines for the polishing of diamonds have recently been devised. The Stern-Coleman machine (Figs. 129 and 130), used in the establishment of Messrs. Stern Brothers and Company, New York, comprises ingenious mechanical devices

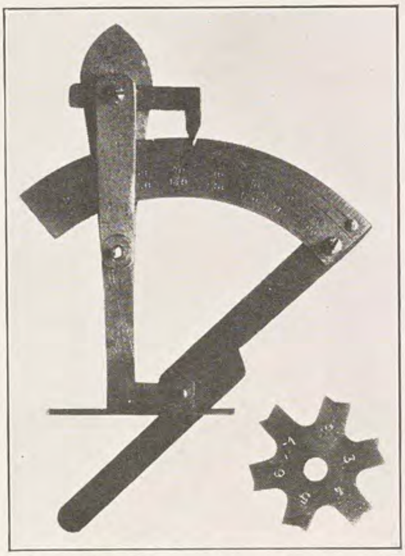

FIG. 128.—Diamond cutter's gauges.[1]

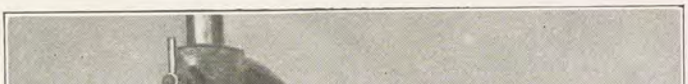

FIG. 129.—Stern-Coleman diamond polishing machine.[2]

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[1] Courtesy of Messrs. Fera and Kadison, diamond cutters, New York.

[2] Figures 129 and 130 by courtesy of Messrs. Stern Brothers and Company, diamond cutters, New York.

consisting of a micrometer guage and a degree finder in combination with a tripping device. The angles and planes to be polished on the diamond are predetermined and the machine is set by the operator. When the desired depth and angle of the stone is polished away, the tripping device automatically removes the stone from the polishing lap. This is accurate and economical.

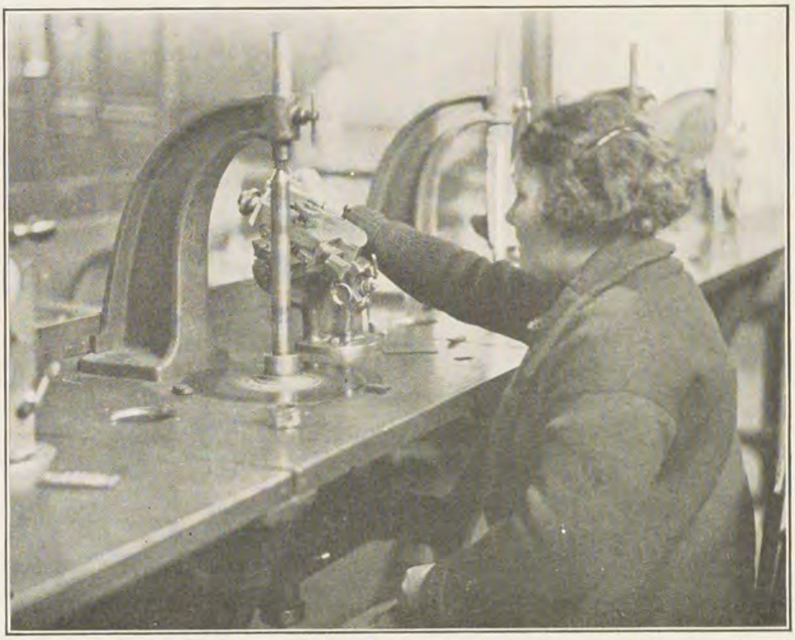


FIG. 130.—Operating a Stern-Coleman diamond polishing machine.

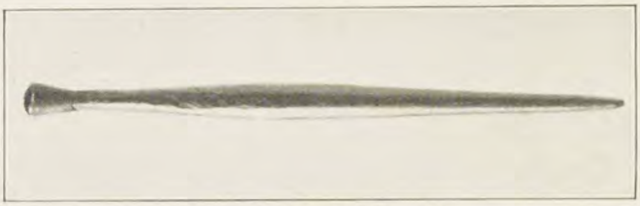


FIG. 131.—Lapidary's stick.

One attendant can operate several machines at a time, and it is claimed that the highest technical skill is no longer required.

In the cutting of a diamond approximately one-half of the rough stone is lost. This naturally increases the value of the finished stone. An unwise attempt to save a large part of the stone may result in an ill-proportioned cut and consequently a great decrease in the value of the gem.

Cutting of Other Gems.—The work of the lapidary (p. 78) is less arduous than that of the diamond cutter, since he handles softer and more easily worked stones. The stones may be divided or *slitted* by means of a rapidly revolving wheel impregnated with diamond dust. The polishing is done on horizontal wheels, *laps*, fed with diamond dust or other abrasives. The gem is mounted upon a wooden stick, in size and shape much like a penholder (Figs. 131 and 132). The stone is first roughly fashioned, after which the facets are polished. An upright is often placed at one side of the lap. In it a series of holes has been bored, into which the end of the holder may be inserted in order that the stone may be held against the lap at the proper angle.

FIG. 132.—Top view of lapidary's stick.

In the cutting of agates at Idar and Oberstein use is made of large wheels resembling grindstones, driven by water power. The operator rests part of his weight upon the larger agates, in order to obtain the requisite pressure for the cutting. The polishing is done on wooden wheels with tripoli or emery powder.

Size and Weight of Gems.—Gems are sold by weight, the unit of weight being the *carat*. The value of a gem mineral, per carat, increases rapidly with weight. Unfortunately it was not until recently that the carat was standardized. Originally grains or leguminous seeds were used as units of weight for gems, and naturally they were not of uniform size. Even in recent times the weight of the carat varied in the different gem centers. In London, the carat was taken as 0.2053 grams; in Florence, 0.1972; Madras, 0.2073; Amsterdam, 0.2057, and so on. In 1871 an attempt was made to establish as the standard the "international carat" of 0.2050 grams. More recently the *metric carat* of 0.2000 grams was proposed. This is now the recognized standard in the principal countries of the world, including Great Britain, Belgium, France, Germany, and Holland. It was adopted by the United States in 1913.

Before the introduction of the metric carat, the weight of a gem was expressed by a series of fractions, such as 2, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{16}$, and $\frac{1}{64}$ carats. In the metric system this weight so clumsily expressed by the older method, is simplified to 2.828 carats, the sum of the fractional parts of a carat being indicated by the more convenient decimals.

The application of the term "carat" as a unit of weight must not be confused with its use in indicating fineness or purity of metals in which gems are mounted. In this latter connection a carat means one twenty-fourth part. Thus, a pure metal is said to be 24 carats fine. The amount of baser metal alloyed with a precious metal is indicated by a proportional decrease in the number of carats fineness. That is, 18-carat gold is eighteen twenty-fourths gold and six twenty-fourths base metal, while 12-carat gold is twelve twenty-fourths or half gold.

CHAPTER VIII

THE NAMING OF GEMS

Many of the popular names of gems are a heritage, having been in use long before mineralogy was developed as a science. They do not conform to the modern technical usage. But they are firmly established and it would be quite impossible to replace them in a short time with the more accurate scientific names. Among these older names may be cited for illustration: agate, from the Greek; amber, Arabic; amethyst, Greek, the name meaning "without drunkenness," since the stone was regarded as a remedy for intoxication; beryl, Greek, probably from the Sanskrit originally; diamond and emerald, Greek; garnet, Latin; jade, Spanish; opal, Sanskrit; quartz, German; ruby, Latin; sapphire, Oriental; and turquois, French.

The names now given to minerals end in *-ite*. Among these names are azurite, chrysolite, fluorite, malachite, smithsonite, and vesuvianite. It is interesting to note that the names of the majority of gem minerals are of the old form, especially those which are the most precious. This indicates that they were known at an early date. On the other hand, minerals not especially valuable as gems usually have the ending -ite, significant of their relatively recent recognition.

Considerable ambiguity has been occasioned by the use of the popular gem names by jewelers, simultaneously with the employment of the scientific nomenclature by the mineralogist. While the popular names are in some respects desirable and ought to be retained, and indeed for some minerals there are no other names, they lack the precision and accuracy of those assigned by scientists. The popular names lend themselves more readily to unscrupulous practices in the selling of gems. In order to increase its sale value a cheap stone is often sold under a name closely resembling that of a valuable gem. For instance, when some red stones are sold they are not infrequently given names which suggest to the uninformed purchaser that they are a variety of ruby. Thus, red pyrope garnets are sold under such trade names as

American ruby, Arizona ruby, California ruby, Cape ruby, Colorado ruby, Montana ruby, and Rocky Mountain ruby. Likewise red and orange spinels are called Balas ruby or rubicelle. A mineral so different from the true ruby as rose quartz is frequently offered under the name Bohemian ruby. Rose and pink topaz may be sold as Brazilian ruby, and red or pink tourmaline is called rubellite or Siberian ruby. While these stones are perfectly good in their own right and are very attractive as gems, the purchaser should know just exactly what he is buying. That knowledge is hardly likely to be his when such deceiving names are used.

Another example of this practice is the assigning to gems names of stones which are frequently better known or more valuable than the one being sold, preceded by the word "Oriental." In this way the sale value is greatly increased. For example, light green corundum is often called Oriental aquamarine. It is obvious that this ambiguity could be avoided by the use of the scientific names as accepted by the mineralogist.

CHAPTER IX

MANUFACTURED STONES

As previously indicated, gems have been used from earliest antiquity for personal adornment and ornamentation. Because many of the more precious gems are very expensive their use has obviously been limited to those able to purchase them. Hence, to satisfy the equally strong desire on the part of those financially less fortunate, various types of rather inexpensive manufactured stones are annually placed upon the market in comparatively large quantities. In this chapter some of the more important kinds of material used in this way will be described.

Manufactured stones may be classified as follows:

1. Doublets and triplets.
2. Imitation stones.
2. Treated stones.
4. Artificial or synthetic stones.

Accordingly, the term "manufactured stones" includes gem material which has been made entirely in the laboratory, as well as some natural stones which have been treated, manipulated, or "doctored" in such a way as to increase their sale value.

Doublets and Triplets.—There are two types of doublets, *true doublets* and *false doublets*. The *true doublet* (Fig. 133) consists of two sections, each of genuine material, joined with an invisible cement to produce a larger stone, the value of which would naturally be greater than the sum of the values of the two smaller pieces. The layer of cement in these doublets may be detected by immersing the stone in a liquid with an index of refraction approximately equal to that of the gem fragments. The cement is frequently soluble in alcohol or chloroform, so that when a doublet is soaked in one of these liquids the two portions may fall apart. Diamond fragments are sometimes used in making true doublets, the crown being one piece, the pavilion another. The two sections are so cut that they are cemented

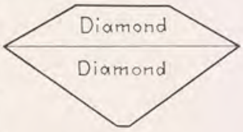


Fig. 133.

together at the girdle, which obviously makes it more difficult to recognize the true character of the stone.

The *false doublet* (Fig. 134) has a genuine crown, while the pavilion ordinarily consists of glass or of an inferior stone. For instance, a thin slice of ruby might be backed with red glass, garnet, or some other inexpensive red stone. The exposed portion, being genuine, would stand successfully the usual tests that might be made upon it. Further, a thin slice of a comparatively hard stone, such as garnet, may be used for the upper portion of the doublet, to withstand abrasion, while the lower portion may be of glass of any desired color (Fig. 135). Many gems are imitated in this way.

FIG. 134.

FIG. 135.

The character of false doublets may be detected by the methods applied in the case of true doublets. Or one may breathe upon the stone, causing a film of moisture to be formed. This permits the boundary between the two portions to be more easily seen. If the two portions of the doublet are differently colored, the character of the stone may be ascertained by holding it above a white background. In case the two parts of a doublet are fused together they naturally cannot be separated by soaking, but here the difference between the sections may be observed by immersion in a liquid whose index of refraction is approximately equal to that of one portion of the stone (Figs. 136 and 137).

FIG. 136.

FIG. 137.

Two more types of false doublets may be briefly referred to. The first consists of an upper portion of quartz or of another hard mineral, to withstand wear, and a lower portion of glass. Instead of being cemented together, the two parts are separated by a piece of foil, a colored layer, or a thin plate of colored mineral, to give the stone a desirable tint. In the *hollow doublet* (Fig. 138) the lower side of the crown is hollowed out, and a colored liquid is placed within this cavity in order to impart the desired color to the stone. These types are now of little importance, being infrequently used.

Closely related to doublets are *triplets*. The triplet has been used to imitate the emerald. A layer of green glass, usually of the type known as paste (p. 92) is cemented between two thicker layers of pale beryl or quartz (Fig. 139). The beryl gives the stone the proper hardness, while the glass contributes the green color. The upper section of beryl is of sufficient thickness to extend below the girdle, whereby the effectiveness of the deception is greatly increased. However, by means of liquids with the proper indices of refraction, this deception may be readily detected. In this way the three sections of the stone are distinctly seen.

FIG. 138.

FIG. 139.

In recent years, with the increase in the use of artificial rubies and sapphires in many colors, the demand for doublets has fallen off to a great extent. These artificial stones are, of course, much more satisfactory, and are comparatively inexpensive.

The term *imitation doublet* is sometimes applied to stones that are nothing but glass, in one piece. The purpose of this term is to enhance the sale value, since doublets consisting in part of genuine stones are naturally considered more valuable than those composed entirely of glass.

Imitations.—Imitation gems are even more valueless than doublets or triplets, for they contain no genuine material whatsoever. They are manufactured from special types of glass known as *paste* or *strass*. Paste is a dense, very transparent, and highly refractive flint glass containing a large proportion of lead, which gives it the density and refractivity. The following is an example of one of the mixtures used in making paste: 300 parts of quartz, 470 of red lead, 163 of pure potash, 22 of borax, and 1 of white arsenic. This glass may be used to imitate the diamond. If a colored stone is to be simulated, pigments must be added to the mixture. The pigments used are compounds of certain metals. Examples are the compounds of manganese, which give a purple color; of cobalt, blue; of copper, red; of iron, yellow to green; and of chromium, green and red.

In some cases these stones are very carefully cut, but often the molten glass is simply poured into properly shaped molds, and allowed to become solid. The edges of such moulded stones are rounded and dull, unless the stones are subsequently ground and polished to enhance their sale value.

Paste may be identified by the following characteristics: (1) It is *softer* than the gems for which it is substituted, being easily scratched by a file. (2) Paste is *isotropic*. (3) It has a good *conchoidal fracture*, which may usually be observed near the prongs used in mounting the stone. (4) Although great care is taken in melting the glass, *air bubbles* are usually present, which are sometimes so prominent as to be readily seen without immersing the stone in a liquid. Air bubbles are not found in natural stones. (5) The *index of refraction* of paste usually differs materially from that of the natural stone which is imitated.

In distinguishing colorless paste from the diamond, it is to be noted that the paste imitation feels warm to the touch, while the diamond, being a much better conductor of heat, has a cold feel. Because of the surface tension relationships a drop of water spreads out upon glass, but assumes a spherical shape on the diamond. This test may be applied by dipping a match stick or toothpick into water, and gently touching the surface of the stone with the drop which is taken up by the stick.

Because of their lower refractivity paste stones have not the brilliancy of the diamond, since light passes through the lower facets without experiencing total reflection. To increase the brilliancy the pavilion and culet of paste stones may be coated with mercury or tinfoil, which reflect the light impinging upon these facets.

"Goldstone" is a very common imitation of yellow or red aventurine quartz. In making this imitation copper filings are stirred into molten glass. During this process, air is entrapped, causing the formation of air bubbles, which help to reveal the true character of the goldstone. Frequently the polished surface is pitted where it has been cut through such air bubbles.

Gablonz, in Czecho-Slovakia, is the world center for glass imitations of gems. Here there are over 100 firms doing an export business. More than 12,000 people are employed in this city in manufacturing glass used in various ways for personal adornment.

Bakelite.—A condensation product of phenol and formaldehyde is upon the market as bakelite. Among other more utilitarian uses it is employed in the imitation of precious stones. It is easily colored in various hues, and is made both transparent and opaque, or with bright inclusions. Bakelite is easily worked and takes a good polish. It can therefore be used to imitate many stones. Beads of this material, in many colors and in great variety of forms, have become rather popular. The manufacturers claim the following advantages for this substance: homogeneity; an index of refraction higher than that of ordinary glass; freedom from cracking or splintering; non-inflammability; and lightness.

Treated Stones.—Treated stones consist of genuine material, which has been subjected to some process to increase its beauty and selling qualities. The processes include: (1) *artificial coloring* or *staining;* (2) *heat treatment;* (3) *radiation with radium;* and (4) *special mountings.* Examples of each of these processes will be given.

1. *Artificial Coloring or Staining.*—Agates frequently occur in pale and unattractive colors. The sale value of such stones may be greatly increased by artificial coloring. This can be accomplished by soaking the natural agate in the proper solutions, due to the fact that the different layers possess varying degrees of porosity, so that they are colored in various shades which stand out in pleasing contrast. For example, the agate may first be soaked in a solution of sugar or honey, followed by a treatment with sulphuric acid solutions. The acid chars the sugar taken up by the agate, coloring the more porous layers in different shades of brown and black, while the denser layers remain grayish or white.

Treatment of agates with hydrochloric acid produces a lemon-yellow color. Another method is staining with a solution of ferrous sulphate, which is converted to ferric oxide by heating, giving the stone a reddish color. Treatment with solutions of chromium and nickel stains some layers of the stone green. The action of a solution of ferrous sulphate upon an agate previously soaked in potassium ferrocyanide brings about a deep blue coloring of the more porous layers. Organic dyes, and solutions of other colored inorganic salts, may also be used. It is nearly always safe to assume that agates with vivid colors have been treated in one of the above ways (Fig. 140).

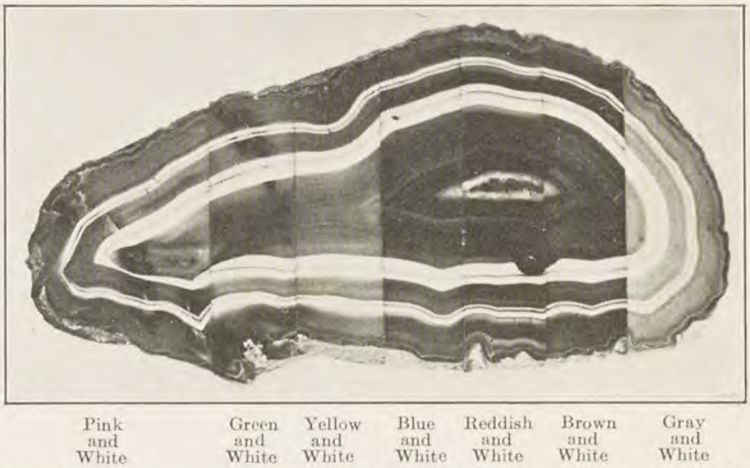


Fig. 140.—Agate, naturally gray and white, cut into seven sections, six of which have been variously colored artificially, at Oberstein, Germany.

Artificial coloring sometimes makes possible the substitution of one stone for another. Thus, lapis lazuli (p. 179), an attractive blue stone which is rather popular for decorative purposes, may be imitated by staining cracked quartz. This blue imitation is known as "Swiss lapis." The color of turquois and opal is sometimes artificially intensified in order to enhance the value.

2. *Heat Treatment.*—In other cases an unattractive color may be improved by heat treatment. In the process known as "pinking," yellow topaz is gently heated. This causes the color to change from yellow to an attractive pink. The stone to be pinked is packed in asbestos or magnesia and carefully brought to

a low red heat. It is then slowly cooled. The temperature to be attained is rather definite, lying between 500 and 600°C. With too low a temperature the stone becomes salmon colored, while if the heat is too great the color is lost entirely.

"Spanish topaz" is the dark brown variety of smoky quartz which has been subjected to heat treatment, by means of which it changes to a yellow or amber color. In the same way zircon can be made colorless by being heated, and having a high index of refraction it may then be used to imitate the diamond. Heat treatment may be applied to improve the color of streaky rubies, and to render yellow sapphire colorless.

3. *Radiation with Radium.*—Treatment with radium often improves the color of yellowish diamonds, causing them to whiten. With long-continued, direct radiation of the diamond by means of radium, colorless stones become green, and artificial "carbon spots" may be produced. Colorless and rose quartz become smoky brown after such treatment, and the original color of heat-decolorized smoky quartz and amethyst may be restored by the action of radium. The colors produced by radium are not always permanent, especially if subjected to moderate temperatures.

4. *Special Mountings.*—Cases are on record in which yellowish diamonds were given a thin coat of a blue dye in order to neutralize their natural yellow tint. Being soluble in alcohol, the dye could easily be removed. Color may also be improved by mounting stones over stained foils or colored enamels.

All types of treated stones are deceptions, even though the material of which they are composed may be essentially genuine. For this reason, they are much less esteemed than untreated stones.

Artificial Stones.—Aside from the fact that artificial or synthetic stones are made in the laboratory, they are in other respects essentially the same as the natural stones. The elements composing these artificial stones are combined by chemical processes. A synthetic ruby, for example, consists of Al_2O_3 just as does the natural ruby. Besides having the same chemical composition, synthetics have the same physical properties as natural stones. The hardness, specific gravity, cleavage, index of refraction, and so on, are identical in artificial and natural gems. But the process by which they are made usually causes the development within the stones of certain incidental and characterizing features which may be used for purposes of identification.

In the development of the manufacture of artificial gems, one of the earliest attempts consisted of fusing together fragments of the natural material. The larger stones, produced in this way, were called *reconstructed gems.* This process was applied to the ruby, especially. The stones made in this way were not clear, and were poor in color, and often brittle. Later, in 1895, Michaud succeeded better, and his reconstructed rubies found a market in France, Germany, America, and India. It is suspected that in India some of the reconstructed rubies were mixed with the natural gems and sold as such. In Michaud's process a fairly large fragment of natural ruby was placed in a revolving platinum crucible and heated to about 1800°C. Smaller chips were added from time to time, and were fused to the original fragment. In this way stones of fairly large sizes were obtained, even though the product would sometimes burst asunder. Reconstructed rubies are no longer manufactured, but have been displaced by the more successful artificial stones described on pages 97 to 104.

The term *scientific gem* is sometimes heard. It is often applied to an artificial product which is substituted for the natural gem, but it may be very different in composition. "Scientific emeralds," for instance, are nothing more than green lead glass or paste imitations.

Artificial Diamonds.—Because of its great value, many attempts have been made to produce the diamond in the laboratory. The process generally followed is to dissolve some form of carbon in a suitable solvent, and then to allow it to crystallize out. Of the many attempts, perhaps those of Moissan and of Noble and Crookes are most worthy of a brief description.

Moissan was able to produce artificial diamonds of microscopic size by dissolving carbon, prepared by the ignition of sugar, in molten iron, and suddenly cooling the mass. The iron was melted in an electric furnace by means of a current of 700 amperes and 40 volts. The temperature attained was about 4000°C. At this temperature the iron quickly melted and became saturated with carbon. The crucible was then suddenly cooled in a water bath. A rigid crust of iron was formed, while the interior of the mass remained molten. As a result of this condition within the mass an enormous pressure was developed. Part of the carbon crystallized out as the diamond, the rest as graphite. To separate the diamonds from the iron in which they were formed the ingot was dissolved by successive treatments with nitrohydrochloric acid. The bulky residue consisted of graphite, flakes of black diamond, and a small quantity of transparent, colorless, diamond. The graphite and other impurities were chemically removed, leaving behind the unattacked diamonds. The crystals formed in this way were rarely if ever whole, but appeared to be broken, as if liberation from the intense pressure prevailing when they were formed had allowed them to burst. In this connection it is interesting to note that natural crystals of the diamond from South Africa have also been known to burst asunder when removed from the peridotite or blue ground in which they were formed.

Sir William Crookes in 1906 reported another method for the production of the diamond artificially. Sir Andrew Noble had previously shown that when the powerful explosive cordite is exploded in a closed steel cylinder a pressure of 50 tons per square inch and a temperature of 5100°C. are momentarily attained. These conditions should be favorable for the liquefaction of carbon. It was thought that if the explosion were to extend over a sufficient period to permit the carbon to be liquefied, it might then solidify in the crystalline form of the diamond. In the experiment Noble used cordite containing a slight excess of carbon, and collected the residue after the explosion. This residue was examined by Crookes, who identified minute crystals of the diamond, the largest being only 0.5 millimeter in length. These had all the properties of the natural stones.

On various occasions the diamond has been reported as occurring in microscopic crystals in steels, especially in those which had been cooled under pressure. The hardness of certain steels may be due to the presence of this crystalline form of carbon. The Canyon Diablo iron meteorite, from Arizona, was found to contain minute diamonds. This observation was made by the late Dr. A. E. Foote of Philadelphia.

Therefore, all attempts to produce the diamond artificially have resulted in the formation of only small microscopic stones, of no commercial value.

Artificial Ruby.—The attempts to produce artificial rubies commercially have been many. Gaudin was one of the first in this field. In 1837 he made microscopic rubies by fusing alum at a high temperature, with the addition of a little chromium as a pigment. Ebelmen in 1847 produced the white sapphire by fusing alumina in boric acid. Frémy and Feil were able, in 1877, to produce crystallized corundum from which small stones could be cut. A lead aluminate was first formed by fusing together Al_2O_3 and PbO. This was kept molten for some time in a fireclay crucible, whereby silica from the crucible combined with the lead of the aluminate to form lead silicate. During this process alumina was liberated, which crystallized as white sapphire. By adding 2 to 3 per cent of a chromium compound the ruby was obtained. Frémy and Verneuil manufactured the artificial ruby by a reaction at red heat between BaF_2 and Al_2O_3 containing a little chromium. Other workers who have attacked this problem are: Elsner, de Senarmont, Sainte Claire-Deville, Caron, and Debray. In their processes the general plan was to form a molten mixture of salts in which alumina was soluble. These mixtures were then saturated with alumina, and on long heating, sometimes for weeks, the solvent volatilized, allowing alumina to crystallize out.

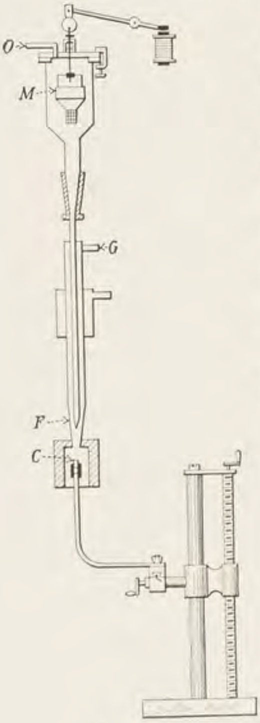


Fig. 141.

Fig. 142.

The Verneuil Process.—In 1902 Verneuil announced a process by which the ruby could be manufactured artificially on a commercial scale. The product is chemically and physically identical with the natural stone, except for certain features incidental to the process (p. 101).

Figure 141 is a cross-section of the Verneuil apparatus. Chromated alumina is placed in a receptacle, the bottom of which is a fine sieve. A mechanical tapping device causes a small amount of the powder to pass through the screen at *M*, and to fall into a flame produced by a mixture of illuminating gas, entering at *G*, and oxygen. The oxygen inlet is at *O* in the diagram. The alumina is fused in the intense flame at *F* and collects on a fire-clay support *C*. A pear-shaped mass of alumina slowly forms, the broader part being uppermost. This inverted pear-shaped mass is known as the *boule* (Fig. 142). When the boule reaches the proper size, which is usually 25 to 30 carats, the furnace is shut down and the boule allowed to cool, after which it is removed, cut, and polished (Fig. 143).

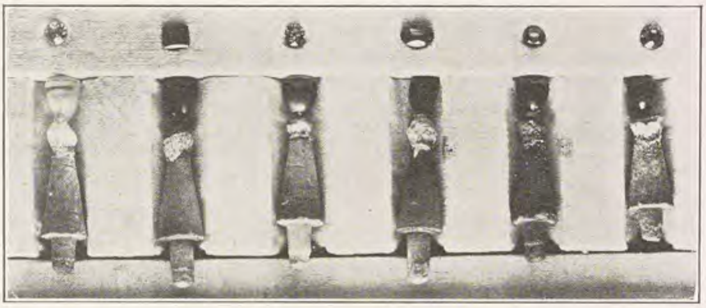


FIG. 143.—Boules, on fire clay supports, and cut stones of differently colored varieties of artificial gem corundum.

As the raw material, very pure recrystallized ammonium alum is used. This is dissolved in water, and from the solution pure aluminum hydroxide is precipitated with ammonia. The precipitate is ignited, yielding the oxide (Al_2O_3) in a fine powder. Pure Al_2O_3 treated by the Verneuil process becomes white sapphire. In order to obtain the ruby some chromium alum must be added to the ammonium alum solution before the precipitation with ammonia. This procedure insures a uniform distribution of the chromium in the powder. To produce the proper red colors, varying amounts of chromium alum sufficient to yield up to 7 per cent of chromium oxide are used. Artificial rubies of the paler red colors are sometimes called "rose topaz." The yellow sapphire is colored by a small amount of nickel oxide and other materials, at present a trade secret. The blue sapphire is obtained when about 2 per cent of iron oxide and 1 per cent of titanium oxide are used as the pigment. The gem mineral alexandrite (p. 138) is simulated by an artificial corundum colored by about 3 per cent of vanadic oxide. Like the true alexandrite, this material has a blue-green color by daylight, and a red color in artificial light.

It usually requires from 6 to 12 hours to produce an average-sized boule, weighing from 1 to 5 grams (5 to 25 carats). One apparatus can produce but one or two boules per day. However, one attendant, usually a girl, can operate about ten machines. As long ago as 1910 it was estimated that the average daily output was from 10,000 to 14,000 carats. France, Switzerland, and Germany are the principal producers of artificial rubies and sapphires.

Properties of the Artificial Rubies and Sapphires.—As previously pointed out, natural and artificial rubies and sapphires possess essentially the same chemical and physical properties. Due, however, to the great differences in the processes whereby the two types of stones have been formed there are certain definite criteria which in general permit their true character to be recognized.

Composition of Sapphires.—The following table, by A. J. Moses, of analyses of natural and artificial sapphires shows that they are the same chemically. Indeed, the artificial product is the purer. No analyses are available for artificial and natural rubies, but the similarity in composition would of necessity be just as close as in the case of the sapphire.

	Artificial			Natural		
	Verneuil			India	Ceylon	
Al_2O_3	99.84	99.85	99.83	97.51	99.33	99.26
Fe_2O_2	trace	trace	trace	1.95	0.92	0.97
TiO_2	0.11	0.12	0.13			
SiO_2	none	none	none	0.80		
	99.95	99.97	99.96	100.26	100.25	100.23

Indices of Refraction.—Similarly, the following table shows the striking agreement of the indices of refraction and birefringence of the natural and the artificial stones:

	ω_{Na}	ϵ_{Na}	$\omega - \epsilon$
Artificial sapphire, Verneuil (Moses)	1.7680	1.7594	0.0086
Natural sapphire, Ceylon (Brauns)	1.7693	1.7610	0.0083
Natural sapphire, Burma (Melczer)	1.7692	1.7609	0.0083
Artificial ruby, German (Brauns)	1.7709	1.7629	0.0080
Natural ruby, Burma (Melczer)	1.7715	1.7632	0.0083
Artificial white sapphire, German (Brauns)	1.7681	1.7599	0.0082
Natural white sapphire, Burma (Melczer)	1.7686	1.7605	0.0081

Specific Gravity.—The following table is of interest in that it shows that the specific gravities of artificial and natural stones are to all intents and purposes identical:

Artificial sapphire, Verneuil, cone (Kraus)	4.03
Artificial sapphire, Verneuil, cut stone (Moses)	4.01
Artificial sapphire, German, cone (Brauns)	3.96
Natural sapphire (Bauer)	4.08
Artificial ruby, German (Brauns)	3.99
Artificial ruby, Verneuil, cone (Kraus)	3.96
Natural ruby (Bauer)	4.08
Artificial white sapphire, Verneuil, cone (Kraus)	4.00
Artificial pink sapphire, Verneuil, cone (Kraus)	3.99
Artificial yellow sapphire, Verneuil, cone (Kraus)	3.97

Also with respect to the other physical properties, such as hardness, crystallization, and the property of parting, the same close agreement between the artificial and natural stones is to be observed.

FIG. 144.—Structure lines in artificial gem corundum.

Distinguishing Characteristics.—While in all essentials artificial rubies and sapphires manufactured by the Verneuil process are identical with the natural stones, they differ in some features, which, though minor, are nevertheless of great importance in revealing the artificial character of the stones. Among these distinguishing features are: structure lines; uneven distribution of color; cloudiness; presence of air bubbles; brittleness; internal cracks; and lack of definite orientation of the cut stones.

Structure Lines.—The artificial stones often show fine *structure lines* (Fig. 144). That is, the material appears to be built up of thin layers parallel to the surface of the boule. This may be due to fluctuations in temperature during the formation of the boule, or to an *irregular distribution of the pigment.* This structure cannot commonly be observed in faceted stones without recourse to the microscope, although it may be apparent when the gem is cut *en cabochon,* that is, with a comparatively large curved surface. These structure lines are characteristically curved, conforming to the shape of the boule, and usually they can be readily distinguished from the more nearly straight, parallel bands due to the zonal distribution of color in natural stones. This distinction can obviously be best made under the microscope.

Cloudiness.—Sometimes a minute quantity of the powder used in the process may not be completely fused during the formation of the boule. This then becomes disseminated through the mass, causing *cloudiness.* However, by the skilful operation of the apparatus, cloudiness may be avoided.

Air Bubbles.—Rounded and not infrequently elongated air bubbles are sometimes to be found in the boules (Fig. 145). Air bubbles are not found in natural corundum, though it may contain liquid inclusions, or inclusions of rutile, present as microscopic needle-like crystals (Fig. 146). If rutile or liquid inclusions are present the stone is without doubt natural. Ordinarily the air bubbles are of microscopic size, and cannot be observed unless the stone is immersed in a liquid, having approximately the same index of refraction, and is viewed under the microscope.

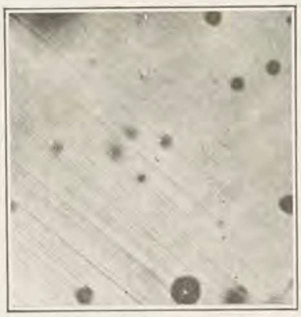


Fig. 145.—Air bubbles (black spots) in artificial gem corundum. Structure lines are also distinct.

Fig. 146.—Needle-like inclusions of rutile (inclined lines) in natural sapphire from Montana.

Internal Cracks.—Because of the rather rapid cooling, boules are *brittle,* and tend to break lengthwise into two parts. In addition, due to the brittleness, the halves frequently show *internal cracks* (Fig. 147). These are sometimes especially noticeable at the junction of the facets, and are often produced by the strains incident to cutting and polishing. These flaws may at first sight give the impression that the stone has been chipped, but a closer examination will reveal that the facets are perfect, and that the flaw is within the stone. Some stones possess what may be designated as *feathers*, which are fairly large internal cracks so situated as to be easily visible.

FIG. 147.—Internal cracks in artificial gem corundum.

Dichroism.—Rubies and sapphires are dichroic. As indicated on page 57, in order to cut them to the best advantage, that is, so that the deepest tint will be obtained, the table of the stone should be perpendicular to the vertical crystal axis. In the case of natural rubies and sapphires this can easily be done, since they are usually well crystallized, and the direction of the vertical axis is readily recognized. However, in the case of artificial stones, it is very difficult in most instances to orient the fragment to be cut. Usually one side of the boule is somewhat flattened, and this flattened surface, which is approximately perpendicular to the vertical crystal axis, corresponds to the basal plane of the natural crystals. When this flattened surface can be recognized the cut stone can be well oriented. However, with other fragments of the boule, proper orientation is much more difficult. Consequently, most artificial rubies and sapphires are cut at random, and hence show dichroism when examined through the table. Natural rubies and sapphires, properly cut, are not dichroic when examined in this way.

While these differences between natural and artificial rubies and sapphires are obviously not readil recognized by the untrained observer, the expert is in general able to pass judgment on the character of the material. In the case of rather small stones, however, which have been selected and fashioned with great care, the distinguishing criteria may be entirely absent. It is of interest to point out that the production of artificial rubies and sapphires on a commercial scale was not begun until the opening of the present century. Consequently, rubies and sapphires with a history considerably antedating the year 1900 are in all likelihood natural.

Value of Artificial Rubies and Sapphires.—Since natural and artificial rubies and sapphires are alike in all important essentials, naturally the artificial stones are in great demand. Furthermore, this popularity has been stimulated by the fact that cut artificial stones may be bought at various prices up to $10 per carat, depending upon the quality, while the price of natural stones is many times higher. The demand for natural stones has consequently fallen off greatly. It is also worthy of note that comparatively large quantities of cut, artificial rubies and sapphires are used as the jewels of watches, and in scientific apparatus where hard bearing surfaces are required.

PART II

GEM MATERIALS

A. DESCRIPTION OF INDIVIDUAL GEMS

In the preceding chapters the important properties and facts about gem material in general have been thoroughly discussed. It is now possible to describe in considerable detail and in a systematic manner, those minerals that are used in various ways as gems or for ornamental and decorative purposes.

(Photo by courtesy of the American Museum of Natural History.)

FIG. 148.—Display of gems and gem minerals in the Morgan Memorial Hall, American Museum of Natural History, New York.

A very satisfactory order of treatment is first to describe the most precious stones, next the semi-precious, then the metallic gem minerals, and finally the ornamental stones. It may be emphasized here that there is no sharp distinction between the precious and the semi-precious gems. It is usual, however, to rank the diamond, ruby, sapphire, and emerald as the precious stones, since they are the most valuable and attractive of all gems. Ornamental stones are those which are rarely worn, but from which decorative objects, such as vases, jewel caskets, table tops, and paper weights are fashioned, or which are used in the beautifying of interiors of buildings, as for example in mosaics. All other stones are called semi-precious. Lastly are to be discussed certain organic materials, used for personal adornment, but which are not minerals. These are the pearl, coral, amber, and jet.

In the following tabulation all the important natural gem materials are grouped according to the above classification:

Precious Stones

Diamond
Corundum (Ruby and sapphire)
Beryl (Emerald)

Semi-precious Stones

Topaz
Garnet
Tourmaline
Olivine
Spinel
Chrysoberyl
Zircon
Opal
Quartz
Turquois
Variscite
Jade
Anatase
Andalusite
Apatite
Axinite
Benitoite
Beryllonite
Cassiterite
Chlorastrolite
Cyanite
Diopside
Enstatite
Epidote
Euclase
Feldspar
Iolite
Moldavite
Obsidian
Phenacite
Prehnite
Rutile
Spodumene
Staurolite
Thomsonite
Titanite
Vesuvianite
Willemite

Metallic Gem Minerals

Chromite
Cobaltite
Gold
Hematite
Pyrite

Ornamental Stones

Azurite
Malachite
Chrysocolla
Datolite
Fluorite
Gypsum
Lazulite
Lazurite
Rhodonite
Sepiolite
Serpentine
Smithsonite
Sodalite
Zoisite

Organic Gem Materials

Pearl
Coral
Amber
Jet

The gem materials listed above will now be described in the order given.

DIAMOND

The diamond, universally acknowledged to be the most precious of all stones, crystallizes in the cubic system, the more common crystal forms being the octahedron (Fig. 149) and rhombic dodecahedron (Fig. 150). However, the cube and some of the more complex forms of the cubic system are also observed. Any one of these forms may occur alone on the crystal, or in combination with other forms. These crystals are often rounded or distorted, and may be twinned. Contact twins according to the spinel law are frequent (Fig. 42, p. 19). Figure 151 is a photograph of an octahedral diamond crystal in the blue ground from Kimberley, South Africa. Diamond crystals vary in size from microscopic dimensions to over 3,000 carats in weight. Sometimes the mineral is massive.


Fig. 149.

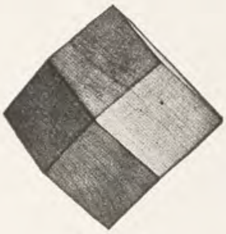


Fig. 150.


Fig. 151.—Diamond in ground. Kimberley, South Africa.

As has been noted, the diamond has a very perfect octahedral cleavage, which is of the greatest assistance in cutting it. The fracture is conchoidal. Its hardness is 10, the diamond being the hardest mineral known. Crystal faces belonging to different forms may vary in hardness. Thus, on the cube faces the hardness is greater than that on the octahedron faces. Furthermore, crystals are said to be harder on the surface than in the interior. Also, the hardness differs with the locality from which the stones are obtained, those from Borneo and Australia being hardest of all, those from India next, followed by those from Brazil, while the South African diamonds are the softest. The specific gravity ranges from 3.15 to 3.53, according to the variety. When the mineral is pure and crystallized the value is nearly constant at 3.52.

The color of the diamond varies markedly. The most common colors are different shades of white, yellow, and brown. Green stones are less common, while those with a red or blue color are rare. The colors are usually pale. Gray, black, milky, and opalescent stones are sometimes found. Pure white or *first water* stones, and those with good green, blue, or red tints are most valuable. The *blue-white* stones are also highly esteemed. If the stone has a tinge of an undesirable color, such as yellow or brown, it is said to be *off color*. The cause of color in diamonds is not known. It is usually ascribed to traces of some of the metallic oxides.

The diamond may be transparent, translucent, or opaque. Only those which are transparent are valued as gems. The luster of the uncut diamond is rather dull or greasy, but it is a brilliant adamantine in the cut stone. Carbonado, described below, has a dull luster.

The index of refraction and the dispersion of the diamond are high: n for red light being 2.407, for yellow 2.417, for green 2.427, and for violet 2.465. The dispersion is $2.465 - 2.407 = 0.058$ (Fig. 64, p. 38). The characteristic fire is due to this unusually strong dispersion. Anomalous double refraction, caused by internal strains, is often noted. Because it is an excellent conductor of heat, the diamond is cold to the touch. On the other hand it is a poor conductor of electricity, and becomes positively electrified when rubbed. After exposure to light or to an electric discharge many diamonds phosphoresce or fluoresce, especially the blue-white stones. The mineral is transparent to X-rays, while paste imitations of the stone are not(p. 34).

The diamond is composed of pure carbon, for when it is burned in an atmosphere of oxygen only carbon dioxide (CO_2) is formed. The colored stones, when burned in this way, leave very small residues which show them to be slightly impure. The stone is unattacked by acids.

There are three varieties of the diamond: (1) *diamond proper;* (2) *bortz* or *bort;* and (3) *carbonado.*

1. Diamond Proper: *Occurrence and Recovery.*—The term *diamond proper* refers to the well crystallized, more or less transparent stones valued as gems. This variety has been known from the earliest times, and was called *adamas* by the ancients. From that name the word *adamantine,* used especially in connection with the luster, is derived. The older diamonds came from India and Borneo. In India the diamond was found in three principal localities: (1) in the Madras Presidency of southern India; (2) farther north, in a large area between the Mahanadi and Godavari Rivers; and (3) in Bundelkhand in central India. The diamonds were found in alluvial deposits and in a conglomerate, neither of which, of course, represented the original source. In Borneo the most important locality is near the town of Pontianak. At present the annual production of diamonds in India and Borneo is very small.

Tradition has it that diamonds were first discovered in Brazil in 1670, in the gold washings, but they were not positively identified until 1721. The provinces of Minas Geraes and Bahia are the most important producers. The deposits in Brazil are secondary, and the diamond is associated with such minerals as gold, cyanite, tourmaline, pyrope garnet, zircon, and some heavy ore minerals. The Brazilian deposits were very productive between 1721 and 1870, but the present yield is small. It is said that 1,666,569 carats were exported between 1732 and 1771.

The recovery of the diamond in Brazil is carried on in a primitive way. Material from the diamond-bearing stream beds is washed in a hemispherical pan called a *batea,* the larger pieces having been first broken up by sledges. Water is added, and by means of an oscillating, rolling motion, the water is allowed to spill over the side, carrying with it the lighter constituents of the sand and gravel. The diamond, being comparatively heavy, remains in the bottom along with a number of other heavy minerals, from which it is easily separated by hand.

The most important diamond producing country at present is South Africa, 95 per cent of the world's diamonds being mined there. It was in 1867 that diamonds were discovered in that country. There are several stories of the manner in which the discovery was made. According to one of these, an ostrich hunter and peddler named John O'Reilly, while traveling along the south shore of the Orange River near Hopetown, called at the home of the Boer peasant, Schalk van Niekerk. O'Reilly's attention was attracted to several stones with which the peasant children were playing, and which they had picked up along the river. When O'Reilly went away the stones were intrusted to him to be identified. He submitted them to various persons but received no decisive information. Some thought that the stones were no more than quartz or topaz. Finally O'Reilly sent them to Dr. W. Guybon Atherstone of Grahamstown, who pronounced them to be diamonds. The larger stone weighed over 21 carats and sold for $2,500. News of the discovery brought many prospectors to the region about Hopetown.

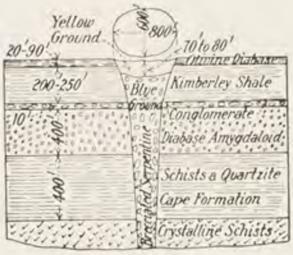


FIG. 152.—Section through the Kimberley Mine.

The first diamonds were found in secondary deposits, that is, in the sands and gravels of stream beds, principally along the Orange, Vaal, and Modder Rivers. They were, therefore, called *river diggings*. The separation of the diamonds from the associated sands was by washing, in much the same way that gold is panned.

In 1870 diamonds were discovered in primary deposits, or *dry diggings*, upon a plateau between the Vaal and Modder Rivers, at the place now known as Kimberley. The occurrences were limited to circular or elliptical areas, varying in diameter from 20 to 700 meters. Near the surface the diamonds were found in a soft, decomposed material known as yellow ground. At a depth of 70 to 80 feet (Fig. 152) the yellow ground passed into a hard, unaltered, basic igneous rock, at first called blue ground or earth, but now commonly known as *kimberlite*. The long, narrow funnels of diamond-bearing rock are known as pipes. The pipes are of volcanic origin. The material of which they are composed was once molten, and welled upwards, filling these pipe-like openings. According to Sir William Crookes no fewer than 80 minerals are found in the diamond-bearing kimberlite. Among these minerals are pyrope garnet, which is placed on the market as "Cape ruby," cyanite, and zircon.

These diamond-bearing areas were staked off into claims about 30 feet square. Separated by two rows of claims, there were roadways across the diggings, which permitted access to the workings. The diamonds were easily recovered from the soft, yellow ground by washing. As the claims were mined deeper and deeper the roadways became steep-sided ridges between the workings. Landslides often occurred, and the removal of the earth from the claims was obviously expensive, especially when it consisted of barren material. As time went on, the financial difficulties of the small claim owners became greater and greater, causing them to dispose of their holdings. In 1888 a consolidation of all the diamond-mining properties of the Kimberley district was effected, largely through the efforts of Cecil J. Rhodes. The powerful organization thus formed is known as the De Beers Consolidated Mines, Ltd.

FIG. 153.—Kimberley Open Diamond Mine, depth 1,000 feet.

For a time open-pit mining (Fig. 153) was continued, the blue ground being hoisted to the surface from deep pits. It finally became evident that such a method was no longer feasible, and underground mining by means of shafts and drifts was inaugurated. The workings of the Kimberley mine are now about 3,600 feet in depth.

Most of the work is done by natives, who live, during the term of their employment, in inclosures known as *compounds*. This precaution is necessary in order to prevent the theft of stones by the natives, who formerly concealed them in various ways and sold them to unscrupulous traders outside the camp. Hence, at present these native workers are allowed to leave the compound only after a most searching examination.

For a long time it has been the practice to remove the blue ground from the mines and to expose it to the processes of weathering upon open fields called *depositing floors*. In due time the hard and consolidated blue ground becomes soft and friable. By the use of sledge hammers or tractors the larger pieces can be easily broken up. The material is then loaded into cars and taken to the crushing and washing plants, where the lighter constituents are removed. Formerly the diamonds were sorted from the other concentrates by hand, but a surer and more rapid method is now employed. It was discovered that of all the minerals of the concentrates grease sticks most tenaciously to the diamond. In making use of this fact, oscillating, grease-covered, corrugated-iron tables known as *pulsators* are employed. In using this method the concentrates are placed on the pulsators, and everything but the diamond passes over, while the diamonds remain in the grease. Practically all the diamonds are removed with one treatment, while the remainder can be recovered by a second treatment. The tables are inclosed, and theft of the diamonds is impossible. At intervals the grease, from which the diamonds. are easily recovered, is scraped off the tables by trusted employees. They are then cleaned by means of acids and alkalies, sorted, weighed, and evaluated, and made up into packets called parcels, for sale.

In the Kimberley district, which is the diamond center of South Africa and of the world, there are four important mines: the Kimberley, Du Toitspan, De Beers, and Bultfontein. Other important South African mines are the Jagersfontein in the Orange Free State, and the Premier near Pretoria, in the Transvaal. The Premier is the largest-known diamond mine, having a productive surface area of about 80 acres. At this mine depositing floors are not used. The blue ground is crushed and washed directly after being mined. Although this involves the risk of breaking up diamonds of considerable size, the tying-up of large amounts of capital on the floors is avoided. This is known as the *double direct* method. The Premier (Fig. 157) is famous as the source of the world's largest diamond, the Cullinan (p. 115).

Some other localities in which diamonds have been found are: near Lüderitz Bay on the west coast of Africa, in secondary deposits; along the Kasai River in the Belgian Congo; Australia; the Ural Mountains; British Guiana; Colombia; and Mexico. In the United States a few isolated diamonds have been found, either in secondary deposits or in glacial drift, in North Carolina, Georgia, Virginia, Michigan, Wisconsin, Ohio, Indiana, Colorado, Idaho, Nevada, and California. On August 1, 1906, the most remarkable discovery of diamonds in the United States was made in Arkansas, near Murfreesboro in Pike County, about 100 miles southwest of Little Rock. The rock in which these diamonds are found is strikingly similar to the kimberlite of South Africa. Up to the present time, about 10,000 diamonds have been recovered from this area. About 40 per cent of these were white stones, the remainder being brown and yellow with 1 per cent bort. Kimberlite also occurs in and near Syracuse, New York, where a single diamond has been reported; and in Elliott County, Kentucky. No stones have been found in the latter locality.

FIG. 154.—Cullinan Diamond (uncut). Premier Mine, South Africa. Weight 3,106 carats.

Famous Diamonds (See Figs. 154, 155, and 156).—Brief mention may be made of some of the historically famous large diamonds. Due to the fact that in the past the unit of weight used in expressing the size of precious stones, namely the carat, fluctuated considerably (see p. 85), the values assigned to famous large diamonds have not always been the same.

Cullinan, 3,106 metric carats in the rough (Fig. 154). This, the world's largest diamond, was found at the Premier mine, South Africa, on January 25, 1905 (Fig. 157). In the rough this stone measured 10 by 6.5 by 5 centimeters, and was a cleavage fragment of a still larger stone. It was purchased for £150,000 by the Transvaal government and presented to King Edward VII on his birthday, November 9, 1907. The stone was intrusted to the well-known firm of Asscher & Co., Amsterdam, for cutting. It was cleaved to remove a flaw. From the cleavage pieces two large stones were cut. The largest, known as *Cullinan I*, and now called the *Star of Africa*, is a drop-shaped stone of 530.2 carats. The *Cullinan II* is a square brilliant of 317.4 carats.

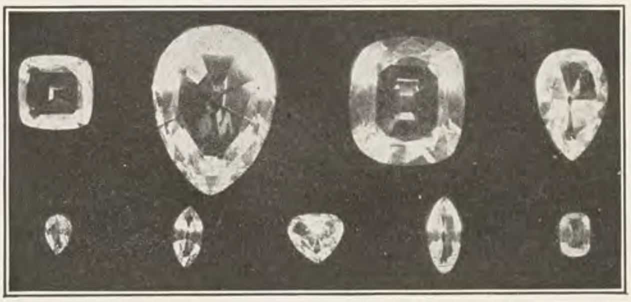


Fig. 155.—The nine largest stones cut from the Cullinan Diamond.

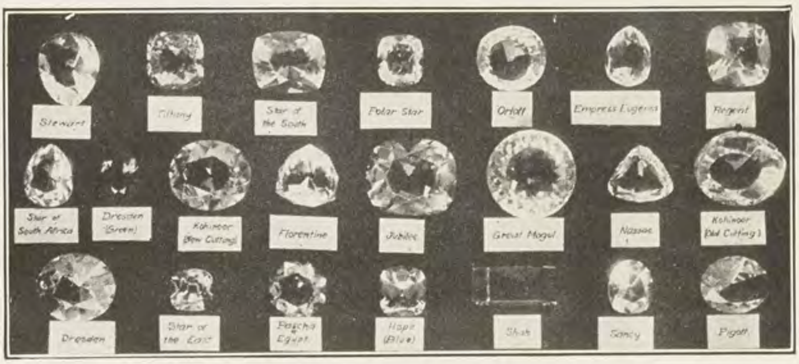


Fig. 156.—Photograph of glass models of famous large diamonds.

In addition 103 other stones were cut from this large diamond. Glass models of the nine largest stones cut from the Cullinan are shown in Fig. 155.

Great Mogul, 240 carats, cut. This is the largest Indian diamond, and is said to have weighed 787 carats, but after being cut into its present form the weight was reduced to 240 carats. We have no knowledge of the stone since 1665, when it was seen in India by a French jeweler, Tavernier.

Jubilee, 245.3 carats, cut. From the Jagersfontein mine, discovered in 1895.

Orloff, 194.8 carats, cut. A rose-cut stone which formed the top of the Russian Imperial scepter. It is said to have been stolen from a temple in Mysore, where it was one of the eyes of an idol.

(Photo by P. Mitchell, through the courtesy of the National Geographic Magazine.)
Fig. 157.—Premier Diamond Mine, near Pretoria, Transvaal.

Kohinoor, old cutting 186.1, new cutting 106.1 carats. The name Koh-i-noor means "mountain of light." History traces the stone back to 1304, in India. In 1850 it was presented to Queen Victoria in the name of the East India Company, and in 1862 it was recut as a shallow brilliant.

Regent or *Pitt*, 136.9 carats. An Indian stone, discovered in 1701. It was owned for a time by William Pitt, governor of Fort St. George at Madras. He had it cut, and sold it in 1717 to the Duc d'Orleans, Regent of France. It was stolen during the French Revolution, but was later returned by the thieves.

Florentine, also known as the *Austrian* and the *Grand Duke of Tuscany*, 133.2 carats. This stone belonged to the Austrian Imperial family, and has an authentic history of two centuries. It is slightly yellowish.

Tiffany, 128.5 carats. The Tiffany is a brilliant of a beautiful deep yellow color, discovered in the Kimberley mine, 1878. It is owned by Tiffany and Company of New York.

Fig. 158.—Carbonado. Brazil.

Fig. 159.—Diamond drill bit.

Star of the South, 125.5 carats. A Brazilian diamond, discovered in 1853.

Hope, 44.5 carats. The largest blue diamond.

Dresden, 40 carats. A flawless apple-green diamond.

Other large diamonds worthy of mention are: the *Stewart*, 120 carats; *Nassak*, 89.5; *Shah*, 88; *Dresden* (*English*), 76.5; *Empress Eugenia*, 51; *Star of South Africa*, 46.5; *Polar Star*, 40; *Pasha of Egypt*, 40. Another large stone, weighing 1,680 carats, the *Braganza* of the Portugese regalia, is reported to be colorless topaz.

2. Bortz, also called *bort* or *boart*, is poorly crystallized diamond of a dark color, often possessing a radial fibrous structure. It is translucent to opaque. Crystals and fragments of inferior quality and unfit for gems are also called bortz. Powdered bortz is employed in polishing diamonds. Bortz is also used as the material for dies for drawing fine wire.

3. Carbonado, also called *black diamond* or *carbon*, is an opaque, black or gray, tough and compact variety of diamond (Fig. 158). It has no cleavage. The specific gravity, 3.15 to 3.29, is lower than that of the diamond proper. Bahia, Brazil, is the chief source of carbonado. The largest piece ever found had practically the same weight as the Cullinan, the largest diamond. Carbonado is much used in diamond drills (Fig. 159) for deep boring.

CORUNDUM

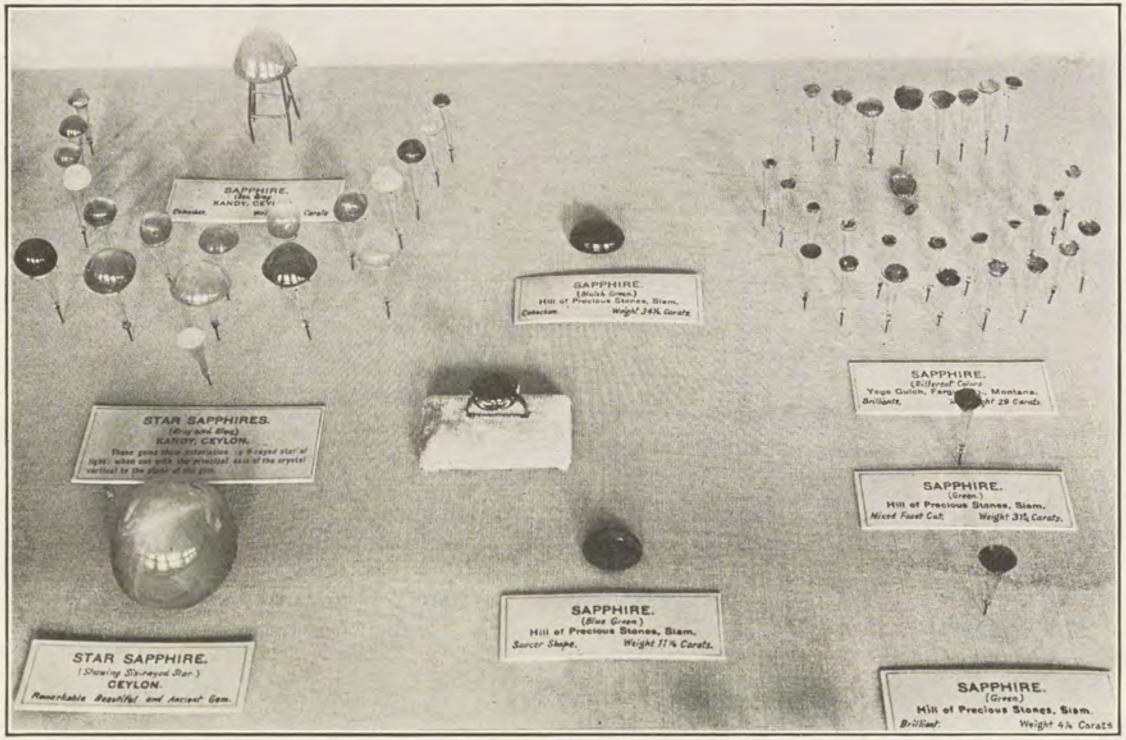
The precious stones, ruby and sapphire, are transparent, colored varieties of the mineral corundum. This mineral frequently occurs in good crystals, often large, which belong to the hexagonal system. The most common forms are the hexagonal prism, bipyramid, rhombohedron, and basal pinacoid (Fig. 160). The larger crystals may be rough or rounded, barrel-shaped, and furrowed. Penetration twins sometimes occur, and polysynthetic twins are often noted, the twinning being parallel to the rhombohedron. Ruby and sapphire usually occur in crystals, but other varieties of corundum may be found as compact, granular, or platy masses.


FIG. 160.—Crystals of natural corundum.

The fracture is conchoidal. Corundum has no cleavage, but rhombohedral and basal partings occur. The hardness is 9, which is next to that of the diamond, and therefore corundum very durable. The specific gravity varies from 3.9 to 4.1.

Corundum occurs in a number of colors. Crystals are often multicolored. The mineral is transparent to opaque, and has a rather dull, greasy, or vitreous luster in the natural state, but is adamantine when cut. Gem varieties, which are transparent, may be colorless, red, blue, green, yellow, or violet, while the common corundum is translucent to opaque and gray, bluish, brown, or black in color.

The mean index of refraction is 1.76. The optical character is negative, and the double refraction is low, 0.008. The dispersion is weak, 0.018, and consequently there is very little fire. The ruby and sapphire therefore depend upon the color for their appeal. Dichroism in corundum is strong. In ruby the colors are pale red for *e* dark red for *o*, and in sapphire, blue for *o*, and



(*Photo by courtesy of the American Museum of Natural History.*)

FIG. 161.—Display of cut sapphires in the Morgan Memorial Hall, American Museum of Natural History, New York.

yellowish blue for *e*. It has already been pointed out (p. 57) that the ruby and sapphire should be cut with the table parallel to the basal pinacoid, in order to obtain the most pleasing colors.

Corundum has the composition Al_2O_3, aluminum oxide. The aluminum is often replaced by small amounts of other metals, such as chromium, titanium, or iron. The colors of the mineral are sometimes ascribed to these impurities, the chromium being thought to give the red color, titanium the blue, and iron the yellow. The more poorly crystallized varieties of corundum are often very impure.

The color of rubies and sapphires is made paler by heat. Some of these stones phosphoresce when placed under the influence of ultraviolet light. Cut *en cabochon*, corundum may exhibit asterism, that is, a six-rayed star is observed, the rays being white regardless of the color of the stone (Fig. 57, p. 32). This effect is due to inclusions or to a lattice-like structure within the mineral. Stones exhibiting such "stars" are called *star rubies* or *star sapphires*.

FIG. 162.—Corundum: Variety, ruby. India.

Common corundum and *emery* are two varieties of corundum not used as gems. Common corundum consists of rather opaque crystals or masses with dull colors. Emery is a black, granular mixture of corundum with magnetite, hematite, quartz, and spinel, which is valued as an abrasive.

Ruby and *sapphire* are the gem varieties of corundum. The color of the *ruby* varies from a rose, through carmine, to a dark, somewhat purplish-red. The most desirable shade is the "pigeon's blood red." All precious corundum of a color other than red is called sapphire (Fig. 161). The true *sapphire* is blue, the best tints being known as royal blue, velvet blue, and cornflower blue. The colorless stones are called *white sapphire*, the yellow ones *yellow* or *golden sapphire*, and the pale pink stones *pink sapphire*. The word "oriental" is often applied as a prefix to the names of other gems in naming varieties of corundum with the less popular colors: thus, *oriental emerald* for green corundum, and *oriental topaz* for the yellow, and *oriental amethyst* for the violet varieties, respectively. Ruby and sapphire are cut step, cabochon, or brilliant.

Ruby and sapphire occur both in placer deposits and *in situ*. Metamorphic rocks, such as metamorphosed limestones (Fig. 162), gneiss, and schist, and igneous rocks, for example granite, nepheline syenite, and peridotite, are the original sources of these stones. The minerals commonly associated with corundum are spinel, tourmaline, cyanite, magnetite, chlorite, and nephelite.

The methods of recovery of rubies and sapphires are rather primitive. The mines are simply open pits, and the gem-bearing sands and gravels are washed in much the same way as are the diamantiferous sands of Brazil.

The best rubies, including many with the esteemed pigeon's blood hue, are mined in upper Burma, in a district of which Mogok is the center. Here the stones occur in granular limestone, and in sand, gravel, and soil, with the "balas ruby" or spinel, sapphire, and tourmaline. These mines have been worked since the fifteenth century. While a great many rubies are found, but few are large, or of the best color.

Important deposits occur near Bangkok in Siam, where the rubies are also associated with the red spinel. Excellent sapphires come from these Siamese deposits, though the rubies are inferior to those from Burma. In Ceylon, also, many sapphires, but few rubies, are mined. Here the sapphires occur with garnet in gneiss, while the rubies are found in limestones, associated with spinel, though the two varieties of corundum are often found side by side in the gravels. Other important sources of these stones are Afghanistan, Hindustan, China, the Ural Mountains, and Queensland.

In the United States fine rubies have been found in the crystalline rocks of North Carolina. Along the Upper Missouri River, near Helena, Montana, sapphires and rubies are found in the river sands.

Rubies of a fine color and of a clear flawless character are very valuable, being worth as much as $1,500 per carat. Sapphires are less expensive, bringing from $6 to $125 per carat. Aside from their use as gems, these stones have found application as jewels in the finer watches and as bearings in many scientific instruments. This is especially true of the rubies and sapphires from Montana and Ceylon. Due to their improved quality and relative inexpensiveness, artificial rubies and sapphires have become very popular in recent years (see p. 97).

BERYL

The mineral beryl includes the precious emerald, as well as the semi-precious aquamarine, golden beryl, and morganite. The emerald takes rank with the ruby as one of the most precious of gems.

Crystals of beryl belong to the hexagonal system and are sometimes of enormous size, exceeding a ton in weight. These mammoth crystals are invariably coarse and opaque, and entirely unfit for use as gems. Beryl crystals are usually long, prismatic (Figs. 163 and 164) and very simple, consisting of prism and pinacoid. They are rarely tabular. Sometimes the crystals have highly modified terminations (Fig. 165).

FIG. 163.—Crystals of gem beryl.

FIG. 164.—Beryl in quartz. Acworth, New Hampshire.

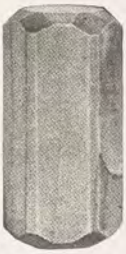


FIG. 165.—Wooden model of a highly modified crystal of beryl.

Beryl has a distinct basal cleavage and a conchoidal to uneven fracture. The hardness is 7.5 to 8, and the stone is therefore durable. The specific gravity is 2.6 to 2.8. Common beryl is generally pale green, yellowish, or grayish-white in color, and often mottled. Other varieties are blue, green, yellow, rose-red, or colorless. The luster is vitreous. Beryl may be transparent to opaque.

Beryl is uniaxial and optically negative. It has a mean index of refraction of 1.58, a low double refraction, 0.006, and a dispersion of 0.014. The refractivity and dispersion are both weak, so that the stone has little brilliancy and no fire. It is another stone which makes its appeal only through its color and transparency. Dichroism is fairly distinct in the more deeply colored varieties.

The composition of beryl is rather complex, at least in comparison with that of diamond and corundum. It is a beryllium aluminum silicate, with the formula $Be_3Al_2(SiO_3)_6$. The beryllium is often replaced by small amounts of the alkalies, lithium, sodium, potassium, and caesium. The pink and colorless varieties especially are rich in these elements.

The *emerald*, far and away the most highly esteemed variety, is transparent and has an emerald-green color. This green color is thought to be due to a trace of chromium. As the red color of the ruby is also ascribed to the same element, it obviously must exist in different states of combination in the two minerals. Accordingly, in minerals and chemical compouds chromium may produce either a green or red to violet color. The emerald has two absorption bands in the orange part of the spectrum.

Aquamarine is transparent and usually blue to sea-green in color.

Yellow or *golden beryl* has a beautiful golden-yellow color.

Heliodor is a variety of yellow beryl from Southwest Africa.

Morganite, also known as *vorobievite*, is a pink or rose-red beryl named after the late J. P. Morgan, who was a great lover of gems.

Goshenite is a very pure, colorless variety of beryl.

All of the transparent, colored varieties of beryl other than the emerald are considered as semi-precious gems.

Flawless emeralds of good color are extremely unusual, and are accordingly very valuable. The stones are usually variable in color, and may be muddy, or flawed. Emerald is generally cut step, but occasionally brilliant. Aquamarine is frequently cut in pendant-shaped forms.

FIG. 166.—Beryl: Variety, emerald. Bogota, Colombia.

The emeralds of ancient times came largely from Upper Egypt, where evidences of old workings are still to be seen. At present the best emeralds are obtained from the mines near Muzo, Colombia. Here the stones are disseminated through a dark limestone, which is thought to have been metamorphosed by solutions from pegmatite intrusions (Fig. 166). Emeralds are also found in mica schist at Tokovoja and Mursinka in the district of Ekaterinburg in the Ural Mountains, where they are associated with chrysoberyl and phenacite, which also are beryllium minerals. Small emeralds are found in the Habachthal, Tyrol, also in schist. Occasionally emeralds are found in the crystalline rocks in North Carolina.

All varieties of beryl other than the emerald occur almost exclusively in granite pegmatites. Aquamarine, which is paler in color than the emerald, is however found in much larger and clearer crystals than the latter variety. Thus, an aquamarine crystal from Morambaya, Minas Geraes, Brazil, weighed 243 pounds and was transparent from end to end. The uncut crystal was sold for $25,000. Aquamarine and other gem varieties of beryl are found on the Island of Elba, in Madagascar, in the Mourne Mountains of Ireland, the Ural Mountains, Maine, Connecticut, North Carolina, Colorado, and California, as well as in secondary deposits in Brazil, Ceylon, and India. Rose-red beryls are obtained in San Diego County, California, and in Madagascar. The stones from Madagascar are of a pure pink tint, while those from California incline to a salmon hue. It is interesting to note that in both localities pink spodumene, called kunzite, and pink tourmaline or rubellite also occur with the pink beryl. Golden beryl is found in Bahia, Brazil, in Ceylon, Madagascar, Maine, and Connecticut. The goshenite variety is found in Maine, Connecticut, and California.

TOPAZ

In former times the name topaz was given to any yellow stone, and especially to the yellowish variety of olivine now known as chrysolite. Even now the name in some modified form is given to other gem stones of a yellow color; thus the yellow sapphire is called *oriental topaz,* and yellow quartz, or citrine, and smoky quartz are sold as *Scotch topaz, false topaz,* or *smoky topaz,* respectively.

Topaz belongs to the orthorhombic system, and its prismatic crystals are often rich in forms (Fig. 167). Usually but one end of the crystal is terminated, the other being a cleavage plane (Fig. 168). Topaz occurs also in granular or compact masses, and in water-worn fragments. The cleavage, parallel to the basal pinacoid, is perfect and easily obtained. It is often clearly indicated by well-defined cracks. In cutting topaz the greatest care must be exercised in order that the stone shall not break along cleavage planes. The fracture is conchoidal to uneven.

Topaz is durable, having a hardness of 8. Its specific gravity ranges from 3.4 to 3.6, according to the composition of the mineral, which is variable.

Pure topaz is colorless, but due to impurities of an unknown nature the crystals are frequently colored. The colors include wine-yellow, brownish, gray, and pale tints of blue, green, violet, and red. The yellow, *precious* topaz is most often used as a gem. As already indicated (p. 94) yellow Brazilian topaz may be changed to a beautiful rose or pink color by heat. Pink topaz is extremely rare in nature. Pleochroism in topaz is weak. The mineral is usually transparent, and has a vitreous luster. Topaz is biaxial and positive in optical character. There are three indices of refraction, the mean index ranging from 1.62 to 1.63. The double refraction is 0.010, and the dispersion 0.014. Colorless stones are fairly brilliant and have a moderate amount of fire, especially when cut in the brilliant style. The step cut is also used.

FIG. 167.—Wooden model of crystal of topaz.

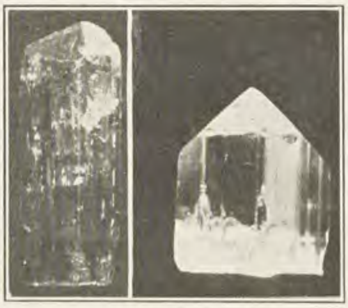


FIG. 168.—Crystals of topaz.

Topaz is an aluminum silicate, containing fluorine and hydroxyl, which are present in varying proportions. The properties of topaz, such as specific gravity and indices of refraction, vary slightly with the change in composition from pure fluorine topaz, $Al_2F_2SiO_4$, to pure hydroxyl topaz, $Al_2(OH)_2SiO_4$. Fluorine usually predominates. Considerable amounts of impurities are frequently present, such as microscopic liquid or gaseous inclusions, especially liquid carbon dioxide.

Topaz occurs in gneisses, schists, granites, and pegmatites. It is characteristically formed by the action of gases, containing fluorine and water vapor, emanating from igneous intrusions. Common mineral associates are tourmaline, quartz, fluorite, apatite, beryl, and the ores of tin and tungsten. The mineral, being durable and fairly heavy, is often found in placer deposits. Among the important localities for topaz are: the Ural Mountains, near Ekaterinburg, green and blue topaz; Miask, in the Ilmen Mountains; reddish crystals from the gold-washings of the Sanarka River in the Government of Orenburg, Russia. Cairngorm in Banffshire, Scotland, and the Mourne Mountains of Ireland have furnished a considerable number of sky-blue topazes. Brazil is important as the source of wine-yellow, blue, light green, and colorless stones. Good crystals also occur in the tin mines of Saxony and Cornwall; and in Ceylon, Japan, Mexico, and Tasmania; in the United States in the Thomas Range of Utah; at Nathrop, Colorado; in the Ramona district, San Diego County, California; and in several localities in New England.

GARNET

Though the term garnet is often understood as referring to a single gem, in reality the name covers a number of closely related minerals. Several chemically similar elements freely replace one another in the garnet group. As a result, the properties of the group are variable, and there are a number of garnet gems, quite different in appearance.

Fig. 169.—Garnet (rhombic dodecahedron). Salida, Colorado.

Garnets are really very attractive stones, but they are so abundant that they are not highly valued. Red garnet is frequently sold under deceptive names, such as "Cape ruby" and "Arizona ruby," while the green garnet from Russia is known as the "Uralian emerald." This undesirable practice has the effect of increasing the price of the gems masquerading under such titles.

All varieties of garnet crystallize in the cubic system with very similar forms. The rhombic dodecahedron (Fig. 169), and the tetragonal trisoctahedron (Figs. 170 and 171), alone or in combination (Figs. 172, 173, and 174), are the only commonly occurring forms. While the mineral is generally well crystallized, it may occur in compact granular aggregates, in rounded and disseminated glassy grains, or as water-worn pebbles. Garnet has an imperfect rhombic dodecahedral cleavage, and a conchoidal to uneven fracture. The hardness varies from 6.5 to 7.5, and the specific gravity from 3.4 to 4.3, depending upon the composition.

FIG. 170.

FIG. 171.—Garnet (tetragonal trisoctahedrons) in mica schist. Sunday River, Maine.

FIG. 172.—Wooden model showing combination of rhombic dodecahedron and tetragonal trisoctahedron.

FIG. 173.—Rhombic dodecahedral crystals of garnet.

Almost any color except blue may be observed in garnet. Red, brown, yellow, green, and black are the more common colors. It may also be colorless. While the colors are largely due to the elements entering into the composition of the various members of the group, they may be attributed in part to impurities present in minute quantities. The lighter-colored garnets are generally transparent to translucent, while the dark-colored varieties are translucent to opaque. The luster is vitreous to resinous.

The index of refraction is as variable as the other properties, lying between 1.70 and 1.90, which is fairly high. The dispersion is likewise high, ranging from 0.024 to 0.028 for most varieties. However, one variety, the demantoid or grass-green andradite, has a dispersion of 0.057, which is comparable to that of the diamond. Hence, when the color is not too dark, garnets have considerable brilliancy and fire.

The composition of the members of the garnet group is easily expressed by the generalized formula $M''_3M'''_2(SiO_4)_3$, in which M'' represents any of the bivalent metals magnesium, calcium, manganese, or iron, while M''' stands for a trivalent metal, aluminum, ferric iron, or chromium. A small amount of titanium may replace part of the silicon. Thus, a garnet may contain all the bivalent and trivalent metals in almost any proportion, so long as the ratio between the bivalent and trivalent elements is three to two. However, based upon composition, six varieties of garnet have been established. These grade over into one another. Usually the composition of a garnet is much more complex than that theoretically assigned to the variety to which it belongs. In the table below the composition, specific gravity, and index of refraction (*n*) of each of the several varieties are given:

FIG. 174.—Crystal of garnet showing a combination of rhombic dodecahedron (large) and tetragonal trisoctahedron.

Variety	Composition	Specific gravity	Index of refraction, *n*
Grossularite	$Ca_3Al_2(SiO_4)_3$	3.4–3.7	1.735
Pyrope	$Mg_3Al_2(SiO_4)_3$	3.7–3.8	1.705
Spessartite	$Mn_3Al_2(SiO_4)_3$	4.0–4.3	1.800
Almandite	$Fe_3Al_2(SiO_4)_3$	3.9–4.2	1.830
Uvarovite	$Ca_3Cr_2(SiO_4)_3$	3.4–3.5	1.870
Andradite	$Ca_3Fe_2(SiO_4)_3$	3.8–3.9	1.895

Each of these varieties will now be discussed, especially with regard to its use as a gem.

Grossularite.—The lime-aluminum garnet is lighter colored than the other varieties. In fact it would be colorless if absolutely pure. However, pale emerald-green, rose-red, or various shades of yellow and cinnamon-brown are most commonly observed. The yellow- and cinnamon-colored stones are the ones used as gems, under the names *cinnamon-stone*, *hessonite*, or *essonite*. The terms *hyacinth* and *jacinth*, the latter more properly applied to yellow or brown zircon, are also used for these stones. The green- and rose-colored varieties are rarely transparent enough for cutting. Hessonite has a peculiar granular structure, visible even in the cut stones.

Grossularite is characteristically found in metamorphosed, impure limestones, associated with vesuvianite, wollastonite, diopside, scapolite, and other lime silicates. Most of the hessonite is obtained from Ceylon, where it occurs with zircon in gravels.

Pyrope.—This is the most popular garnet, probably because it frequently has a beautiful ruby-red color, due to impurities. Pure pyrope would be colorless. Pyrope is the variety occurring with the diamond in South Africa, where it is sold as "Cape ruby." It is not often found in good crystals, but usually occurs in grains, small irregular masses, and as rolled pebbles. The color varies from deep red to black, often with an undesirable tinge of yellow. *Rhodolite*, which has a color inclining to rose-red or purple, is a mixture of pyrope and almandite, from Macon County, North Carolina.

Pyrope occurs chiefly in basic igneous rocks, such as peridotite, and in the serpentines derived from them. Bohemia, Saxony, South Africa, Arizona, and Colorado are important localities. Rose-cut pyrope is used in cheap Bohemian jewelry.

Spessartite.—This variety is not commonly used in jewelry, since ordinarily its color is an unpopular brown. The color may also be brownish-red, orange-red, or dark hyacinth-red with a tinge of violet. It occurs in granite, quartzite, and with topaz in rhyolite. Bavaria, Tyrol, Ceylon, Virginia, and Nevada are some of the localities for this variety.

Almandite.—The almandite garnet was known to the ancients. It includes the once popular *carbuncle*. The color of almandite varies from deep red and violet-red through brownish-red to black. The transparent red varieties are used as gems. However, most almandite is too dark and opaque for that purpose, and accordingly on account of its superior hardness finds use as an abrasive. In artificial light almandite occasionally has an orange hue. The absorption spectrum is strong, and contains a pronounced band in the yellow, which accounts for the violet hue of some stones (Fig. 97, p. 60). The cabochon cut is most used for the carbuncle, the darker stones being often cut in the hollow cabochon style, whereby a more attractive color is obtained. On some carbuncles a four-rayed cross of light is seen, constituting an interesting type of asterism.

Almandite is found in a variety of rocks, including gneiss, schist, granite, pegmatite, and other igneous rocks. Some localities for the gem variety of almandite are: South Australia; India; Ceylon, in gem gravels; Minas Geraes, Brazil; Uruguay; Tyrol; various parts of the United States, especially Salida, Colorado; and Fort Wrangel, Alaska.

Uvarovite.—This is a rather uncommon emerald-green variety of garnet. Its color is due to the presence of chromium. The crystals are too small to be of value as gems. This variety is obtained principally from Russia.

Andradite.—Since the composition of andradite varies considerably, it is not surprising that it occurs in many colors—brownish-red, brown, black, and various shades of yellow and green. *Topazolite*, as the name indicates, is a variety resembling topaz in yellow color and transparency. *Demantoid* is a grass-green variety, known erroneously as olivine. Demantoid is very brilliant, and has a high dispersion, which is unusual among colored stones. The *Uralian emerald* is an emerald-green andradite, from the Ural Mountains. The black opaque andradite called *melanite* has been used as mourning jewelry. These garnets occur in nepheline syenite, serpentine, chlorite schist, and crystalline limestone. Demantoid is found in the Ural Mountains, in Saxony, and in Hungary. Topazolite occurs in the Piedmont region of Italy.

TOURMALINE

Tourmaline is rather unique in coloring, since a single crystal may be zoned in a variety of beautifully contrasting colors. In addition, the mineral shows strong dichroism, and can be cut in such a way that the colors due to this phenomenon may be seen, which adds still more to the attractiveness of the stone.

Tourmaline commonly occurs in well-developed, prismatic, vertically grooved or striated crystals of the hexagonal system

(Figs. 175, 176, and 177). These crystals generally exhibit a rounded triangular outline (Fig. 178). The vertical axis is polar, that is, different crystal forms are present at opposite ends, one termination being more obtuse than the other. This polar character is further evidenced by the electrical properties of the mineral (see p. 34). Tourmaline occurs also in compact or disseminated masses, and in radially divergent aggregates, also in loose, more or less rounded crystals in secondary deposits.

FIG. 175. FIG. 176.

FIGS. 175 and 176.—Wooden models of crystals of tourmaline.

Tourmaline has no well-defined cleavage. The fracture is subconchoidal to uneven. The hardness is 7 to 7½, a little low for satisfactory use in rings, where the wear is great, though hard enough for brooches, pendants, and so forth. The specific gravity of the mineral is 2.9 to 3.2.

FIG. 177.—Tourmaline in albite. Mesa Grande, California.

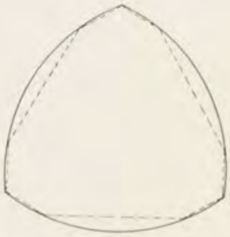


FIG. 178.—Generalized cross-section of a crystal of tourmaline.

In color tourmaline may be pitch black, brown, gray, yellow, green, red, pink, blue, or colorless. The mineral is transparent to opaque. The black and brown varieties are generally opaque, while the lighter-colored stones are more or less transparent. Tourmaline has a vitreous luster.

The colors of the alkali tourmalines are frequently arranged in regular zones or bands. The zones may be horizontal, running across the length of the crystals (Fig. 179, the two outside specimens). Typical arrangements of color are as follows: green at one end, and red at the other, with a narrow colorless zone between; green, followed by yellow, red, and green again; or perhaps crimson or green tipped with black. The contacts between the zones are sharp, increasing the contrast in coloring. Again, the colors may be arranged in vertical, somewhat cylindrical zones, parallel to the prism faces of the crystal. In this case, a cross-section through the stone reveals the zonal character (Fig. 179, the central specimen, and Figs. 180 and 181). In Brazilian stones the core is generally red, with a marginal zone of green, and an intermediate colorless band. This arrangement is reversed in the case of crystals from southern California, which are most often green inside and red outside. Stones from Madagascar frequently have numerous narrow zones in various shades. Sometimes both types of zoning are observed in a single crystal.

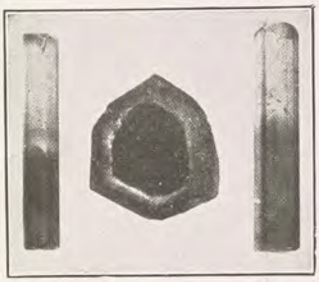


Fig. 179.—Tourmaline crystals showing zonal distribution of color and spherical triangular outline. San Diego County, California.

Fig. 180.

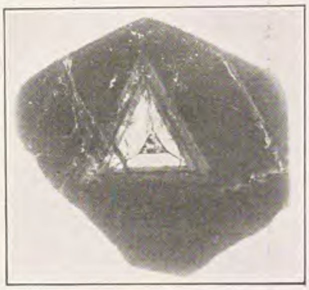


Fig. 181.

Figs. 180 and 181.—Sections of tourmaline from Madagascar showing pronounced zonal distribution of color. Fig. 180, pink and green. Fig. 181, light and dark green.

Tourmaline is optically negative, and has a strong birefringence, 0.020. The mean index of refraction is near 1.63, and the dispersion is 0.016. The strong dichroism is a prominent character. The ordinary ray is much more strongly absorbed than the extraordinary ray, and, therefore, to obtain the best color, the stone is usually cut with the table parallel to the vertical axis and prism faces. Not only is the color brighter if the stone is so cut, but both of the dichroic colors may be seen as the stone is turned about in various directions, giving a very pleasing variation in color.

The composition of tourmaline is rather complex. Authorities differ somewhat as to the correctness of the formula, which is generally written $H_{20}B_2Si_4O_{21}$, the mineral being a borosilicate. It is assumed that fluorine, lithium and other alkalies, magnesium, calcium, manganese, iron, and aluminum replace hydrogen in the above formula.

It is chiefly the tourmaline that is rich in alkalies which is transparent and possesses the most attractive colors. The varieties of tourmaline used as gems are: *achroite*, colorless; *rubellite*, rose-red or pink; *Brazilian emerald*, green; *Brazilian sapphire*, blue; *Brazilian peridot*, yellowish-green; *peridot of Ceylon*, honey-yellow; *siberite*, violet; *indicolite*, dark blue. The iron tourmaline, or *schorl*, is black; and the tourmaline rich in magnesia is brown.

In the cutting of tourmaline various styles are employed. The multicolored stones are very attractive when cut in a long cabochon or step style. The brilliant cut is also used for the mineral. Internal feathers and cracks are the flaws most common in tourmaline.

Tourmaline occurs in metamorphic rocks, such as gneiss, schist, and limestone, and in pegmatites. It is in pegmatites that the gem varieties are principally found. Quartz, beryl, apatite, topaz, and fluorite are some of the associated minerals. Localities for the mineral are numerous. On the Island of Elba are found pink, red, green, black, colorless, and zoned crystals; crystals, black at the upper end and colored below, are called "nigger-heads." Magnificent tourmalines, in a great variety of colors, and frequently zoned, are found at many localities in Madagascar. Small yellow stones of gem quality are obtained from Ceylon. These were the first tourmalines to appear in Europe. Other important foreign localities are India; Burma, in alluvial deposits; Siberia; and Brazil. In the United States there are two widely separated regions famous for their beautifully colored tourmalines: in Maine, at Mount Mica, Mount

Apatite, and Mount Rubellite, in the towns of Paris, Auburn, and Hebron, respectively; and the Mesa Grande district, in San Diego County, California. Other localities in this country are Chesterfield and Goshen, Massachusetts; Haddam, Connecticut; Gouverneur, DeKalb, and Pierrepont, New York; and Chester County, Pennsylvania.

OLIVINE

The mineralogist's olivine is better known to the jeweler as *peridot* and *chrysolite*, or as the *evening emerald*. Olivine is used, improperly, as a trade name for green garnet and other green stones.

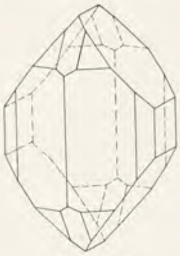


FIG. 182.

FIG. 183.—Olivine (green glassy grains). Near Balsam, North Carolina.

Olivine belongs to the orthorhombic system. It occurs in crystals (Fig. 182), rounded and disseminated grains, granular masses (Fig. 183), and as water-worn pebbles (Fig. 184). The mineral has pinacoidal cleavages in two directions. The fracture is conchoidal. The hardness of olivine is not high for a gem, $6\frac{1}{2}$ to 7. The specific gravity is 3.2 to 3.6, or even higher.

In color olivine has less variety than the previously described minerals. Various shades of green and yellow, brown, reddish, grayish, and colorless comprise the list. The best color is a beautiful bottle green, which, however, is not observed as frequently as the other less-desired shades. The olive-green variety is called *peridot*, the yellow to greenish-yellow stones have the name *chrysolite*. The

FIG. 184.—Water-worn pebbles of olivine. Fort Defiance, Arizona.

luster of olivine in general is vitreous, on fractured surfaces greasy. It is transparent to translucent.

Olivine is biaxial and optically positive, with the high birefringence of 0.04, and a mean index of refraction of about 1.68. The dispersion is 0.018. Pleochroism is weak in this mineral.

The composition of olivine is $(Mg,Fe)_2SiO_4$, that is, iron and magnesium freely replace one another.

The cuts generally employed are the step and the brilliant, but the cabochon is sometimes used. Being soft, the stone does not long retain a good polish or sharp edges when exposed to wear.

Olivine occurs in basic igneous rocks and in limestones. It has been reported that olivine of gem quality occurs in meteorites. Most gem olivine is obtained from an island in the Red Sea, named Zeboiget, belonging to Egypt. Other localities are Burma, Ceylon, Queensland, Brazil, and the Navajo Indian country of Arizona and New Mexico, where it occurs as a constituent of sand. It is believed that much of the modern olivine has been recut from old jewelry.

SPINEL

As indicated by the names of some of its varieties, such as ruby spinel, balas ruby, and rubicelle, red spinel has often been confused with the ruby, especially since the two minerals are associated in gem gravels. Spinel has been called "mother of ruby," on account of this association, and many historic "rubies" were in all probability red spinel. Blue spinel may likewise be mistaken for sapphire. Actually the distinction between spinel and the ruby and sapphire is not difficult, since spinel is softer, lighter in weight, isotropic, and not pleochroic.

FIG. 185.—Spinel (octahedron and rhombic dodecahedron) in calcite. Franklin Furnace, New Jersey.

FIG. 186.—Octahedral crystals of ruby spinel. Ceylon.

Spinel is cubic. Generally the crystals have an octahedral habit, and are often modified by the rhombic dodecahedron (Fig. 185). Contact twins, in which an octahedron face is the twinning plane, are common. These are known as *spinel twins* (Fig. 42, p. 19). The mineral occurs as disseminated or loose crystals (Fig. 186), or as rounded grains.

The cleavage is imperfect octahedral, the fracture conchoidal. In hardness spinel is rather superior, the value being 8. The specific gravity is 3.5 to 4.1, that of the gem varieties lying between 3.5 and 3.7.

The colors of spinel are red, orange, yellow, green, blue, violet, brown, and black, with many intermediate hues. Blue varieties have an absorption spectrum characteristic of cobalt, which is probably their pigment. The red and green varieties are thought to be colored by chromium and iron, respectively. The luster is vitreous splendent to dull, and the mineral is transparent to opaque. Most varieties have an index of refraction near 1.72, and a dispersion of 0.020. Being cubic, spinel is isotropic.

Spinel is a magnesium aluminate, $Mg(AlO_2)_2$. The magnesium may be replaced in part by ferrous iron, zinc, manganese, or cobalt; the aluminum by ferric iron or chromium.

The following gem varieties are distinguished: *ruby spinel*, deep red and transparent, the most popular gem variety; *balas ruby*, rose-red to pink; *rubicelle*, yellow to orange-red; *almandine*, violet and purple; *sapphirine*, blue spinel; *chlorospinel*, iron-bearing, of a grass-green color which is probably due to a trace of copper.

Spinel occurs in contact metamorphosed rocks, such as limestone, serpentine, and gneiss, and in gravels. Gem spinels are found as pebbles in the placers of Ceylon, Burma, and Siam. Some are also supplied by India, Tartary, Afghanistan, and Brazil. Important European localities are: Åker, Sweden, pale blue spinel; and Expailly, France. Some good gem material has been obtained from the limestones and serpentines of northern New Jersey and southeastern New York.

CHRYSOBERYL

Two rather unusual gems are varieties of the mineral chrysoberyl. To one, alexandrite, belongs the striking property of having a different color in artificial light than in daylight; the other, cat's eye, has a marked chatoyancy, and was once very popular.

Chrysoberyl is orthorhombic, and the usually striated crystals are often twinned into heart-shaped (Figs. 187 and 188) and pseudo-hexagonal (Fig. 189) forms. Crystal fragments and loose or rounded grains are also found. The mineral has a distinct pinacoidal cleavage, and a conchoidal fracture. The hardness is 8½, and chrysoberyl is therefore very durable. Its specific gravity is 3.5 to 3.8. The color is greenish-white, greenish-yellow, or asparagus to emerald-green; less often yellow to brown. The luster is generally vitreous, in cat's eye silky. Chrysoberyl is transparent to translucent. Pleochroism is noted in the more deeply colored varieties. The mean refractive index is 1.75, the double refraction 0.010, and the dispersion 0.015. The optical character is positive.

FIG. 187.

FIG. 188.—Chrysoberyl (twin). Haddam, Connecticut.

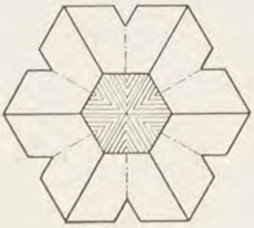


FIG. 189.

Chrysoberyl is a beryllium aluminate, $Be(AlO_2)_2$. It may contain a little iron and chromium.

There are three gem varieties of chrysoberyl:

Chrysolite is a name given to the yellowish-green chrysoberyl, but more properly applied to olivine with the same color.

Cat's eye or *cymophane* is a chatoyant variety, with a silky luster and a greenish color. When it is cut cabochon, a white line of light crosses the stone, giving it the resemblance to a cat's eye. This is due to the more or less fibrous structure of the mineral.

Alexandrite, the last variety, is interesting in more than one way. It was named in honor of Czar Alexander II of Russia, for it was first discovered in 1833, in the Ural Mountains, on the day on which his attainment to majority was celebrated. The gem is strongly pleochroic, showing the colors emerald-green, columbine-red, and orange-yellow. This difference in color is easily visible to the unaided eye. A striking property of alexandrite is that it has an emerald-green color in daylight, but in artificial light it is columbine-red. It has a strong absorption band in the yellow, and this in conjunction with the difference in composition of sunlight and artificial light causes the above phenomenon, which is further intensified by the strong pleochroism. This stone has been in considerable vogue in Russia, where red and green have been popular as military colors. Furthermore, the gem was named after the Czar, and for a time was found only in the Ural Mountains.

Certain solutions containing trivalent chromium have the same strikingly characteristic property of being blue-green by daylight and red in artificial light. This strongly suggests chromium as the cause of the color, and analyses of alexandrite show a trace of that element. Alexandrite has been rather successfully imitated by appropriately colored artificial corundum, vanadium being the pigment (p. 100). Vanadium and chromium are closely related elements, and some of the solutions of vanadium also have a color that varies according to the type of illumination, though the phenomenon is less marked than in the case of chromium.

Alexandrite cat's eye is the name given to chatoyant alexandrite from Ceylon.

Chrysoberyl occurs in gneiss, mica schist, and granite, with such minerals as beryl, tourmaline, and apatite. Chrysolite is found in Brazil; Haddam, Connecticut; Greenfield, New York; and Norway and Stoneham, Maine. The cat's eye variety is obtained from Ceylon, China, and Brazil. Alexandrite is found in the Ural Mountains, and in Ceylon and Tasmania.

ZIRCON

Colorless zircon is next after the diamond in brilliancy and fire. The mineral also occurs in very pleasing colors. However, it is not nearly as well known as its properties would warrant.

Zircon is tetragonal. The crystals are usually prismatic in habit (Figs. 190, 191, and 192). It is also found in rounded or angular lumps or grains. The cleavages, prismatic and pyramidal, are imperfect; the fracture conchoidal. The hardness varies from one specimen to another, but is never far from 7½. The specific gravity has a wide range, 4.0 to 4.8.

The more usual colors are brown, brownish-red, and gray; less often yellow, green, blue, and colorless. The color is said to be due to iron and other constituents. Zircon is transparent to opaque, and has an adamantine luster. The indices of refraction, ω 1.92 and ϵ 1.97, the double refraction, 0.05, and the dispersion, 0.038, are all high. The mineral is normally uniaxial and positive in optical character. Some crystals, however, show anomalous optical properties, being biaxial, with indices of refraction of 1.79 to 1.84. The varieties containing uranium have a very characteristic absorption spectrum, consisting of a number of sharp, narrow bands throughout the spectrum (Fig. 97, p. 60).

FIG. 190.

FIG. 191.

FIGS. 190 and 191.—Wooden models of crystals of zircon.

FIG. 192.—Zircon in syenite. Ilmen Range, Ural Mountains.

Zircon is an oxide of zirconium and silicon, $ZrSiO_4$, but it is sometimes grouped with the silicates. Usually a little iron is present, and a number of other elements are occasionally contained in the mineral. A rather constant impurity in zircon is the most recently discovered element, hafnium.

The gem varieties of zircon are as follows:

Hyacinth and *jacinth* are the terms applied to the clear, transparent, yellow, orange, red, and brown varieties.

Jargon includes most of the other colors.

Matura diamond is the name given to zircon from Ceylon, either naturally colorless, or made so by subjecting pale brown stones to a heat treatment.

Attractive pale blue zircons have recently been exported from Siam and Queensland.

The variability in the characters of zircon is noteworthy. Indeed it has been proposed to recognize three different forms of the mineral, differing in specific gravity, hardness, optical properties, and behavior on heating. The three types are characterized by different colors, also. One type is usually green, sky-blue, or golden-yellow; another is light green, blue, or honey-yellow; and the third is yellowish-green, cloudy-blue, or green.

Gem zircons are found, largely in secondary deposits, in Ceylon, which is the home of "Matura diamonds"; Mudgee, New South Wales, red; Policeman Knob, Queensland, blue; Expailly, France, hyacinth and red zircon; Ilmen Mountains, Russia. In the United States little gem material is found, though zircon occurs in Maine, New York, and North Carolina.

OPAL

The opal was long in disfavor, for it had been considered a stone likely to bring misfortune and disaster upon its owner. In recent times this superstition has lost ground, and the opal has become much more popular. Some of the finer varieties are now highly valued. The ancients regarded opal as a very precious stone. Pliny ranked it next after the emerald, and describes it as embodying in one stone the colors of many gems.

Unlike most gem minerals, opal, being amorphous, has no crystal form. Accordingly it occurs as compact and irregular masses in veins and cavities. It may also be stalactitic or earthy. Opal has a good conchoidal fracture. It is fairly soft, 5½ to 6½, and therefore should not be exposed to undue wear. However, a worn and scratched stone can be restored by repolishing. Opal is light in weight, the specific gravity being 2.1 to 2.3.

The luster of opal is vitreous, dull, or greasy, and the mineral is transparent to opaque. The color varies greatly. Opal may be colorless, white, yellow, brown, red, pink, green, gray, blue, or black. A beautiful play of colors is to be observed, especially in the precious varieties. This is due to the interference of light, and must not be confused with the fire caused by dispersion

(p. 37). It is a result of the breaking up of white light into its component colors within the mineral. This is caused either by minute cracks, or more probably, by the presence in the mineral of scattered patches in which the water content and consequently the refractivity differ from those of the body of the substance. Opal is formed from gelatinous silica, deposited in cracks and cavities from aqueous solution. In hardening the silica loses some of its water and contracts, thus becoming opal. This contraction is likely to produce fissures, which may be later filled with another generation of silica, yielding opal with an index of refraction differing somewhat from that of the remainder of the mass. When these areas are thin enough, a play of colors is produced in the same way that an oil film on water shows rather vivid colors.

Opal is isotropic, with an index of refraction of about 1.44 to 1.45, varying with the water content. Anomalous double refraction is not unusual.

The formula for opal is $SiO_2.xH_2O$, that is, it is a hydrated silica. The content of water varies from 1 to 21 per cent. It usually ranges from 3 to 13 per cent, and in the precious opal the amount of water is generally from 6 to 10 per cent. Impurities are not uncommon, as is the case with all amorphous minerals, which seem to have the faculty of absorbing foreign matter. Calcium, iron, magnesium, sodium, and aluminum compounds as well as bitumen, are frequently present.

Precious opal includes only the opals with a good play of colors. These are cut cabochon, in order best to display this phenomenon.

Common opal is translucent to opaque, and of many dull colors.

The following are varieties of precious opal:

White opals are those precious opals of a light color.

Black opals include the dark gray, blue, and black types.

Harlequin opals have patches of color which are rather uniform in size.

Lechosos opal is a variety showing a deep green play of color.

Fire opal is a semi-transparent variety of yellow or red color, with a fiery play of color.

Girasol is blue-white and translucent, with a red play of color.

Opal matrix is the term applied to cut stones consisting of opal in its matrix.

The following varieties of common opal, having little or no play of color, are not precious, but nevertheless of interest:

Milk opal is milk-white, yellowish, bluish, or greenish in color.

Resin opal is wax-, honey-, or ocher-yellow in color, and has a resinous luster.

Agate opal is a banded opal.

Opal jasper is red, reddish-brown, or brown, resembling jasper.

Prase opal is green in color.

Rose opal or *quinzite* is a beautiful pink variety.

Liver opal or *menilite* is concretionary, and brown or gray.

Wood opal is pseudomorphous after wood, the woody structure being faithfully retained. Pseudomorphs of opal after bones and shells are also known.

Hyalite is colorless and transparent, resembling drops of molten glass.

Hydrophane is cloudy, white, dehydrated opal, which becomes transparent when its pores are filled by immersion in water.

Tabasheer is deposited within the joints of bamboo, and likewise becomes transparent in water.

Cacholong is a bluish-white, porcelain-like variety, which is very porous, and adheres to the tongue.

Moss opal, like moss agate, contains inclusions of manganese oxide, which resemble moss.

Geyserite or *siliceous sinter* is a porous variety which is deposited from hot springs. It has a cauliflower-like structure.

Tripolite or *diatomaceous earth* is earthy and porous, chalk-like in appearance, and is composed of the siliceous remains of minute sea organisms.

Opal is formed in a variety of ways, but most of it results from the decomposition of silicate minerals by hot waters. The dissolved silica is subsequently deposited in cracks or crevices. This process takes place especially in recently erupted lavas. The early source of opal was Czerwenitza, near Kashau, Hungary. Lately much precious opal of fine quality has been obtained from various localities in Australia:—in New South Wales—at White Cliffs as pseudomorphs, and at Lightning Ridge as black opal; in Queensand, blue opal has been obtained from Bulla Creek and also from Barcoo River. Gracia á Dios, in Honduras, is another locality for precious opal. Fire opal is found at Queretas and Zimapan, Mexico. Humbolt County, Nevada, has produced some fine black opals. Good opal has also been found in Latah County, Idaho. Common opal is widely distributed.

QUARTZ

Quartz is the most common mineral in the earth's crust. It occurs in nearly every type of rock, igneous, sedimentary, or metamorphic. It is found in formations of all ages. Quartz occurs filling cracks and crevices, and it is the most abundant constituent of sands and gravels. It has been aptly called a "tramp" mineral. Some varieties are quite attractive, and are classed as semi-precious stones. In one form or another, quartz has been known from the earliest times. One of its varieties, flint, was employed in the manufacture of primitive weapons, and for the production of a spark in the building of fires. Because of its useful and definitely recognized properties, it was undoubtedly one of the first minerals to be eagerly sought.

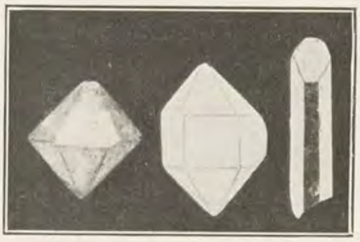


FIG. 193.—Quartz crystals—pyramidal, prismatic, long prismatic.

FIG. 194.

FIG. 195.

FIGS. 194 and 195.—Models of right- (195) and left-handed (194) crystals of quartz.

FIG. 196.—Model of twinned crystal of quartz.

Quartz is hexagonal, and occurs in well-developed prismatic crystals (Figs. 193 to 196). The prism faces are generally horizontally striated. More rarely the crystals have a pyramidal development (Fig. 193). Over 140 crystal forms have been observed on this mineral. The crystals are sometimes bent or twisted, or otherwise greatly distorted. That quartz may occur in right- and left-handed crystals (Figs. 195 and 194) has already been indicated (p. 55). Twins are frequently observed. Figure 196 illustrates the most common type, in which the vertical axis is the axis of twinning. The twin may be considered as composed of interpenetrating right- and left-handed crystals. Other types of twins are not uncommon.

Quartz crystals frequently contain various inclusions, as follows: (*a*) solids, such as rutile, hematite, epidote, and organic matter; (*b*) liquids, including water and liquid carbon dioxide; and (*c*) gases, mostly carbon dioxide.

The cleavage is rhombohedral, but indistinct and only rarely observed. The fracture is perfect conchoidal. Quartz, having a hardness of 7, is durable (p. 24). The specific gravity of pure quartz is 2.66, though the varieties range from 2.5 to 2.8.

Pure quartz is colorless, but the mineral is to be seen in practically every color, due to impurities. Many of the varieties are based on differences in color. Various shades of gray, yellow, pink, red, blue, green, brown, purple, and black are to be noted. The colors are in many cases unstable, being destroyed by a low heat. They are also susceptible to change by the action of radiations, such as ultra-violet light and those of radium. The colors are generally attributed to traces of inorganic, or possibly organic, impurities. For some of the more labile colorings the action upon quartz of radioactive waters or minerals, subsequent to the formation of the mineral, has been suggested as the cause of the color. The luster of quartz is vitreous. The mineral may be transparent, translucent, or opaque.

Quartz is uniaxial and optically positive. Its mean index of refraction, 1.55, its double refraction, 0.009, and its dispersion. 0.013, respectively, are all low. It is optically active, rotating the plane of polarized light. Right-handed crystals rotate the plane of polarization to the right, left-handed crystals, to the left.

The composition of quartz is simply SiO_2, silicon dioxide. Some quartz is very pure, being composed almost entirely of silica. But usually quartz is somewhat impure, containing as inclusions varying amount of minerals, besides other foreign matter. It is frequently pseudomorphous after other minerals, or after wood, as in silicified wood. Quartz is usually considered a very resistant mineral, but in nature it may be replaced by other minerals, including even the very soft talc.

The varieties of quartz may be grouped into the following three large classes:—

Phanerocrystalline varieties are vitreous, crystallized or crystalline, and more or less transparent.

Cryptocrystalline varieties are compact and homogeneous, with a crystalline structure which may be observed with the microscope.

Clastic varieties are those which are made up of fragments of quartz, usually cemented into a coherent mass. These include the pure siliceous rocks known as sandstone and quartzite.

The gem varieties of quartz belong to the first two groups. Those which are phanerocrystalline may be cut in faceted forms or cabochon, while those which are cryptocrystalline are cut cabochon or in large polished pieces. The value of quartz gems is determined principally by the cost of cutting.

Phanerocrystalline Varieties.—*Rock crystal* is pure, transparent and water-clear quartz (Fig. 197). It is usually, but not always, well crystallized (Fig. 198). Rock crystal, cut into vases, crystal balls, and so on, has long enjoyed considerable popularity. Cut into beads and fancy shapes, or fashioned to resemble the diamond, this variety of quartz is often sold under such names as "Rhinestone," "Herkimer diamond," "Lake George diamond," "Alaska diamond," or "Cornish diamond." Rock crystal is among the most abundant of gem minerals. However, the following principal localities may be mentioned: Japan, Madagascar, Switzerland, Brazil, New York, and Arkansas.

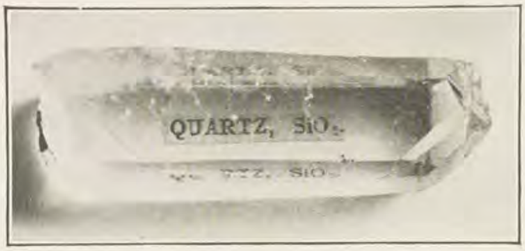


FIG. 197.—Rock crystal. Dauphiné, France.

Amethyst is a purple or violet, transparent, variety of quartz. It is usually well crystallized. The color varies a great deal in intensity, and is often unevenly distributed. The pigment is probably an iron compound. The color is easily discharged by heat, changing first to yellowish, and finally becoming colorless. Amethyst is slightly dichroic. It is cut step or brilliant. Important localities are: Ceylon, India, Madagascar, Persia, Siberia, Uruguay, Brazil, Mexico, Maine, Pennsylvania, North Carolina, and the Lake Superior district.

Rose quartz is invariably massive, transparent to translucent, and of a rose-pink color, due to manganese. In the darker specimens there is slight dichroism. The mineral is often opalescent and asteriated. It is cut cabochon, or in beads. *Bohemian ruby* is a trade name for rose quartz. Japan, Madagascar, Bavaria, France, Brazil, Maine, South Dakota, and California are important localities.

FIG. 198.—Quartz. Dauphiné, France.

FIG. 199.—Smoky quartz with muscovite. Paris, Maine.

Smoky quartz is a variety which is smoky-yellow to dark brown or black in color (Fig. 199). *Scotch topaz* and *cairngorm* are other names for smoky quartz, while *morion* is a term applied to the black variety. Like amethyst, smoky quartz is easily decolorized by heat. The color is probably due to the action of radium radiations. Smoky quartz is slightly dichroic. It is usually cut in the brilliant style, and is a great favorite in Scotland, where it is used in brooches, pins, and other ornaments. Important localities are: Ceylon; the Alps; Cairngorm, Scotland; Paris, Maine; and Pike's Peak, Colorado.

Citrine, also known as *false topaz,* is yellow quartz resembling topaz in color and transparency (Fig. 200). It is usually found in crystals. The color is ascribed to ferric iron. Citrine is sometimes produced by a partial decolorization of other varieties of quartz, by means of heat. Much citrine comes from Brazil.

Milky quartz is translucent to opaque. It has a milky-white color. Milky quartz containing native gold is sometimes cut cabochon or with a flat surface and called *gold quartz*. California and Alaska supply this variety of quartz, which also occurs in other gold-mining districts.

Siderite or *sapphire quartz* is a rare variety having an indigo or Berlin blue color.

Aventurine quartz contains glistening scales of hematite or other brightly colored minerals. It is usually yellow, brown, green, or red in color. Aventurine is found in Siberia, China, and Madagascar. An imitation aventurine, known as *gold-stone* (p. 93), is extensively used in cheap jewelry.

FIG. 200.—Citrine intaglio.

FIG. 201.—Rutilated quartz. Alexander County, North Carolina.

Rutilated quartz or *sagenite*, more fancifully known as *Venus* or *Thetis hairstone*, is rock crystal containing long, fine, hair-brown needles of rutile (Fig. 201). This variety is found in Madagascar, Switzerland, Brazil, Vermont, and North Carolina. Other minerals, such as hornblende, actinolite, and goethite, may occur in quartz in a similar manner. Pale amethyst penetrated by needles of goethite is cut and sold as "Cupid's darts." It is also called *onegite*, from Lake Onega, Russia, a locality for this variety.

Tiger's eye is quartz which is pseudomorphous after crocidolite, and which retains the fibrous structure of the original mineral (Fig. 202). When cut cabochon this variety is strongly chatoyant. It is yellowish-brown, bluish, or red in color. It is used in cheap jewelry, and for ornamental objects, such as paper weights and umbrella handles. Griqualand West, in South Africa, is the principal source of tiger's eye.

Cat's eye is chatoyant, containing parallel fibers of asbestos, and is grayish, brownish, or green in color. This variety somewhat resembles the more valuable chrysoberyl cat's eye or cymophane (p. 138). Like that mineral, it is cut cabochon. Important localities are Ceylon, India, Bavaria, and Brazil.

Cryptocrystalline Varieties.—*Chalcedony* is a transparent to translucent, light-colored, white, gray, brown, or blue form of quartz, with a waxy luster. It may occur as stalactitic (Fig. 203) or concretionary forms, or as a lining of cavities. It was very popular in ancient times, and is frequently referred to in Biblical literature. Chalcedony is cut cabochon. Uruguay, Brazil, and the Lake Superior district are localities for chalcedony.

Carnelian or *sard* is a reddish chalcedony. It varies in color from a pale red to deep clear red, and through brownish-red to brown. Ferric oxide causes the color.

FIG. 202.—Tiger's eye. Griqualand West, South Africa.

FIG. 203.—Chalcedony (stalactitic). Havana, Cuba.

Chrysoprase is a variety of chalcedony having an apple-green color due to a trace of nickel. Chyrsoprase is obtained from Silesia.

Prase is translucent, with a dull leek-green or sage-green color. It was used by the ancients for engravings. Saxony is a locality for prase.

Plasma has for its color some shade of green, often a dark grass-green. It contains irregularly distributed white or yellowish spots.

Heliotrope or *bloodstone* is a dark green chalcedony containing scattered spots of red jasper. It was frequently used in the early church as the material for engraved sacred objects, in which the red spots represented blood stains, and was called "St. Stephen's stone." Bloodstone is used in signet rings. It is found in India, Siberia, and the Hebrides.

Agate is one of the most popular cryptocrystalline varieties of quartz. It consists of chalcedony in which the color is irregularly distributed. Usually the colors are disposed in parallel bands, which are more or less wavy. Such varieties are called *banded agates* (Figs. 204, 205, 206, and 207). Sometimes the differently colored bands are circularly or elliptically arranged in such a manner as to resemble an eye (Fig. 208). The term "*eye agates*" is applied to such occurrences. In *fortification agates* the bands are angular, and so arranged as to simulate the outline of a fortification. The name *clouded agate* is self-explanatory. *Moss agate* (Fig. 209) is a variety which contains dendritic inclusions of dark pigmenting matter. These resemble moss or ferns. *Agatized wood* is clouded agate pseudomorphous after wood.

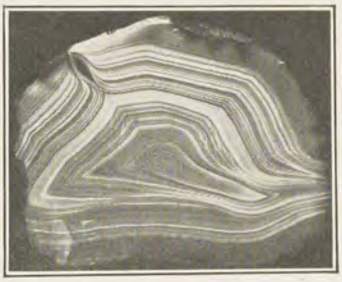


Fig. 204.—Agate. Brazil.

Fig. 205.—Agate. Serra do Mar, Brazil.

The colors of agate are white, brown, red, bluish, and so on. More often than not cut agates have been artificially colored

(p. 93). This variety of quartz is most frequently cut with large plane or slightly curved surfaces such as will best display the banding. Oberstein and Idar, in Germany, are very important localities, where much of the cutting is done. Other localities are Uruguay and the Lake Superior district.

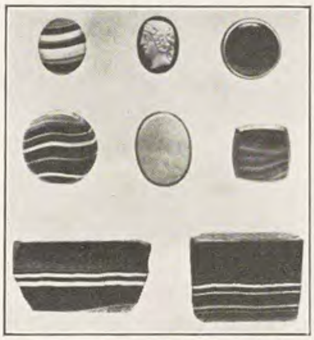


FIG. 206.—Cut and polished agate and onyx.

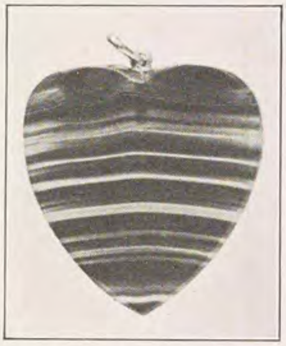


FIG. 207.—Agate. Serra do Mar, Brazil.

Onyx is like agate, except that the colored bands are horizontal (Fig. 210). The colors are generally white or black. Onyx is used for cameos (Fig. 206).

Sardonyx consists of layers of red carnelian in combination with white layers of onyx.

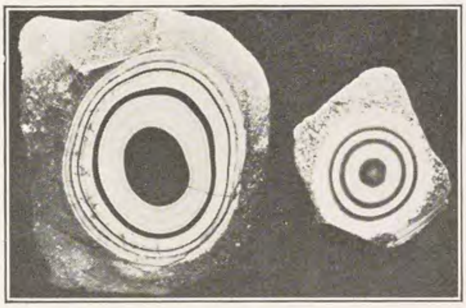


FIG. 208.—"Eye" agates.

Jasper is an opaque, red, yellow, brown, dark green, or grayish-blue cryptocrystalline quartz. It is rather impure. When the colors are in broad bands or stripes, the name *riband jasper* is applied. *Egyptian jasper* is a yellow to brown variety, irregularly marked.

Flint is translucent to opaque, and gray, smoky, brown, or black in color. It is usually found in nodules in limestone or chalk beds, and frequently has a white coating upon the exterior of the mass (Fig. 211). The conchoidal fracture is very conspicuous. Flint was used very generally by primitive peoples for knives and for arrowheads and spearheads. The Chalk Cliffs along the English Channel are a famous locality for flint.

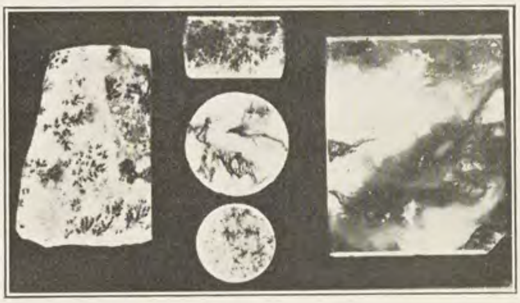


FIG. 209.—Moss agate.

Basanite is a velvet-black variety of quartz formerly used for determining the streak of alloys of precious metals. It was also called *touchstone*.

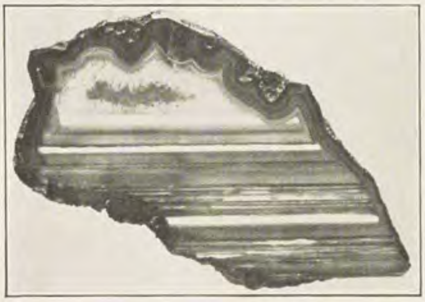


FIG. 210.—Onyx. Serra do Mar, Brazil.

FIG. 211.—Flint. Dover Cliffs, England.

Hornstone and *chert* are rather impure and unattractive varieties of cryptocrystalline quartz. They are generally of a grayish color.

Clastic Varieties.—The clastic varieties of quartz include no gems. *Sand, sandstone,* and *quartzite* are widely distributed. *Itacolumite* is rather unique in that it is a flexible sandstone. It is found in India and Brazil.

TURQUOIS

Because its distinctive blue color forms a very agreeable contrast to a gold setting, turquois has been popular since ancient times. The cabochon cut is employed for this stone.

Turquois is apparently amorphous, occurring in veins or crusts, and as rounded masses, disseminated grains, or rounded pebbles. It was not until 1912, when minute crystals of turquois were found in Virginia, that the true, crystalline character of this mineral became known. It is triclinic. With the exception of this one occurrence, it has never been found in crystals. The fracture is conchoidal. Its hardness is 6, the specific gravity 2.6 to 2.8. Turquois is usually opaque. The luster is somewhat waxy.

The color varies from greenish-gray, yellowish-green, apple-green, and greenish-blue, to sky-blue. Turquois with a sky-blue color is most valued. Unfortunately the color is susceptible to a change to an undesirable green. The mineral is porous, and easily becomes dirty and greasy. Perspiration has a bad effect on the color. Exposure to sunlight and heating causes the color to fade. It is said that a temporary restoration of the blue color can be effected by soaking the gem in ammonia, followed by an application of grease. The stone is sometimes dyed in blue solutions in an attempt to improve the color.

Since turquois is opaque, its optical properties have no relation to its appearance. The mean index of refraction is 1.63.

The formula for turquois is not simple: $H_5[Al(OH)_2]_6Cu(OH)(PO_4)_4$. It is a basic phosphate of copper and aluminum. Ferric iron may replace part of the aluminum. The blue color is due to copper. Ferric iron, if present, imparts a greenish shade.

Turquois matrix is the name applied to gems consisting of bits of turquois in the associated rock. The matrix is usually limonitic.

Bone or *fossil turquois*, also called *odontolite*, is mineralogically not a variety of true turquois. It consists of fossil bones or teeth, colored blue by vivianite, a hydrated iron phosphate. Odontolite and true turquois may be distinguished, when dissolved in hydrochloric acid, by the addition of ammonia to the solution. The solution of turquois becomes deep blue, due to the copper, while this is not the case with odontolite. Aside from the substitution of odontolite, turquois is imitated in appropriately colored opaque glass.

Turquois is formed by deposition from solutions, and its most common associates are limonite, quartz, feldspar, and kaolin, of which the first is very characteristic. Fine turquois is found near Nishapur, in the province of Khorassan, Persia. *Egyptian turquois* comes from the Sinai peninsula. Other localities for turquois are: New South Wales; Queensland; Victoria; and Turkestan. In the United States the mineral occurs at Los Cerillos, New Mexico; Turquois Mountain, Arizona; San Bernardino County, California; and Nye County, Nevada.

VARISCITE

Being somewhat like turquois in appearance, variscite is sometimes used in its place. The properties of the two minerals, however, are entirely different. Variscite is orthorhombic, and occurs in crusts, rounded nodules, or crystalline aggregates. It has a hardness of 4 to 5. The specific gravity is 2.55. The color, apple-green to blue-green, is due to chromium or vanadium. The luster is vitreous, and the mineral is translucent to opaque. Variscite is a hydrated aluminum phosphate ($AlPO_4.2H_2O$).

Variscite occurs in shales or slates. Important localities are Lucin, Utah, and Tooele County in the same state. The name *utahlite* is given to the compact variety.

JADE

The material known as jade includes two minerals of similar appearance, nephrite and jadeite. It is convenient to discuss them together, since a distinction is rarely made except by the mineralogist. Jade is placed above all other precious stones by the Chinese and Japanese, by whom it is carved into elaborate figures and designs. The Chinese believe that jade embodies the five cardinal virtues: charity, modesty, courage, justice, and wisdom. Remedial qualities are also ascribed to it. Primitive peoples likewise regarded jade with esteem, and they fashioned it into ornaments, and axes and other implements. Such objects have been found in the Swiss lake dwellings; and in France, Greece, Egypt, Asia Minor, New Zealand, Alaska, British Columbia, Mexico, Central America, and northern South America.

Nephrite is the more common form of jade. It is a monoclinic variety of amphibole. The mineral is compact and tough, and the fracture is splintery. The hardness is 6½, and the specific gravity 2.9 to 3.1. The color, which is often irregularly distributed, varies from white to leaf-green and dark green, the green being due to ferrous iron (Fig. 212). Nephrite has a glistening luster, and is translucent to opaque. It is pleochroic, and has a mean index of refraction of 1.62. The composition of nephrite is $Ca(Mg, Fe)_3(SiO_3)_4$; that is, it is a calcium, magnesium and iron silicate.

Jadeite is a monoclinic member of the pyroxene group of minerals. It is rarer than nephrite. Like nephrite, it is tough and compact, and has a splintery fracture. In hardness it is 6½ to 7. The specific gravity is 3.3. A specific gravity determination will, therefore, serve to distinguish the two minerals. The color is white or greenish-white to emerald-green. The luster is subvitreous to pearly. Jadeite is translucent to opaque. The mean index of refraction is 1.67. Jadeite is a sodium aluminum silicate, $NaAl(SiO_3)_2$. It fuses more readily than nephrite. *Chloromelanite* is a dark green to nearly black variety of jadeite.

FIG. 212.—Jade: Variety, nephrite, South Island, New Zealand. (One-fifth natural size.)

Nephrite occurs in various parts of China, and in Turkestan, Siberia, New Zealand, and Alaska. Jadeite is found in Upper Burma, Yunnan, southern China, Tibet, and perhaps Mexico and South America.

Certain greenish varieties of a number of other minerals have some resemblance to jade. Some of these are: saussurite, a tough, white to greenish-gray variety of zoisite (p. 183); bowenite, a green serpentine (p. 181) resembling jade, from Rhode Island and New Zealand; amazonite, a green microcline feldspar (p. 164); and also massive greenish forms of pectolite, prehnite (p. 165), and vesuvianite (p. 169).

ANATASE

Transparent brown anatase is occasionally cut for gem purposes. This mineral is also called *octahedrite*. It is tetragonal, the crystals being of an octahedral habit. The hardness is 5½ to 6, the specific gravity 3.8 to 4.0. Anatase is brown to black, and varies from transparent to nearly opaque. The luster is adamantine. It has high indices of refraction, ω 2.55, ϵ 2.49, and a strong double refraction, 0.06. The mineral is uniaxial and optically negative. Anatase has the composition $TiTiO_4$ or TiO_2, titanium oxide. Rutile, a mineral frequent as inclusions in quartz (p. 166), has the same formula. Transparent crystals of anatase occur in Burke County, North Carolina. Other important localities are: Cornwall, England; France; Germany; Switzerland; and Brazil.

ANDALUSITE

This mineral occurs in large orthorhombic crystals. Its hardness is 7 to 7½, and the specific gravity is 3.1 to 3.2. Andalusite may be gray, green, yellow-green, bottle-green, brown, pink, red, or violet in color. Often the colors are mixed. It has a vitreous to dull luster, and is transparent to opaque. The pleochroism is sometimes strong in green and red, yellow, or brown. Andalusite has a mean index of refraction of 1.64, and a double refraction of 0.01. It is biaxial, with a negative optical character. The composition of andalusite is Al_2SiO_5, aluminum silicate. Cut stones of brown or green andalusite are hard to distinguish from tourmaline of the same color. Andalusite is usually cut in the step fashion. Important localities are: the province of Andalusia, in Spain, from which the mineral takes its name; also Ceylon and Brazil.

Fig. 213.—Andalusite: Variety, chiastolite. Lancaster, Massachusetts.

Chiastolite is a variety of andalusite containing black carbonaceous inclusions. These usually have a definite arrangement, resembling a cross (see Fig. 213). Chiastolite is cut cabochon.

APATITE

Attractive gems are cut from this mineral. There are several varieties of apatite which differ widely in appearance, but the material used for gem purposes is usually found in well-developed hexagonal crystals (Figs. 214 and 215). It has a hardness of 5 and hence is quite soft. The specific gravity is 3.1 to 3.2. Apatite is colorless when pure, but it is usually colored by impurities, being then green, pink, blue, purple, or violet. The gem varieties are transparent. Apatite has a vitreous to greasy luster. The mean index of refraction is 1.64, the double refraction, 0.004, which is low. The mineral is uniaxial with a negative optical character. Apatite has the formula $Ca_5(F,Cl)(PO_4)_3$ being a calcium fluo- or chloro-phosphate. It occurs in many rocks, but crystals are found principally in pegmatites, and in other igneous and metamorphic rocks. Gem apatite occurs at Ehrenfriedersdorf, Saxony; Schlaggenwald, Bohemia; St. Gothard, Switzerland; Ceylon; and in Auburn, Maine.

Fig. 214.

Fig. 215.

Figs. 214 and 215.—Apatite crystals—prismatic, fused edges and corners, tabular.

AXINITE

This is not an important gem mineral. It occurs in wedge-shaped triclinic crystals. The hardness is 6½. It has a specific gravity of 3.3. Axinite is brown, yellow-brown, or violet. It has a vitreous luster, and is transparent to translucent. The mean index of refraction is 1.68. The double refraction is low, 0.009. Axinite is biaxial. It has a negative optical character. It is a boro-silicate of iron, calcium, and aluminum, with the formula $(Ca,Fe)_7Al_4B_2(SiO_4)_8$. The most important locality is Le Bourg d'Oisans, Dauphiné, France.

BENITOITE

This mineral was discovered in 1907, in San Benito County, California, the only known locality. It is of especial interest as the sole representative, either natural or artificial, of one of the crystal classes of the hexagonal system, the ditrigonal bipyramidal class. Previous to 1907 the existence of this class was a matter of mathematical deduction from the principles of symmetry, the validity of which was strikingly confirmed by the discovery of benitoite. Because of its deep blue color it greatly resembles the sapphire, from which it is, however, easily distinguished through its inferior hardness and its optical properties.

The hardness of benitoite is 6½. Its specific gravity is 3.65. Benitoite has a pale to deep blue color, such as is caused by trivalent titanium. The luster is vitreous. Benitoite is transparent. It has strong pleochroism, white for the ordinary and blue for the extraordinary ray, so that the stone should be cut with the table parallel to the vertical axis. The indices of refraction are high, ω 1.757, and ϵ 1.804. The double refraction is strong, 0.047. It is uniaxial, and optically positive. The formula for benitoite may be most simply given as $BaTiSi_3O_9$, that is, it is a silicate containing titanium and barium.

Benitoite is cut brilliant, sometimes cabochon. It has not met with much favor, possibly on account of the limited supply, and the prejudice against new gems.

BERYLLONITE

This mineral is but little used as a gem. It is orthorhombic. The hardness is 5½ to 6, and the specific gravity is 2.85. Beryllonite is transparent, and colorless to pale yellow. It has a vitreous luster. The mean index of refraction is 1.56, the double refraction, 0.01. The mineral is biaxial and optically negative. It is a sodium beryllium phosphate, $NaBePO_4$. Beryllonite is found in veins in granite at Stoneham, Maine. It is distinguished only with difficulty from other colorless gems with low indices of refraction.

CASSITERITE

Transparent cassiterite is rare, but is sometimes used as a gem. Cassiterite is tetragonal, and the crystals are often twinned.

It also occurs in massive forms. The hardness is 6 to 7, the specific gravity 6.8 to 7.0. It has a brown, reddish-brown, black, or yellow color. Cassiterite is transparent to opaque, with an adamantine luster. The mean index of refraction is 2.04, the double refraction 0.10. It is uniaxial and optically positive. Cassiterite has the composition $SnSnO_4$, or SnO_2, tin oxide. It is the chief ore of tin. Good crystals occur in Cornwall, England; Bohemia; and Saxony (Fig. 216).

FIG. 216.—Cassiterite with fluorite. Saxony.

FIG. 217.—Chlorastrolite—"Green stone." Isle Royale, Lake Superior. (Two-thirds natural size.)

CHLORASTROLITE

This is a greenish, fibrous mineral occurring in small spherical aggregates in the basic igneous rocks in the vicinity of Lake Superior. Especially fine specimens have been found on Isle Royale. The chlorastrolite weathers out along the shore of the lake and is rounded by the waves into pebbles of various sizes.

This mineral is closely related to prehnite (p. 165). It depends upon its chatoyancy and unique markings in white and dark green for its attractiveness (Fig. 217). Chlorastrolite is especially popular about Lake Superior. Its hardness is 5 to 6, the specific gravity, 3.2. The gem is cut cabochon, and worn in brooches, pins, or occasionally in rings.

CYANITE

The name of this mineral is also spelled *kyanite*. Cyanite occurs in bladed triclinic crystals (Fig. 218), the hardness of which varies greatly with direction, ranging from 4 to 7 (p. 24). The specific gravity is 3.5 to 3.7. This mineral is light to sky-blue, or white, gray, green, brown, or colorless. The color is usually irregularly distributed. Cyanite has a vitreous luster, and is transparent to translucent. The mean index of refraction is 1.72, the double refraction, 0.012. It is biaxial, with a negative optical character. Cyanite has the formula Al_2SiO_5, aluminum silicate. In this respect it is identical with andalusite. Cyanite occurs in metamorphic rocks, commonly associated with staurolite and garnet. Important localities are: St. Gothard, Switzerland; the Tyrol; Brazil; Massachusetts; Pennsylvania; North Carolina. When clear and of good color cyanite may be cut to advantage.

FIG. 218.—Cyanite (bladed). Litchfield, Connecticut.

DIOPSIDE

Transparent diopside of a pleasing green color is sometimes used as a gem. It is monoclinic and occurs in well-developed crystals. There is a good prismatic cleavage, as well as a basal parting. The hardness is 5 to 6, and the specific gravity is 3.2 to 3.3. Diopside is light to dark green, colorless, gray, or yellow. The color is often zonally distributed (Fig. 219). It has a vitreous to resinous or dull luster, and is transparent to opaque. The mean index of refraction is 1.68. Diopside has strong double refraction, 0.03. It is biaxial and optically positive. The formula is $CaMg(SiO_3)_2$, calcium magnesium silicate. Other names are *malacolite* and *alalite*. Diopside occurs in metamorphosed limestones, much of the best material coming from the Ala Valley, Piedmont, Italy; the Tyrol; Renfrew County, Ontario; and New York. *Violan* is a variety with a fine blue color, from St. Marcel, Piedmont, Italy.

FIG. 219.—Diopside with zonal distribution of color. Ala, Italy.

ENSTATITE, BRONZITE, AND HYPERSTHENE

These closely related minerals have occasionally been cut for gem purposes. The so-called "green garnets" from the South African diamond localities are green enstatite. Bronzite, which is fibrous, has a pleasing chatoyant bronzy luster. However, this mineral is not of gem quality. Hypersthene is sometimes cut cabochon because of its metalloidal iridescence. The minerals are orthorhombic members of the pyroxene group, and usually occur in fibrous, platy, or compact masses. They have prismatic and pinacoidal cleavages. The hardness is 5 to 6, the specific gravity 3.1 to 3.5. In color they are grayish white, greenish, yellowish, brown, to black; enstatite being the lightest and hypersthene the darkest. The luster is vitreous, bronzy, or pearly-

These minerals are translucent to opaque. The mean index of refraction is 1.67 for enstatite, 1.70 for hypersthene. The double refraction of these minerals is 0.01. Both are biaxial, but enstatite is optically positive, while hypersthene is negative. Enstatite has the formula $MgSiO_3$, magnesium silicate. Hypersthene is $(Fe,Mg)SiO_3$, iron magnesium silicate. Bronzite is intermediate in composition and properties.

EPIDOTE

The distinctive pistachio green color of epidote, also called *pistacite*, does not have a wide appeal, though the mineral is not uncommonly cut. Epidote is monoclinic, occurring in excellent prismatic crystals (Fig. 220), or in fibrous aggregates or granular masses. It has a basal cleavage. The hardness is 6 to 7, the specific gravity 3.3 to 3.5. Epidote is yellowish to blackish-green, pistachio-green, or more rarely colorless or brown. In manganiferous varieties the color may be red. The luster is vitreous to resinous, and epidote is transparent to opaque. The mean index of refraction is 1.75, and the double refraction is strong, 0.04. Epidote has a dispersion of 0.018. The mineral is biaxial with a negative optical character. The pleochroism is marked, in yellow, green, and brown. The formula is $Ca_2(Al,Fe)_2(AlOH)(SiO_4)_3$, calcium, iron, and aluminum silicate. Epidote occurs in metamorphic rocks. Localities yielding good crystals are: Tyrol; Piedmont, Italy; Elba; Dauphiné, France; Arendal, Norway; and Prince of Wales Island, Alaska.

FIG. 220.—Epidote. Untersulzbachthal, Tyrol.

EUCLASE

Largely because of its rarity euclase is not well known as a gem. It is monoclinic, occurring in prismatic crystals. Euclase has an excellent pinacoidal cleavage. The hardness is $7\frac{1}{2}$, the specific gravity, 3.1. It is colorless when pure, but is usually pale green, sea-green, or blue, resembling aquamarine. The luster is vitreous, and the mineral is transparent. The mean index of refraction is 1.65, the double refraction, 0.02. Euclase is biaxial and optically positive. It is a beryllium aluminum silicate, with the formula $Be(AlOH)SiO_4$. It occurs in metamorphic rocks, with topaz, beryl, and chrysoberyl; the principal localities being the Ural Mountains and Minas Geraes, Brazil.

FELDSPAR

The minerals known as the feldspars are very important as major constituents of igneous rocks. Much feldspar is opaque and unattractive, but certain varieties are of gem quality.

Orthoclase is monoclinic, while the other feldspars are triclinic. These minerals occur in good crystals (Figs. 221 and 222), or as cleavage masses. Twinning is very common (Figs. 223 and 224).

FIG. 221.—Orthoclase. Lincoln County, Nevada.

FIG. 222.—Orthoclase: Variety, sanidine. Fort Bayard, New Mexico.

FIG. 223.

FIG. 224.

FIGS. 233 and 224.—Orthoclase (left and right Karlsbad twins). Fort Bayard, New Mexico.

There are excellent cleavages in two directions. The hardness is 6 to 6½, the specific gravity 2.5 to 2.8. Feldspars are colorless, white, pale yellow, green, or reddish. They have a vitreous to pearly luster, and are transparent to opaque. The mean index of refraction varies from 1.52 to 1.58, and the double refraction is low, ranging from 0.005 to 0.012. Dispersion in the feldspars is also low, albite having the value of 0.012. All feldspars are biaxial, albite and labradorite being optically positive, while the others are negative.

The composition is as follows: *orthoclase,* monoclinic, and *microcline,* triclinic ($KAlSi_3O_8$), potassium aluminum silicate; *albite,* triclinic ($NaAlSi_3O_8$), sodium aluminum silicate; *anorthite,* triclinic ($CaAl_2Si_2O_8$), calcium aluminum silicate; *oligoclase,* *andesine*, and *labradorite*, all triclinic, are intermediate in composition between albite and anorthite, and with them form a continuous series, called the *plagioclase feldspars*. The feldspars occur in igneous and metamorphic rocks.

The gem varieties of orthoclase are transparent and colorless, and are called *adularia*, or when opalescent, *moonstone*. Moonstone varieties of albite and oligoclase also occur. Moonstones are cut cabochon, and occur at St. Gothard, Switzerland; in Elba, and Ceylon. An interesting transparent yellow orthoclase, which is very attractive when faceted, has recently been found in Madagascar.

FIG. 225.—Microcline: Variety, Amazon stone. Pike's Peak, Colorado.

The bright green *amazonstone* or *amazonite* variety of microcline (Fig. 225) is often cut cabochon, on account of its pleasing color, which resembles that of jade. It is used in brooches and pendants. Localities are: the Ural Mountains; Pennsylvania; Virginia; and Pike's Peak, Colorado.

Sunstone or *aventurine oligoclase* is of a reddish color, with bright yellow or red reflections from included crystals of iron oxide. The principal locality is Norway.

Labradorite is characterized by a beautiful play of colors in blue and green, and less often in yellow, red, or gray. This attractive effect is caused by fine microscopic inclusions. The mineral takes its name from the most important locality, Labrador.

IOLITE

This stone is also known as *cordierite*, or *dichroite* because of its pleochroism. It is not much used as a gem, and when cut it is rarely faceted. The most interesting property is the very strong pleochroism in dark blue, light blue, and yellowish-white. This variation of color in different directions is distinctly evident to the unaided eye. Iolite is orthorhombic, but is usually found in massive forms. The hardness is 7 to 7½, and the specific gravity is 2.6. The mineral has a dark smoky-blue to light blue color. It is transparent to translucent, with a vitreous luster. Iolite greatly resembles quartz. The mean index of refraction of iolite is somewhat variable, but generally is about 1.55. The double refraction is low, 0.008. Iolite is biaxial, and optically negative. The formula is $(Mg,Fe)_4Al_8(OH)_2(Si_2O_7)_5$, that is, a magnesium, iron, and aluminum silicate. Iolite occurs in metamorphic rocks and gravels. Ceylon is the most important locality, and the gems from that country are sometimes called *saphir d'eau,* or "water sapphire."

MOLDAVITE AND OBSIDIAN

In the strict sense moldavite and obsidian are not minerals, for they are natural glasses of variable composition and physical properties. Obsidian, or *volcanic glass,* results from the rapid cooling of an acidic magma. It is similar to ordinary glass, being transparent to translucent, and breaking with a conchoidal fracture and sharp edges. The hardness is 5½, the specific gravity near 2.5. The color is variable, but usually black. and lighter in thin fragments; also red, brown, or greenish. The index of refraction is 1.5 to 1.6. Obsidian is isotropic. If of an attractive color it is occasionally cut as a gem.

Moldavite, also called *tektite,* resembles ordinary green bottle glass. Its origin is a problem to geologists, for it has always been found as loose, rounded fragments on the surface. Moldavite is found in Bohemia, Moravia, and Australia, and it is difficult to correlate it with volcanic activity. An artificial, or possibly a meteoric origin, has been assigned to this substance. In properties it is nearly identical with obsidian.

PHENACITE

Although brilliant, phenacite has little fire, and is but little used as a gem. It occurs in well-formed hexagonal crystals. The hardness is 7½ to 8, and the specific gravity 3.0. Phenacite is colorless, yellowish, or pale rose-red. It is transparent to translucent with a vitreous luster. The mean index of refraction is 1.66, the double refraction 0.016. The mineral is uniaxial with a positive optical character. Phenacite has the formula Be_2SiO_4, beryllium silicate. It occurs in pegmatites and metamorphic rocks, and is very similar in appearance to quartz and topaz, which occur in the same rocks. Localities are: near Ekaterinburg in the Ural Mountains; Minas Geraes, Brazil; Durango, Mexico; Stoneham, Maine; and Colorado.

PREHNITE

This mineral is sometimes used as gem, especially when of an oil-green color. Prehnite is orthorhombic, but it is rarely found in distinct crystals, usually occurring in rounded masses. The hardness is 6 to 7, and the specific gravity 2.8 to 3.0. Prehnite may be colorless or white, but it is generally light-green, apple-green, oil-green, or yellowish-green. It has a waxy vitreous luster, and is transparent to translucent. The mean index of refraction is 1.63. The double refraction is strong, 0.03. Prehnite is biaxial and optically positive. The mineral is a calcium aluminum silicate with the formula $H_2Ca_2Al_2(SiO_4)_3$. It occurs in veins and cavities in the more basic igneous rocks, with datolite. Dauphiné, France; the Lake Superior district; and New Jersey are important localities. Chlorastrolite (p. 159) is a closely related stone.

RUTILE

Although very dark in color, rutile is used to a slight extent as a gem. *Rutilated quartz* (p. 148) is a gem variety of quartz containing slender needles of rutile. Rutile is tetragonal, occurring in prismatic crystals, which are often striated and twinned (Fig. 226). The hardness is 6 to 6½, the specific gravity 4.2 to 4.3. Its color is red-brown, blood-red, or in the variety *nigrine* black. Rutile is opaque to transparent, and has a metallic adamantine luster. The indices of refraction, ω 2.62, and ϵ 2.90, are very high, and the double refraction, 0.28, is strong. Rutile is uniaxial and optically positive. The formula is $TiTiO_4$, titanium oxide, which is the same as the formula of anatase. Rutile occurs in Norway, Sweden, the Urals, Tyrol, Switzerland, France, and the United States. Rutilated quartz is found in Madagascar, Switzerland, Brazil, Vermont, and North Carolina.

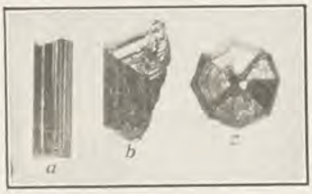


FIG. 226.—Rutile crystals—(*a*) prismatic and striated, (*b*) knee-shaped, (*c*) rosette (eightling).

SPODUMENE

Spodumene is ordinarily white, opaque, and unattractive, but two of its varieties are rather valuable as gems. These are *hiddenite*, of a yellow-green to emerald-green color, and *kunzite*, (Fig. 227), of a delicate pink to lilac color. Both are transparent. Spodumene is monoclinic, occurring in crystals, sometimes of enormous dimensions (p. 9), and as tabular masses. It has perfect prismatic cleavage, and pinacoidal parting. The hardness is 6 to 7, the specific gravity 3.1 to 3.2. Spodumene in general is white, gray, green, pink, or rarely purple. The luster is vitreous to pearly. It is transparent to opaque. The mean index of refraction is 1.66, and the double refraction is strong, 0.026. The dispersion is 0.017. Spodumene is biaxial, and the optical character is positive. There is pleochroism in the colored varieties. The composition of spodumene is $LiAl(SiO_3)_2$, lithium aluminum silicate. Kunzite is phosphorescent with an orange-pink light when exposed to the radiations of X-rays and radium. Hiddenite is found at Stony Point, Alexander County, North Carolina, in kaolin veins in metamorphic rocks. The kunzite variety of spodumene occurs in pegmatites near Pala, California, and in Madagascar. Yellowish, transparent crystals of spodumene come from Minas Geraes, Brazil.

FIG. 227.—Spodumene: Variety, kunzite. San Diego County, California.

STAUROLITE

This mineral is also known as *cross-stone* or *fairy-stone* because of the cross-shaped twins commonly formed by the crystals, which are orthorhombic (Fig. 228). It is of little value except as a curiosity. The twin crystals are polished and worn as ornaments, as, for instance, crosses worn by the clergy. Their shape has caused the growth of legends assigning to them a supernatural origin. Staurolite has a hardness of 7 to $7\frac{1}{2}$, and a specific gravity of 3.4 to 3.8. The color is usually reddish-brown.

FIG. 228.—Staurolite crystals—simple, plus- and X-shaped twins.

FIG. 229.—Staurolite (dark) in paragonite schist. Tepin, Switzerland.

The mineral is translucent to opaque, with a dull to vitreous luster. It has a mean index of refraction of 1.74, and a double refraction of 0.010. The dispersion is 0.021. Staurolite is biaxial, and optically positive. It shows some pleochroism. This mineral is an iron aluminum silicate, $HFeAl_5Si_2O_{13}$. It occurs in metamorphic rocks (Fig. 229), at St. Gothard, Switzerland, with cyanite; in the Tyrol; in Brazil; in Georgia and other eastern states.

FIG. 230.

FIG. 231.

FIGS. 230 and 231.—Thomsonite. Isle Royale, Lake Superior. (Natural size.)

THOMSONITE

When mottled in white, red, green, and yellow, thomsonite pebbles (Fig. 232) are frequently cut as semi-precious stones. "Eye markings," concentric layers of different colors, are especially popular. The mineral occurs in the basic igneous rocks of the Lake Superior district, and like chlorastrolite is weathered out and rounded by the waves along the shores of the lake. The pebbles are cut cabochon and used in pins and brooches (Figs. 230 and 231). Their popularity is largely confined to the country about Lake Superior. Thomsonite is orthorhombic, occurring in crystals, compact masses, or spherical concretions. It has a hardness of 5 to 5½, and a specific gravity of 2.3 to 2.4. The color is white, grayish, yellowish, brownish, and reddish; in the variety known as *lintonite* the color is greenish. Thomsonite is transparent to opaque, with a vitreous to pearly luster. The mean index of refraction is 1.51, and the double refraction is strong, 0.03. Thomsonite is biaxial, and optically positive. It is a hydrated calcium, sodium, and aluminum silicate, $2(Ca,Na_2)Al_2(SiO_4)_2.5H_2O$.

FIG. 232.—Thomsonite pebbles. Isle Royale, Lake Superior.

TITANITE

Titanite or *sphene* makes a brilliant and attractive gem, but it is rather soft. It is usually faceted when cut. The mineral is monoclinic, the crystals often being wedge- or envelope-shaped (Fig. 233). It has a hardness of 5 to 5½, and a specific gravity of 3.4 to 3.6. When titanite is pure its color is gray, but it is more often yellow, green, or brown. The luster is adamantine. The mineral is transparent to opaque. Titanite is biaxial, with a positive optical character. The indices of refraction are very high, α 1.90, γ 2.03. The double refraction is strong, 0.13, and the dispersion likewise is notable, 0.050. The formula is $CaTiSiO_5$, calcium titanium silicate. Titanite occurs in schists and limestone: in Switzerland, at St. Gothard; in Zillerthal, Tyrol, and in many other European localities; in Maine, New York, and Pennsylvania.

FIG. 233.—Titanite. Arendal, Norway.

VESUVIANITE

Another name for this mineral is *idocrase*. A compact green variety, resembling jade, is called *californite*. *Cyprine* is a blue variety, containing copper. Vesuvianite occurs in prismatic tetragonal crystals (Fig. 234), and in compact masses. Its hardness is 6½, its specific gravity, 3.3 to 3.5. Vesuvianite occurs in various shades of yellow, green, or brown; more rarely blue, red, or nearly black. It is translucent, with a vitreous or greasy luster. The mean index of refraction is 1.72, and the double refraction is very low, less than 0.006. Vesuvianite is uniaxial, and either negative or positive in optical character. It has weak pleochroism. The composition is calcium aluminum silicate, $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$. Cut stones resemble diopside and epidote, but can be distinguished by their optical properties. Vesuvianite is a contact metamorphic mineral.

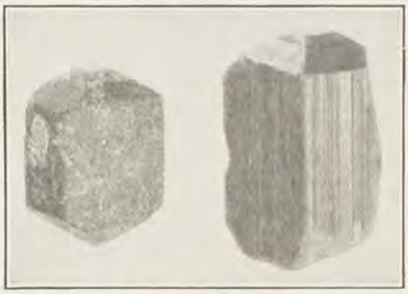


FIG. 234.—Vesuvianite. (*a*) Wilui River, Siberia; (*b*) Achmatovsk, Russia.

Localities are: Mount Vesuvius, from which the name is derived; Wilui River, Siberia, for the variety *wiluite;* Eger, Hungary, for *egeran;* Norway; and California, from which the name *californite* is derived.

WILLEMITE

Although transparent willemite is not common. It has occasionally been cut in the brilliant style for use as a gem. Willemite is hexagonal, occurring in small crystals or granular masses. It has a hardness of 5 to 6, and the specific gravity is 3.9 to 4.3. The color is yellow, green, brown, or reddish; more rarely colorless, white, blue or black. It is transparent to opaque, and has a greasy, vitreous luster. The mean index of refraction is 1.70, the double refraction, 0.02. Willemite is uniaxial, and optically positive. It is a zinc silicate, Zn_2SiO_4. Willemite of gem quality is found only at Franklin Furnace, New Jersey.

CHROMITE

Chromite is occasionally cut into beads, which being black and opaque, somewhat resemble jet. Chromite, however, is much heavier than jet, a fact which allows the two minerals to be readily distinguished. Chromite is cubic. It occurs granular, massive, or in octahedral crystals. Its hardness is 5½, the specific gravity, 4.3 to 4.6. Chromite has an iron-black to brownish-black color, and the streak is pale brown. Its luster is pitchy submetallic to metallic. The mineral is opaque. Chromite has the formula $(Fe,Cr)[(Cr,Fe)O_2]_2$, a ferrite of iron containing chromium. Localities are New Zealand, New Caledonia, Asiatic Turkey, Silesia, Pennsylvania, and Maryland.

COBALTITE

Cobaltite is sometimes cut as a gem. It may resemble pyrite, but inclines toward a flesh color rather than yellow. Cobaltite is cubic, and well crystallized. Its hardness is 5½, the specific gravity, 6.0 to 6.4. The color is silver-white, often with a reddish tinge. The mineral has a grayish-black streak, and is opaque, with a metallic luster. Its formula is $CoAsS$, cobalt and arsenic sulphide. Sweden; Norway; Cornwall, England; and the Cobalt district in Ontario are localities.

GOLD

Native gold, alone as crystals or nuggets, or in white quartz (Fig. 235, p. 148) is frequently worn in pins. Much of such material is obtained from California and Alaska, as well as from other gold-mining districts. Gold is cubic, but crystals are comparatively rare. It usually occurs in scales, grains, or nuggets. The hardness is 2½ to 3, the specific gravity 16 to 19. In color and streak it is golden-yellow. The luster is metallic.

FIG. 235.—Gold in quartz. Tuolumne County, California.

HEMATITE

Cut cabochon, or faceted, black hematite is suitable for mourning jewelry. This mineral is hexagonal, occurring in crystals (Fig. 236), or in compact, granular, fibrous, earthy, micaceous, or rounded masses. The hardness is 5½ to 6½, and the specific gravity 4.9 to 5.3. Hematite has a black color when occurring in crystals and hard compact masses, while it is red in softer masses and when finely divided. The streak is cherry-red. The mineral is opaque, with a metallic splendent to dull luster. The formula is Fe_2O_3, ferric oxide. Important localities are Elba, Norway, Sweden, England, and the Lake Superior district.

FIG. 236.—Hematite. Island of Elba.

PYRITE

Like hematite, pyrite is an iron mineral. It occurs in brilliant crystals of the cubic system (Fig. 237), which are frequently striated. The hardness is 6 to 6½, the specific gravity 4.9 to 5.2. The mineral has a brass-yellow color and a greenish-black streak. The luster is bright metallic. Pyrite is iron sulfide,

FIG. 237.—Pyrite crystals—octahedron, striated cube, cube and octahedron, pyritohedron.

FeS_2. It is of widespread occurrence. Groups or clusters of small natural crystals are often mounted, uncut, in pins and other similar pieces of jewelry.

AZURITE AND MALACHITE

These are two brightly colored minerals, blue and green, respectively. They are not very durable when used for personal adornment, but are extensively employed in the fashioning of ornamental objects, for example, table tops and vases. Malachite, especially, is much used for this purpose. Malachite and azurmalachite find some use as pins, shirt buttons, and other similar articles.

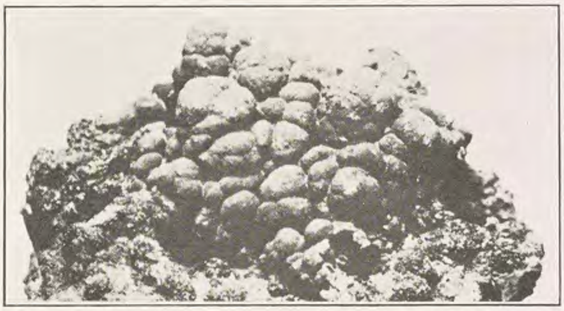


FIG. 238.—Malachite and azurite. Morenci, Arizona.

FIG. 239.—Malachite (polished). Rhodesia, Africa.

Both azurite and malachite are monoclinic. Azurite is often well crystallized, while malachite usually occurs in rounded masses (Fig. 238) with a fibrous or banded structure, which is very attractive in polished specimens (Figs. 239 and 240). Their hardness is 3½, and their specific gravity, 3.7 to 4.0. Malachite is emerald-green to grass-green, azurite light azure to deep blue. The streaks are lighter shades of the same colors. These minerals are translucent to opaque, with a silky, vitreous, adamantine, or dull luster. The mean indices of refraction are 1.81 for malachite, and 1.77 for azurite. The double refraction is strong, 0.26 for malachite, 0.11 for azurite. Both are biaxial, azurite being optically positive, malachite, negative. The formulas are: azurite, $2CuCO_3.Cu(OH)_2$; malachite, $CuCO_3.Cu(OH)_2$, both minerals being copper carbonates.

Malachite matrix is the term applied to polished specimens containing some of the gangue minerals. When azurite and malachite are intimately associated, as frequently is the case, the material is called *azurmalachite*. Azurite and malachite are the alteration products of other copper minerals. Azurite has a tendency to alter gradually into the more stable malachite. These minerals occur in the Ural Mountains; Rhodesia; Chile; Bisbee and Clifton, Arizona; and the Lake Superior district.

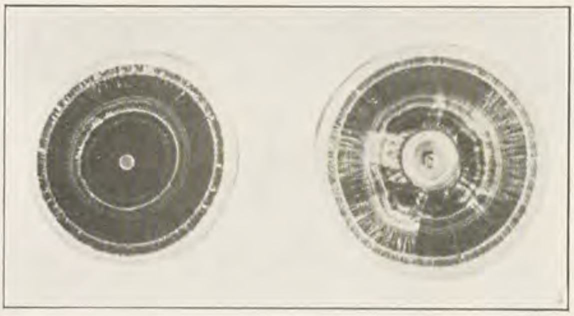


FIG. 240.—Polished sections of malachite with concentric structure. Bisbee, Arizona. (Natural size.)

CHRYSOCOLLA

This is another copper mineral which is occasionally used for ornamental purposes or cut as charms or pendants. It is apparently amorphous, occurring in compact or earthy masses, veins, or crusts. The hardness is 2 to 4, the specific gravity 2.0 to 2.2. The mineral occurs in various shades of green and blue. It is translucent to opaque, with a vitreous, greasy, or dull luster. The mean index of refraction is 1.50, the double refraction, 0.11. Chrysocolla is uniaxial and optically positive. It is a hydrous copper silicate, with an indefinite composition. Chrysocolla is formed by the alteration of other copper minerals, and is found in the Ural Mountains, Arizona, and the Lake Superior district.

DATOLITE

This mineral occurs both in glassy monoclinic crystals, often rich in forms, and in compact, opaque masses, with a dull luster, and resembling unglazed porcelain (Fig. 241). The latter variety is found in the Lake Superior copper district, and frequently contains native copper inclusions (Fig. 242). The color of massive datolite is white, yellowish, reddish, greenish, or brownish, and often mottled. The material is very attractive when polished (Figs. 242 and 243). It is used for ornamental purposes, or cut cabochon for brooches or pins. Datolite has a hardness of 5 to $5\frac{1}{2}$, and a specific gravity of 2.9 to 3.0. The mean index


FIG. 241.—Datolite. Lake Superior Copper District.


FIG. 242. FIG. 243.

FIGS. 242 and 243.—Polished sections of massive datolite. Franklin Mine, Lake Superior Copper District. (One-third natural size.)

of refraction is 1.65, the double refraction 0.04. It is biaxial, and has a negative optical character. Datolite is a calcium borosilicate, $Ca(B.OH)SiO_4$.

FLUORITE

This mineral, also known as *fluor-spar*, occurs in excellent crystals of the cubic system (Fig. 244). These are frequently twinned in the form of interpenetrating cubes (Fig. 245). It is also cleavable, granular, or fibrous. The cleavage is perfect octahedral (Fig. 246). The hardness is inferior, being only 4. The specific gravity is 3.0 to 3.2 It is the color which makes fluorite attractive, and like quartz this mineral exhibits nearly every hue: yellow, orange, green, blue, red, violet, pink, or brown. It may also be colorless. Fluorite is transparent to opaque, has a vitreous luster, and is often fluorescent and phosphorescent. It is isotropic, with an index of refraction of 1.434. The dispersion

FIG. 244.—Fluorite. Cumberland, England.

FIG. 245.—Fluorite (penetration cubes). Durham, Weardale, England.

is very low, 0.006. The composition is CaF_2, calcium fluoride. Fluorite is used a great deal for vases, paper weights, and other similar articles (Fig. 247). It occurs in veins, and in pegmatites and other rocks. The best material is found in England, in Derbyshire, the source of the deep purple and fibrous "blue john;" also in Cumberland, Cornwall, Devonshire, and Durham.

FIG. 246.—Fluorite (octahedral cleavage). Near Rosiclare, Illinois.

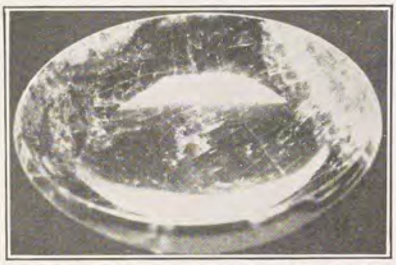


FIG. 247.—Fluorite dish. Derbyshire, England. (Four-fifths natural size.)

GYPSUM

The satin spar and alabaster varieties of gypsum are of importance as ornamental stones. Satin spar is also used in cheap jewelry. Gypsum is monoclinic, with a perfect pinacoidal cleavage, yielding thin sheets. It is very soft, having a hardness of 2. The specific gravity is 2.2 to 2.4. It is usually colorless or white, also gray, yellow, brown, reddish, or black. Gypsum is transparent to opaque. The luster is subvitreous, pearly, silky, or dull. The mean index of refraction is 1.525; the double

FIG. 248.—Gypsum (polished). Grand Rapids, Michigan.

FIG. 249.—Gypsum: Variety, satin spar. Montmartre, Paris, France

refraction 0.010. It is biaxial, and optically positive. The composition is $CaSO_4.2H_2O$, hydrated calcium sulphate.

Massive gypsum will take a good polish (Fig. 248). *Selenite* occurs in colorless, transparent, crystals or cleavage masses. The crystals are often twinned, and may be very large. *Satin spar* is a chatoyant, fibrous variety with a silky luster (Fig. 249). This variety is cut cabochon (Fig. 250), or as beads, although it is so very soft as to quickly lose its polish and luster. Two important localities are England, and Niagara Falls, New York. *Alabaster* is a fine-grained, massive variety, usually snow-white in color, easily carved and therefore used for statuary and decorative purposes or for ornamental objects (Fig. 251). Castelino, near Leghorn, Italy, and Michigan and Tennessee supply some of this type of gypsum.

FIG. 250.—Gypsum: Variety, satin spar. Cut cabochon. (Natural size.)

FIG. 251.—Alabaster vase. Grand Rapids, Michigan. (One-third natural size.)

LAZULITE

This mineral is sometimes mistaken for lazurite, which it closely resembles in outward appearance, although quite different in composition. Lazulite is monoclinic, occurring in pyramidal crystals. It may also be massive, or granular. It has a hardness of 5 to 6, and the specific gravity is 3.1. In color it is azure blue. The luster is vitreous. Lazulite is translucent to opaque. The mean index of refraction is 1.62, the double refraction 0.036. The mineral is biaxial, and optically negative. It is pleochroic. In composition lazulite is a basic iron, magnesium, and aluminum phosphate, $(Fe,Mg)Al_2(OH)_2P_2O_8$. It occurs in Austria, North Carolina, and Georgia.

LAZURITE

This mineral is often called *lapis lazuli* or simply *lapis*. It was known as sapphire by ancient peoples. Lazurite has long been used for mosaics, inlaid work, vases, and other ornamental objects. It is also cut cabochon for jewelry. Beads of lazurite are very popular at present. The mineral was formerly ground for use as a blue pigment called ultramarine, but artificial ultramarine has now replaced the natural pigment. Lapis lazuli is now known to be a mixture of a number of minerals, the most prominent constituent being lazurite, which gives it the deep blue color. The others are haüynite, diopside, amphibole, mica, calcite, and pyrite. Lapis lazuli has a hardness of 5 to 5½, and a specific gravity of 2.4. It is deep blue, azure-blue, Berlin-blue, or greenish-blue. The luster is vitreous to greasy. It is opaque to translucent. Lazurite is cubic, and has the formula $(Na_2,Ca)_2Al_2[Al(NaSO_4,NaS_3,Cl)](SiO_4)_3$, being a sodium, calcium, and aluminum sulpho- and chloro-silicate. The blue color is thought to be due to the presence of sulphur. The mineral is isotropic, with an index of refraction of 1.50.

Lapis lazuli may be imitated by blue glass, or by stained quartz. Two other minerals, sodalite (p. 183), and lazulite have a similar appearance. Lazurite occurs in Afghanistan; at the southern end of Lake Baikal, Siberia; in Ovalle, Chile; and in San Bernardino County, California.

RHODONITE

This pink or red mineral polishes well and is used as an ornamental stone, especially in Russia. It is occasionally cut cabochon for use in pins, or as beads or buttons. Rhodonite is triclinic, occurring in crystals or compact masses (Fig. 252). Its hardness is 5 to 6, the specific gravity, 3.4 to 3.7. In color it is rose-red or pink, also yellowish, greenish, or brownish, easily changing to black due to a superficial alteration to manganese oxides. The luster is vitreous to pearly. Rhodonite is transparent to opaque. It has a mean index of refraction of 1.73, and a double refraction of 0.01. The mineral is biaxial, and optically negative. The formula is $MnSiO_3$, manganese silicate.

Fig. 252.—Rhodonite in calcite (white). Franklin Furnace, New Jersey.

Fig. 253.—Meerschaum. Grant County, New Mexico.

This mineral is not uncommon. The material used for ornamental purposes is obtained principally from the Ural Mountains, in the neighborhood of Ekaterinburg, but some rhodonite from Franklin Furnace, New Jersey, has been cut for gem purposes.

SEPIOLITE

Sepiolite, known to commerce as *meerschaum*, is easily carved and takes a fine polish. It is used extensively for pipe bowls and cigar holders. Sepiolite is monoclinic, but occurs only in earthy or compact nodular masses, with a conchoidal to earthy fracture (Fig. 253). The hardness is 2 to 2½, the specific gravity, 1 to 2. On account of its low specific gravity and its porosity, it may float upon water, and because of this fact the mineral is called meerschaum. This is a German word literally translated "sea foam." The color is white, yellowish, or grayish. The luster is dull, and the mineral opaque. It adheres to the tongue. The mean index of refraction is 1.55. Sepiolite is biaxial, and optically negative. The formula is $H_4Mg_2Si_3O_{10}$, hydrated magnesium silicate. This mineral is derived from serpentine and magnesite, by their alteration. Meerschaum is mined in Asia Minor, on the plains of Eski-Shehr. Other localities are Greece, Spain, Moravia, Morocco, Pennsylvania, South Carolina, Utah, New Mexico, and California.

SERPENTINE

This mineral is employed for ornamental purposes, and is sometimes cut cabochon as a gem, though it is too soft for satisfactory use in that way. Although it is monoclinic, serpentine is never found in crystals, but occurs in compact, fibrous, or platy masses. The hardness is 2½ to 4, the specific gravity, 2.5 to 2.8. Serpentine occurs in various shades of green, also yellowish, grayish, reddish, brownish, or black. It is often spotted, clouded, or multicolored. The luster is dull, resinous, greasy, or waxy. It is translucent to opaque. The feel is smooth to greasy. The mean index of refraction is about 1.53. Serpentine is a hydrated magnesium silicate, $H_4Mg_3Si_2O_9$. Iron and nickel may replace some magnesium. This tends to give the mineral its characteristic green color.

Precious serpentine is translucent, massive, and of a uniform green or yellowish color. *Bowenite* is a fine granular variety, green in color, and resembling jade. *Williamsite* has a blackish-green color. *Verd antique* is a massive green serpentine, mottled or veined with white calcite, dolomite, or magnesite (Fig. 254). It is much employed as an ornamental stone for interior decoration. *Chrysotile* is a fibrous variety, and includes the asbestos used in the manufacture of heat-resisting materials (Fig. 255). Occasionally the fibrous serpentine is cut. Serpentine results from the alteration of other magnesian rocks or minerals. Localities are Sweden, Scotland, Silesia, Saxony, Rhode Island (bowenite), Vermont, Massachusetts, Pennsylvania (williamsite), and California.

Fig. 254.—Serpentine: Variety, verd antique. Roxbury, Vermont.

Fig. 255.—Serpentine: Variety, asbestos. Near Globe, Arizona.

SMITHSONITE

This mineral is usually rather unattractive in color. However, some specimens with a soft yellow, green, or blue color are cut cabochon, or used for ornamentation. The mineral is hexagonal. Crystals are small and rough. Compact and stalactitic forms are more common. The hardness is 5, the specific gravity 4.1 to 4.5. Smithsonite is colorless when pure, but it is usually gray or brown, sometimes white. It may also be yellow, due to cadmium sulphide; pink, when cobaltiferous; and green or blue, due to included particles of copper carbonates. It has a vitreous to pearly luster, and is translucent to opaque. The mean index of refraction is 1.75. The double refraction is high, 0.20. It is uniaxial, and optically negative. The formula is $ZnCO_3$, zinc carbonate. It often contains small amounts of iron, manganese, cobalt, copper, and cadmium. Smithsonite is formed by the alteration of zinc sulphide, and much of it occurs in limestones and dolomites. The gem variety of smithsonite occurs at Laurium in Greece; Sardinia; Marion County, Arkansas; and Kelly, New Mexico.

SODALITE

Sodalite has a deep blue color which is similar to that of lazurite, a mineral to which it is closely related. Its properties vary but little from those of lazurite. The composition of sodalite is sodium aluminum chloro-silicate, $Na_4Al_2(AlCl)(SiO_4)_3$. It is polished as an ornamental stone, or sometimes cut cabochon. It is found in the Ural Mountains, Mount Vesuvius, Norway, Ontario; and at Litchfield, Maine.

ZOISITE

This is a calcium aluminum silicate, belonging to the epidote group. It crystallizes in the orthorhombic system. Its color is gray, greenish, or red. The other properties are practically the same as for epidote (p. 162). The rose-red, strongly pleochroic variety, colored by manganese, is *thulite* (Fig. 256). It is used for ornamental objects or cut cabochon. Thulite occurs in Norway and in Piedmont, Italy.

FIG. 256.—Zoisite: Variety, thulite. Norway.

PEARL

Pearls are found within the shells of certain mollusks or shellfishes. These animals are able to withdraw calcium carbonate from the water of the sea, and use it in building their shells. These are composed of a horny organic material called conchiolin, and the two crystalline forms of calcium carbonate, calcite (hexagonal) and aragonite (orthorhombic). The outside of the shell is of conchiolin, while the inner portion is made up of two layers. The outer of these layers consists of calcite and conchiolin, and the inner of aragonite and conchiolin. The inner layer furnishes *mother-of-pearl*, used for buttons, knife handles, and so forth. If a foreign object, such as a sand grain, or more often the dead body of a minute parasitic organism, finds its way within the shell of the mollusk, the consequent irritation causes the animal to deposit a secretion about the offending particle, and gradually, layer by layer, a pearl is built up.

Pearls are composed largely of calcium carbonate in the aragonite form, with some conchiolin. They have a hardness of 2½ to 3½, and a specific gravity of 2.5 to 2.7. Pearls are most often white, or faintly yellowish or bluish, but they may be pink, yellow, purple, red, green, blue, brown, or black. They are translucent to opaque. The luster can only be described as pearly. The stones may be iridescent, due to the interference of light by fine striations upon their surface.

The best pearls are those with a round or pear-shaped form, and which are also lustrous, free from blemishes, and somewhat transparent. Fine black pearls are well thought of, but are not as valuable as the best grade of white ones. *Baroque pearls* are of irregular shape, but when of good color they are in demand. *Button pearls*, as the name implies, are flat beneath. *Blister pearls* are growths on the shells, stimulated by a parasite.

Being soft, pearls are easily scratched. The original luster, once lost, can rarely be restored, and then only by peeling off some of the outer layers of the pearl. Acids and perspiration also affect them. Even age alone causes pearls to deteriorate, since the organic conchiolin finally decays.

Pearls are obtained from many oysters and mussels, but most of them are furnished by members of the following families: Aviculidae, including the pearl oysters; Unionidae, fresh-water mussels; and Mytilidae. Pearl fisheries are operated along the coasts of India, Ceylon, the Persian Gulf, Red Sea, Japan, Australia, the Sulu Archipelago northeast of Borneo, other Pacific Islands, western Central America and Mexico, and the Caribbean Sea. Fresh-water mussels inhabit the streams of Europe in Great Britain, Saxony, Bohemia, and Bavaria; and also in North America in Canada, Ohio, Indiana, Iowa, Arkansas, and Tennessee; also in Japan and China.

Pearls are artificially cultivated by the placing of a small object inside the pearl oyster or mussel. The shellfish is then returned to the water, and after a year or two is again taken out, when the pearl which has formed about the introduced particle is removed. These are called *culture pearls*. In Japan a process has recently been employed, by which the oysters are caused to grow pearls of spherical shape, resembling the finest natural pearls. A patch is cut from the mantle of an oyster. This is tied as a sac about a small, round object such as a bead of mother-of-pearl. The sac is then imbedded in the tissues of another live oyster. After proper treatment of the wound this oyster is returned to its bed. In the course of a few years a fine pearl is formed about the sac. Such pearls are not easily to be distinguished from natural pearls. It is of interest to note that the Chinese sometimes place small images of Buddha within an oyster to become covered with a pearly layer.

Pearls are imitated by hollow spheres of thin glass, which are coated with a preparation made from fish scales to give them a pearly luster. The glass sphere is then filled with white wax. A translucent white glass with a pearly luster is also used to imitate the natural gem.

CORAL

The composition of coral, like pearl, is principally calcium carbonate. This substance is secreted by small sea animals known as coral polyps, and used by them in building up their skeletons. The variety most employed as a gem is the *precious* or *red coral*. In color it is red or pink. Its hardness is 3½, its specific gravity, 2.6 to 2.7. The red coral is dredged from waters of moderate depth along the shores of the Mediterranean Sea—Tunis, Algeria, Morocco, Sardinia, Corsica, France, and near Naples. *Black coral* has been obtained from the Persian Gulf and the Great Barrier Reef of Australia. Coral is used for necklaces, bracelets, rosaries, and so on.

AMBER

Amber is a fossil resin, derived from coniferous trees. It is generally found in loosely consolidated and geologically young deposits. It is amorphous, occurring in irregular lumps with a conchoidal fracture. Amber is brittle, but may be easily worked upon the lathe. It has a hardness of 2 to 2½, and a specific gravity of 1.0 to 1.1. The color is yellow, also reddish, brownish, or whitish. Amber varies from clear and transparent material to that which is cloudy and translucent. The luster is greasy. Amber is often opalescent and fluorescent. It is isotropic, and has an index of refraction of about 1.54. It is easily electrified by rubbing with a cloth. Amber is a hydrocarbon composed of resins, oil, and succinic acid, hence the mineralogical name *succinite* is sometimes applied to it. It melts easily at about 280°C. Amber often contains inclusions of insects, and of vegetable remains, such as seeds, leaves, flowers, and mosses, as well as of liquids. These inclusions are frequently very well preserved and are of scientific as well as of popular interest. It is used for beads, earrings, pipe stems, cigar holders, and various ornaments. Much of the amber of commerce is washed up from submarine deposits along the coast of the Baltic and North Seas. It also occurs in Sicily, India, and the United States. Some substances very similar in appearance to amber and of the same origin are *burmite*, *copalite*, and *retinite*. Inferior amber or chips of good material are pressed together and sold as *ambroid*.

JET

Jet is a hard, compact, homogeneous, and coal-black variety of lignite or brown coal. It takes a good polish and is often used for ornaments and cheap jewelry, beads, and so forth. Jet has a conchoidal fracture. It is tough, so that it can be worked upon the lathe. Localities are: Yorkshire, England; Asturias, Spain; France; Wurtemburg; the United States. Anthracite from the Pennsylvania mines and Scotch cannel coal are both used in place of jet. Black cryptocrystalline varieties of quartz, sometimes artificially colored, as well as obsidian and glass, are also employed as imitations of true jet. *Bakelite* (p. 93) is an artificial product used for beads, pipe stems, and ornamental objects, in imitation of amber and jet.

B. CLASSIFICATION OF GEM MATERIALS, ACCORDING TO VARIOUS PROPERTIES

TABLES I–XI

In Tables I, IV, V, and VI the gem minerals are arranged in order of importance, that is, in the same sequence followed in Part II-A of this book: (1) precious stones; (2) semi-precious stones; (3) metallic gem minerals; (4) ornamental stones; (5) organic gem materials.

A summary of all the important properties of each gem mineral is to be found in Table XI.

TABLE I.—CRYSTAL FORM

Cubic System.—Diamond, garnet, spinel, chromite, cobaltite, gold, pyrite, fluorite, lazurite, sodalite.

Tetragonal System.—Zircon, anatase, cassiterite, rutile, vesuvianite.

Hexagonal System.—Corundum, beryl, tourmaline, quartz, apatite, benitoite, phenacite, willemite, hematite, smithsonite.

Orthorhombic System.—Topaz, olivine, chrysoberyl, variscite, andalusite, beryllonite, enstatite, bronzite, hypersthene, iolite, prehnite, staurolite, thomsonite, zoisite.

Monoclinic System.—Nephrite, jadeite, diopside, epidote, euclase, orthoclase, spodumene, titanite, azurite, malachite, datolite, gypsum, lazulite, sepiolite, serpentine.

Triclinic System.—Turquois, axinite, cyanite, microcline, albite, oligoclase, labradorite, rhodonite.

Amorphous.—Opal, obsidian, moldavite, amber, jet, chrysocolla (apparently).

TABLE II.—HARDNESS

Diamond	10
Corundum	9
Chrysoberyl	8.5
Topaz	8
Spinel	8
Beryl	7.5–8
Phenacite	7.5–8
Zircon	7.5
Euclase	7.5
Tourmaline	7–7.5
Andalusite	7–7.5
Iolite	7–7.5
Staurolite	7–7.5
Quartz	7
Garnet	6.5–7.5
Olivine	6.5–7
Jadeite	6.5–7
Axinite	6.5
Benitoite	6.5
Nephrite	6.5
Vesuvianite	6.5
Cassiterite	6–7
Epidote	6–7
Prehnite	6–7
Spodumene	6–7
Feldspar	6–6.5
Rutile	6–6.5
Pyrite	6–6.5
Turquois	6
Opal	5.5–6.5
Hematite	5.5–6.5
Anatase	5.5–6
Beryllonite	5.5–6
Enstatite	5.5
Hypersthene	5.5
Obsidian	5.5
Chromite	5.5
Cobaltite	5.5
Cyanite	4–7
Chlorastrolite	5–6
Diopside	5–6
Willemite	5–6
Rhodonite	5–6
Lazulite	5–6
Thomsonite	5–5.5
Titanite	5–5.5
Datolite	5–5.5
Lazurite	5–5.5
Apatite	5
Smithsonite	5
Variscite	4–5
Fluorite	4
Azurite	3.5
Malachite	3.5
Coral	3.5
Serpentine	2.5–4
Pearl	2.5–3.5
Chrysocolla	2–4
Gold	2.5–3
Amber	2–2.5
Sepiolite	2–2.5
Gypsum	2

TABLE III.—SPECIFIC GRAVITY

Because of the variation in the specific gravity of minerals the values are given only to the first decimal place. The figures are either mean values or for pure specimens.

Gold	16–19
Cassiterite	6.9
Cobaltite	6.2
Hematite	5.2
Pyrite	5.0
Chromite	4.5
Zircon	4.0–4.8
Smithsonite	4.3
Spessartite	4.2
Rutile	4.2
Almandite	4.1
Willemite	4.1
Corundum	4.0
Malachite	4.0
Andradite	3.8
Anatase	3.8
Azurite	3.8
Pyrope	3.7
Chrysoberyl	3.7
Staurolite	3.7
Spinel	3.6
Benitoite	3.6
Cyanite	3.6
Rhodonite	3.6
Diamond	3.5
Topaz	3.5
Grossularite	3.5
Uvarovite	3.5
Titanite	3.5
Olivine	3.4
Hypersthene	3.4
Epidote	3.4
Vesuvianite	3.4
Jadeite	3.3
Axinite	3.3
Andalusite	3.2
Apatite	3.2
Enstatite	3.2
Chlorastrolite	3.2
Diopside	3.2
Fluorite	3.2
Tourmaline	3.1
Euclase	3.1
Spodumene	3.1
Lazulite	3.1
Phenacite	3.0
Nephrite	3.0
Datolite	2.9
Prehnite	2.9
Beryllonite	2.8
Beryl	2.7
Oligoclase	2.7
Labradorite	2.7
Quartz	2.7
Turquois	2.7
Coral	2.7
Orthoclase	2.6
Microcline	2.6
Albite	2.6
Iolite	2.6
Serpentine	2.6
Pearl	2.6
Obsidian	2.5
Variscite	2.5
Lazurite	2.4
Thomsonite	2.3
Gypsum	2.3
Opal	2.2
Chrysocolla	2.1
Sepiolite	1–2
Amber	1.1

TABLE IV.—COLOR

In this table are included for the most part only those colors of gem minerals which are met with in cut stones.

Colorless

Diamond, corundum (white sapphire), beryl (goshenite), topaz, grossularite, tourmaline (achroite), zircon, opal, quartz (rock crystal), apatite, beryllonite, euclase, orthoclase (adularia), albite, oligoclase, phenacite, fluorite, gypsum (selenite).

White

White.—Opal, quartz (milky quartz, chalcedony, agate, onyx), thomsonite, datolite, gypsum (satin spar, alabaster), sepiolite, pearl, amber.

Greenish-white.—Nephrite, jadeite, serpentine.

Purple

Purple.—Rhodolite, spinel (almandine), quartz (amethyst), fluorite, pearl.

Lilac.—Spodumene (kunzite).

Violet

Corundum (oriental amethyst), topaz, tourmaline, spinel (almandine), quartz (amethyst), andalusite, apatite, axinite, fluorite.

Blue

Violet-blue.—Lazurite, apatite, fluorite.

Dark Blue.—Tourmaline (indicolite), iolite, azurite.

Azure-blue.—Turquois, lazurite, sodalite, lazulite.

Sapphire-blue.—Corundum (sapphire), beryl, tourmaline, spinel (sapphirine), quartz (sapphire quartz), benitoite.

Sky-blue.—Beryl, turquois, odontolite, cyanite, fluorite.

Pale Blue.—Diamond, beryl, topaz, zircon, euclase, vesuvianite (cyprine), smithsonite, pearl.

Grayish-blue.—Opal, quartz (chalcedony, agate, jasper).

Greenish-blue.—Turquois, chrysocolla, fluorite, lazurite, beryl (aquamarine).

Green

Bluish-green.—Apatite, variscite, microcline (amazonstone), chrysocolla.

Dark Green.—Quartz (jasper), nephrite, chlorastrolite, diopside, epidote, serpentine.

Olive-green.—Olivine (peridot), enstatite, serpentine.

Emerald-green.—Beryl (emerald), grossularite, uvarovite, andradite (Uralian emerald), chrysoberyl (alexandrite), jadeite, spodumene (hiddenite), malachite.

Grass-green.—Andradite (demantoid), spinel (chlorospinel), malachite.

Pistachio-green.—Epidote.

Bottle-green.—Olivine (peridot), andalusite, moldavite.

Oil-green.—Prehnite, serpentine.

Bright Green.—Corundum (oriental emerald), tourmaline, quartz (plasma) cyanite, fluorite, serpentine.

Dull Green.—Quartz (cat's eye, prase), nephrite, labradorite, obsidian, vesuvianite (californite), serpentine.

TABLE IV.—COLOR.—*Continued*

GREEN—*Continued*

Apple-green.—Quartz (chrysoprase), turquois, variscite, willemite, prehnite.

Sea-green.—Beryl (aquamarine), apatite, euclase.

Pale Green.—Diamond, topaz, zircon, opal, diopside, enstatite, euclase, thomsonite, titanite, datolite, smithsonite, pearl.

Brownish-green.—Andalusite, obsidian, moldavite.

Yellowish-green.—Tourmaline, olivine (chrysolite), chrysoberyl, andalusite, epidote, prehnite, spodumene (hiddenite).

Yellow

Greenish-yellow.—Olivine (chrysolite), chrysoberyl, willemite, serpentine.

Golden-yellow.—Corundum (golden sapphire), beryl (golden beryl), spinel.

Bright Yellow.—Smithsonite.

Honey-yellow.—Tourmaline, amber.

Wine-yellow.—Topaz, grossularite, andradite (topazolite), fluorite.

Straw-yellow.—Titanite.

Pale Yellow.—Diamond, opal, beryllonite, orthoclase, phenacite, thomsonite, datolite, sepiolite, pearl.

Brownish-yellow.—Zircon (jacinth), tourmaline, quartz (citrine, tiger's eye, jasper), axinite, staurolite, willemite, amber.

Orange

Orange.—Fluorite.

Reddish-orange.—Spinel (rubicelle), zircon (jacinth).

Red

Violet-red.—Almandite.

Scarlet-red.—Coral.

Crimson-red.—Fluorite.

Ruby-red.—Corundum (ruby), pyrope, spinel (ruby spinel).

Dark Red.—Spessartite, almandite.

Dull Red.—Quartz (carnelian, agate, jasper), obsidian, hematite.

Pale Red.—Opal, thomsonite, datolite, pearl.

Pink to Rose-red.—Diamond, corundum (pink sapphire), beryl (morganite), topaz, grossularite, tourmaline (rubellite), spinel (balas ruby), opal, quartz (rose quartz), andalusite, apatite, phenacite, spodumene (kunzite), fluorite, rhodonite, smithsonite, zoisite (thulite), pearl, coral.

Flesh-red.—Apatite, willemite.

Brownish-red.—Andradite, spessartite, almandite, zircon (jacinth), quartz (carnelian, agate), rutile, staurolite, amber.

Brown

Brown.—Andradite, anatase, cassiterite, hypersthene, thomsonite, titanite vesuvianite, willemite, fluorite, amber.

Dull Brown.—Opal, quartz (cat's eye, chalcedony, carnelian, agate, jasper, flint), obsidian.

Smoky-brown.—Quartz (smoky quartz).

Clove-brown.—Zircon (jacinth), axinite.

Cinnamon-brown.—Grossularite (cinnamon stone).

Yellowish-brown.—Topaz, tourmaline.

Pale Brown.—Datolite, pearl.

Table IV.—Color.—*Continued*

Gray

Opal, quartz (cat's eye, chalcedony, flint), labradorite.

Black

Almandite, andradite (melanite), tourmaline (schorl), opal, quartz (morion, onyx, flint, basanite), anatase, cassiterite, obsidian, rutile (nigrine), chromite, hematite, pearl, jet.

Metallic Colors

Silver-white.—Cobaltite.
Golden-yellow.—Gold.
Brass-yellow.—Pyrite.

Banded and Mottled Colors

Banded Colors.—Tourmaline, quartz (agate, onyx, sardonyx, jasper).
Mottled Colors.—Quartz (jasper, agate), nephrite, jadeite, chlorastrolite, cyanite, datolite, thomsonite, serpentine, azurmalachite.

Colored Streak

Blue.—Azurite.
Green.—Malachite.
Pale Green.—Turquois.
Golden-yellow.—Gold.
Red.—Hematite.
Brown.—Chromite.
Pale Brown.—Rutile, cassiterite.
Black.—Jet.
Greenish-black.—Pyrite.
Grayish-black.—Cobaltite.

Table V.—Miscellaneous Physical Properties

Chatoyant.—Chrysoberyl (cat's eye), quartz (tiger's eye, cat's eye), bronzite, gypsum (satin spar).
Opalescent.—Opal, orthoclase, albite, and oligoclase (moonstone).
Play of Color.—Opal, labradorite.
Asteriated.—Corundum (star ruby and sapphire).
Containing Inclusions.—Opal (moss opal), quartz (aventurine, rutilated quartz, moss agate), andalusite (chiastolite), oligoclase (sunstone).

Table VI.—Optical Character

Isotropic.—Diamond, garnet, spinel, opal, obsidian, fluorite, lazurite, amber.
Uniaxial Positive.—Zircon, quartz, benitoite, cassiterite, phenacite, rutile, willemite, chrysocolla.
Uniaxial Negative.—Corundum, beryl, tourmaline, anatase, apatite, smithsonite.
Biaxial Positive.—Topaz, olivine, chrysoberyl, turquois, diopside, enstatite, euclase, albite, labradorite, prehnite, spodumene, staurolite, thomsonite, titanite, azurite, gypsum.
Biaxial Negative.—Andalusite, axinite, beryllonite, cyanite, hypersthene, epidote, orthoclase, microcline, oligoclase, iolite, vesuvianite, malachite, datolite, lazulite, rhodonite, serpentine.

TABLE VII.—MEAN INDEX OF REFRACTION AND BIREFRINGENCE

The mean index of refraction is: for isotropic minerals, n; uniaxial, $\frac{2\omega + \epsilon}{3}$; biaxial, $\frac{\alpha + \beta + \gamma}{3}$. The birefringence indicates the range in indices. The asterisk (*) denotes isotropic minerals, which have no birefringence.

	Mean index	Birefringence		Mean index	Birefringence
Rutile	2.71	0.38	Phenacite	1.66	0.02
Anatase	2.53	0.06	Spodumene	1.66	0.03
Diamond	2.42	*	Euclase	1.65	0.02
Cassiterite	2.03	0.10	Datolite	1.65	0.04
Titanite	1.95	0.13	Andalusite	1.64	0.01
Zircon	1.94	0.05	Apatite	1.64	0.004
Andradite	1.89	*	Tourmaline	1.63	0.02
Uvarovite	1.87	*	Prehnite	1.63	0.03
Almandite	1.83	*	Turquois	1.63	0.04
Malachite	1.81	0.26	Topaz	1.62	0.01
Spessartite	1.80	*	Lazulite	1.62	0.04
Benitoite	1.78	0.05	Nephrite	1.61	
Azurite	1.77	0.11	Beryl	1.58	0.006
Corundum	1.76	0.008	Beryllonite	1.56	0.01
Chrysoberyl	1.75	0.01	Labradorite	1.56	0.01
Epidote	1.75	0.04	Quartz	1.55	0.01
Smithsonite	1.75	0.20	Iolite	1.55	0.008
Staurolite	1.74	0.01	Obsidian	1.5–1.6	*
Grossularite	1.73	*	Oligoclase	1.54	0.01
Rhodonite	1.73	0.01	Amber	1.54	*
Spinel	1.72	*	Microcline	1.53	0.008
Vesuvianite	1.72	0.006	Albite	1.53	0.01
Cyanite	1.72	0.01	Serpentine	1.53	
Pyrope	1.70	*	Orthoclase	1.52	0.006
Hypersthene	1.70	0.01	Gypsum	1.52	0.01
Willemite	1.70	0.02	Thomsonite	1.51	0.03
Olivine	1.68	0.04	Chrysocolla	1.50	0.11
Axinite	1.68	0.01	Lazurite	1.50	*
Diopside	1.68	0.03	Opal	1.44	*
Enstatite	1.67	0.01	Fluorite	1.43	*
Jadeite	1.67				

Table VIII.—Dispersion

The values for the dispersion of the indices of refraction, as given in this table, have been obtained from several authorities, and for this reason the wave-lengths of light at which maximum and minimum values were measured are not uniform for all the gems. In each case, however, the dispersion recorded is that between the red and blue portions of the spectrum.

Andradite (demantoid)	0.057	Olivine	0.018
Titanite	0.050	Epidote	0.018
Diamond	0.044*	Spodumene	0.017
Zircon	0.038	Tourmaline	0.016
Grossularite (hessonite)	0.028	Chrysoberyl	0.015
Pyrope	0.027	Topaz	0.014
Almandite	0.024	Beryl	0.014
Staurolite	0.021	Quartz	0.013
Spinel	0.020	Albite	0.012
Corundum	0.018	Fluorite	0.006

* Between red and violet, 0.058.

Table IX.—Pleochroism

The following gem minerals are usually pleochroic in two or three shades of the color visible to the unaided eye, or in that color and colorless, *e.g.*, ruby, pale yellowish-red, and deep red.

Pleochroism strong to distinct: Corundum, tourmaline, benitoite, cyanite, spodumene, malachite.

Pleochroism distinct to weak: Beryl, olivine, blue topaz, smoky quartz, amethyst, euclase, vesuvianite, azurite.

The following are pleochroic in two or three different colors, as indicated:

Gem mineral	Pleochroic colors
Chrysoberyl	Green, red, orange-yellow; strong.
Andalusite	Colorless, yellow, red, or green; strong.
Axinite	Green, brown, blue, or violet; strong.
Epidote	Green, brown, yellow; strong.
Iolite	Yellow, blue; strong.
Zoisite, thulite variety	Pink, yellow; strong.
Anatase	Pale blue or yellowish, dark blue or orange; distinct.
Hypersthene	Red, yellow, green; distinct.
Staurolite	Red, brown, or yellow; distinct.
Topaz, yellow and pink varieties	Yellow, pale pink to colorless; distinct to weak.
Titanite	Red, yellow, greenish, or colorless; weak to distinct.

Isotropic gems are of course non-pleochroic. Other gems not mentioned in this table are either (*a*) non-pleochroic; (*b*) or only weakly pleochroic; (*c*) or being opaque do not readily reveal their pleochroic character.

TABLE X.—COMPOSITION

	Elements
Diamond	C
Gold	Au
	Sulphides
Pyrite	FeS_2
Cobaltite	CoAsS
	Oxides and Hydroxides
Quartz	SiO_2
Rutile	$TiTiO_4$
Anatase	$TiTiO_4$
Zircon	$ZrSiO_4$
Cassiterite	$SnSnO_4$
Corundum	Al_2O_3
Hematite	Fe_2O_3
Opal	$SiO_2.xH_2O$
	Haloids
Fluorite	CaF_2
	Carbonates
Smithsonite	$ZnCO_3$
Malachite	$CuCO_3.Cu(OH)_2$
Azurite	$2CuCO_3.Cu(OH)_2$
	Sulphates
Gypsum	$CaSO_4.2H_2O$
	Aluminates
Spinel	$Mg(AlO_2)_2$
Chromite	$[Fe,Cr][(Cr, Fe)O_2[_2$
Chrysoberyl	$Be(AlO_2)_2$
	Phosphates
Beryllonite	$NaBePO_4$
Apatite	$Ca_5(F,Cl)(PO_4)_3$
Lazulite	$(Fe,Mg)Al_2(OH)_2(PO_4)_2$
Variscite	$AlPO_4.2H_2O$
Turquois	Basic copper aluminum phosphate.
	Silicates and Titanates
Staurolite	$HFeAl_5Si_2O_{13}$
Andalusite	Al_2SiO_5
Cyanite	Al_2SiO_5
Topaz	$Al_2(F,OH)_2SiO_4$
Datolite	$Ca(B.OH)SiO_4$

TABLE X.—COMPOSITION.—*Continued*

Silicates and Titanates

Euclase	$Be(Al.OH)SiO_4$
Tourmaline	$H_{20}B_2Si_4O_{21}$
Epidote	$Ca_2(Al,Fe)_2(Al.OH)(SiO_4)_3$
Zoisite	$Ca_2Al_2(Al.OH)(SiO_4)_3$
Vesuvianite	$Ca_6[Al(OH,F)]Al_2(SiO_4)_5$
Olivine	$(Mg,Fe)_2SiO_4$
Willemite	Zn_2SiO_4
Phenacite	Be_2SiO_4
Garnet	$M''_3M'''_2(SiO_4)_3$
Grossularite	$Ca_3Al_2(SiO_4)_3$
Pyrope	$Mg_3Al_2(SiO_4)_3$
Almandite	$Fe_3Al_2(SiO_4)_3$
Spessartite	$Mn_3Al_2(SiO_4)_3$
Andradite	$Ca_3Fe_2(SiO_4)_3$
Uvarovite	$Ca_3Cr_2(SiO_4)_3$
Chrysocolla	CuO, SiO_2, H_2O
Prehnite	$H_2Ca_2Al_2(SiO_4)_3$
Axinite	$(Ca,Fe)Al_4B_2(SiO_4)_8$
Serpentine	$H_4Mg_3Si_2O_9$
Sepiolite	$H_4Mg_2Si_3O_{10}$
Sodalite	$Na_4Al_2(AlCl)(SiO_4)_3$
Lazurite	$(Na_2,Ca)_2Al_2[Al(NaSO_4, NaS_3, Cl)](SiO_4)_3$
Enstatite	$Mg_2(SiO_3)_2$
Bronzite	$(Mg,Fe)_2(SiO_3)_2$
Hypersthene	$(Fe,Mg)_2(SiO_3)_2$
Diopside	$CaMg(SiO_3)_2$
Spodumene	$LiAl(SiO_3)_2$
Jadeite	$NaAl(SiO_3)_2$
Rhodonite	$Mn_2(SiO_3)_2$
Nephrite	$Ca(Mg,Fe)_3(SiO_3)_4$
Beryl	$Be_3Al_2(SiO_3)_6$
Iolite	$(Mg,Fe)_4Al_8(OH)_2(Si_2O_7)_5$
Orthoclase	$KAlSi_3O_8$
Microcline	$KAlSi_3O_8$
Albite	$NaAlSi_3O_8$ (*Ab*)
Anorthite	$CaAl_2Si_2O_8$ (*An*)
Oligoclase	Ab_6An_1 to Ab_3An_1
Labradorite	Ab_1An_1 to Ab_1An_3
Titanite	$CaTiSiO_5$
Benitoite	$BaTiSi_3O_9$
Thomsonite	$2(Ca,Na_2)Al_2(SiO_4)_2.5H_2O$

Table XI.—Summary of the Properties of the Gem
for Ready

Name, page reference, composition, and varieties	Color	Luster, transparency
AMBER *Fossil resin*, a hydrocarbon. 185	Yellow, also reddish, brownish, or whitish.	Greasy. Transparent to translucent.
ANATASE TiTiO$_4$ 156	Brown to black.	Adamantine. Transparent.
ANDALUSITE Al$_2$SiO$_5$ *Chiastolite*, regular internal arrangement of dark matter. 156	Gray, green, yellow-green, bottle-green, brown, pink, red, or violet.	Vitreous to dull. Transparent to opaque.
APATITE Ca$_5$(F,Cl)(PO$_4$)$_3$ 157	Green, pink, blue, purple, violet, or colorless.	Vitreous to greasy. Transparent.
AXINITE (Ca, Fe)$_7$Al$_4$B$_2$(SiO$_4$)$_7$ 157	Brown, yellow-brown, or violet.	Vitreous. Transparent.
AZURITE 2CuCO$_3$.Cu(OH)$_2$ 173	Blue. Blue streak.	Vitreous to dull. Translucent to opaque.
BENITOITE BaTiSi$_3$O$_9$ 158	Blue.	Vitreous. Transparent.
BERYL		Vitreous.
Be$_3$Al$_2$(SiO$_3$)$_6$ *Emerald*	Emerald-green.	Transparent.
Aquamarine	Blue to sea-green.	
Golden beryl	Yellow.	
Morganite	Pink to rose.	
Goshenite	Colorless.	
123		
BERYLLONITE NaBePO$_4$ 158	Colorless to pale yellow.	Vitreous. Transparent.

Materials Described in the Text, Arranged Alphabetically

Reference

Hardness (H.), specific gravity (S.G.)	Crystallization, structure, cleavage (C), and fracture (F)	Optical properties n = mean index	Characteristics, occurrence, and principal localities
H. 2–2½ S.G. 1.0–1.1	Amorphous, irregular lumps. F—Conchoidal.	Isotropic n 1.54.	Electrified when rubbed. Melts at 280°C. Often contains inclusions—insects, vegetable remains, etc. Coasts of Baltic and North Seas.
H. 5½–6 S.G. 3.8–4.0	Tetragonal, only in crystals. C—Pyramidal, basal perfect.	Uniaxial; − ω 2.55, ϵ 2.49 ω-ϵ 0.06.	With rutile. Crystals often resemble elongated octahedrons. Cornwall, England; France; Germany; Switzerland; Brazil.
H. 7–7½ (often softer on surface.) S.G. 3.1–3.2	Orthorhombic, prismatic crystals.	Biaxial; − n 1.64. γ-α 0.01.	Pleochroism sometimes strong. With cyanite, garnet, tourmaline, in metamorphic rocks. Andalusia, Spain; Ceylon; Brazil.
H. 5 S G. 3.1–3.2	Hexagonal, prismatic, tabular crystals. F—Conchoidal.	Uniaxial; − n 1.64. ω-ϵ 0.004.	With quartz, fluorite, tourmaline, in pegmatites and metamorphic rocks. Saxony; Bohemia; Switzerland; Ceylon; Maine.
H. 6½ S.G. 3.3	Triclinic, tabular crystals. F—Conchoidal.	Biaxial; − n 1.68. γ-α 0.009.	Crystals sharp wedge-shaped. Dauphiné, France.
H. 3½ S.G. 3.7–3.8	Monoclinic, tabular crystals, massive, fibrous.	Biaxial; + n 1.71. γ-α 0.11.	With malachite and other copper minerals. Ural Mountains; Rhodesia; Chile; Arizona.
H. 6½ S.G. 3.3	Hexagonal, tabular crystals. F—Conchoidal.	Uniaxial; + ω1.76, ϵ1.80. ϵ-ω 0.047.	Resembles sapphire. Strong dichroism: ϵ blue; ω white. San Benito County, California.
H. 7½–8 S.G. 2.6–2.8	Hexagonal, prismatic crystals, massive. F—Conchoidal.	Uniaxial; − n 1.58. ω-ϵ 0.006. Dispersion 0.014.	Generally in pegmatites, with quartz, topaz, tourmaline, chrysoberyl, garnet. *Emerald* in metamorphic rocks. *Emerald:* Egypt, Colombia, Urals, Tyrol, North Carolina. *Other varieties:* Brazil, Elba, Madagascar, Urals, Ireland, Ceylon, India, Maine, California.
H. 5½–6 S.G. 2.85	Orthorhombic, highly modified crystals.	Biaxial; − n 1.56. γ-α 0.01.	In veins in granite, Stoneham, Maine.

TABLE XI.—SUMMARY OF THE PROPERTIES OF THE GEM
FOR READY

Name, page reference, composition, and varieties	Color	Luster, transparency
CASSITERITE $SnSnO_4$	Brown, reddish-brown, black, or yellow.	Adamantine. Transparent.
158		
CHLORASTROLITE Silicate of calcium and aluminum.	Green, with attractive white markings.	Vitreous. Translucent.
159		
CHROMITE $(Fe, Cr)[(Cr, Fe)O_2]_2$	Iron-black to brownish-black. Streak brown.	Pitchy submetallic to metallic. Opaque.
170		
CHRYSOBERYL		Vitreous or silky.
$Be(AlO_2)_2$ *Chrysolite*	Yellowish-green.	Transparent to translucent.
Cat's eye	Green, chatoyant.	
Alexandrite	Emerald-green in daylight, red by artificial light.	
137		
CHRYSOCOLLA Hydrous copper silicate.	Green and greenish-blue.	Vitreous, greasy, or dull . Translucent to opaque.
174		
COBALTITE CoAsS	Silver-white with a reddish tinge. Streak black.	Metallic. Opaque.
171		
CORAL		Dull.
$CaCO_3$ *Precious coral*	Red.	Translucent.
Black coral	Black.	
185		
CORUNDUM		Adamantine when cut.
Al_2O_3 *Ruby*	Rose to deep purplish-red.	Transparent.
Sapphire	Blue.	
White sapphire	Colorless.	
Golden sapphire	Yellow.	
Pink sapphire	Pink.	
Oriental emerald	Green.	
Oriental topaz	Yellow.	
Oriental amethyst	Violet.	
119 *Star sapphire and ruby*	Show asterism.	

MATERIALS DESCRIBED IN THE TEXT, ARRANGED ALPHABETICALLY REFERENCE.—*Continued*

Hardness (H.), specific gravity (S.G.)	Crystallization, structure, cleavage (C), and fracture (F)	Optical properties n = mean index	Characteristics, occurrence, and principal localities
H. 6–7 S.G. 6.8–7.0	Tetragonal; prismatic crystals, often twinned.	Uniaxial; + n 2.04 $\epsilon-\omega$ 0.10.	High specific gravity. In veins in granite, gneiss. With quartz, tourmaline, fluorite, apatite. Cornwall, England; Bohemia; Saxony.
H. 5–6 S.G. 3.2	Always in rounded grains or pebbles, fibrous.		Weathers out of basic igneous rocks. Color unevenly distributed. Chatoyant. Lake Superior district.
H. 5½ S.G. 4.3–4.6	Cubic; compact.		With serpentine and chromium garnet. New Zealand; New Caledonia; Asiatic Turkey; Silesia; Pennsylvania; Maryland.
H. 8½ S.G. 3.5–3.8	Orthorhombic; tabular heart-shaped twins, or pseudohexagonal. Loose grains. Cat's eye is fibrous.	Biaxial; + n 1.75. $\gamma-\alpha$ 0.010. Dispersion 0.015.	Crystals striated. Pleochroism strong: green, red, and orange-yellow. Strong absorption band in yellow. In gneiss, mica schist, granite; with beryl, tourmaline, apatite. *Chrysolite* from Brazil; *cat's eye*, Ceylon, China, Brazil; *alexandrite*, Urals, Ceylon.
H. 2–4 S.G. 2.0–2.2	Amorphous masses; compact. F—Conchoidal.	Uniaxial; + n 1.50. $\epsilon-\omega$ 0.11.	Enamel-like appearance. With other copper minerals. Urals, Arizona, Lake Superior district.
H. 5½ S.G. 6.0–6.4	Cubic; pyritohedrons.		Sweden; Norway; Cornwall, England; Ontario.
H. 3½ S.G. 2.6–2.7	Branching.		Skeletons of small sea animals. From waters of moderate depth along shores of Mediterranean, Persian Gulf, Australia.
H. 9 S.G. 3.9–4.1	Hexagonal; rough, barrel-shaped, or tabular crystals. Sometimes twinned. Conspicuous partings. F—Conchoidal.	Uniaxial; − n 1.76. $\omega-\epsilon$ 0.008 Dispersion 0.018.	Pleochroism strong. Darkest red through base. Cut cabochon may show asterism. Heat makes color paler. Phosphoresces with ultra-violet light. In placers, limestone, gneiss, schist, igneous rocks; with spinel, tourmaline. Burma, Ceylon, Siam, Urals, Montana, North Carolina.

TABLE XI.—SUMMARY OF THE PROPERTIES OF THE GEM
FOR READY

Name, page reference, composition, and varieties	Color	Luster, transparency
CYANITE Al_2SiO_5 160	Light to sky-blue, green, brown, or colorless.	Vitreous. Transparent.
DATOLITE $Ca(B.OH)SiO_4$ 175	White, yellowish, reddish, greenish, brownish; mottled.	Dull. Opaque.
DIAMOND C 109	White, blue-white, yellow, brown, green, red, blue; pale.	Adamantine. Transparent.
DIOPSIDE $CaMg(SiO_3)_2$ 160	*Common* . . Green, yellow, colorless. *Violan* . . . Blue.	Vitreous to resinous. Transparent.
ENSTATITE $MgSiO_3$ **HYPERSTHENE** $(Fe,Mg)SiO_3$ 161	Grayish-white, greenish, yellowish, brown, black; enstatite, light; hypersthene, dark.	Vitreous, bronzy, or pearly. Translucent to opaque.
EPIDOTE $Ca_2(Al, Fe)_2(AlOH)(SiO_4)_3$ 162	Yellowish to blackish or pistachio-green; brown, red.	Vitreous to resinous. Transparent.
EUCLASE $Be(Al.OH)SiO_4$ 162	Pale green or blue, colorless.	Vitreous. Transparent.
FELDSPAR $KAlSi_3O_8$, *orthoclase* and *microcline*. $NaAlSi_3O_8$, *albite*. $Ca_2Al_2Si_2O_8$, *anorthite*. *Oligoclase* and *labradorite* are intermediate between albite and anorthite. 163	*Adularia* . . Colorless. *Moonstone* . . Opalescent, white. *Amazonstone* . . Green. *Sunstone* or *aventurine* . . Reddish. *Labradorite* . . Gray with marked play of colors. *Yellow orthoclase*.	Vitreous to pearly. Transparent to opaque.

Materials Described in the Text, Arranged Alphabetically Reference.—*Continued*

Hardness (H.) specific gravity (S.G.)	Crystallization, structure, cleavage (C), and fracture (F)	Optical properties n = mean index	Characteristics, occurrence, and principal localities
H. 4–7, varying with direction. S.G. 3.5–3.7	Triclinic; bladed crystals. C—Perfect pinacoidal.	Biaxial; − n 1.72. γ-α 0.012.	Color irregularly distributed. Hardness varies greatly with direction. In metamorphic rocks, with staurolite and garnet. Switzerland, Tyrol, Brazil, Massachusetts.
H. 5–5½ S.G. 2.9–3.0	Monoclinic; compact. F—Conchoidal.	Biaxial; − n 1.65. γ-α 0.04.	Resembles unglazed porcelain. Native copper inclusions. In basic igneous rocks. Lake Superior district.
H. 10 S.G. 3.5	Cubic; octahedrons, rounded, distorted; twinned. C—Perfect octahedral. F—Conchoidal.	Isotropic. n 2.42. Dispersion high, 0.058.	Cold feel. Electrified on rubbing. Phosphoresces and fluoresces. Transparent to X-rays. With pyrope, gold; in placers and blue ground. South Africa, Brazil, India, Australia, Arkansas.
H. 5–6 S.G. 3.2–3.3	Monoclinic, prismatic crystals. C—Prismatic, basal parting.	Biaxial; + n 1.68. γ-α 0.03.	Often zonally colored. In metamorphosed limestones. Piedmont, Italy; Tyrol; Renfrew County, Ontario; New York.
H. 5–6 S.G. 3.1–3.5	Orthorhombic; fibrous or lamellar masses. C—Prismatic.	Biaxial; *enstatite* +; *hypersthene* − n 1.67–1.70. γ-α 0.01.	*Hypersthene* has metalloidal iridescence. South African *enstatite* sold as "green garnet." In basic igneous rocks.
H. 6–7 S.G. 3.3–3.5	Monoclinic; excellent prismatic crystals. C—Basal perfect.	Biaxial; − n 1.75. γ-α 0.04. Dispersion 0.018.	Pleochroism marked: yellow, green, brown. In metamorphic rocks. Tyrol; Piedmont, Italy; Elba; Dauphiné, France; Arendal, Norway; Prince of Wales Island, Alaska.
H. 7½ S.G. 3.1	Monoclinic; prismatic crystals. C—Pinacoidal.	Biaxial; + n 1.65. γ-α 0.02.	In metamorphic rocks with topaz, beryl, chrysoberyl. Brazil; Urals. Resembles aquamarine.
H. 6–6½ S.G. 2.5–2.8	Orthoclase monoclinic; others triclinic. Prismatic or tabular crystals and cleavage masses. C—Perfect in two directions.	Biaxial; *albite* and *labradorite* +; others − n 1.52–1.58. γ-α 0.005–0.012. Dispersion low, for *albite*, 0.012.	*Adularia* a variety of orthoclase; *moonstone*, of orthoclase, albite, and oligoclase; *amazonstone*, of microcline; *sunstone*, of oligoclase. *Adularia* and *moonstone:* Switzerland, Elba, Ceylon. *Amazonstone:* Urals, Pennsylvania, Colorado. *Labradorite;* Labrador. All varieties occur in igneous rocks, or in veins and cavities in metamorphic rocks.

Table XI.—Summary of the Properties of the Gem
for Ready

Name, page reference, composition, and varieties	Color	Luster, transparency
FLUORITE	Yellow, orange, green, blue, red, violet, pink, brown, colorless.	Vitreous. Transparent to translucent.
CaF_2		
176		
GARNET		Vitreous to resinous.
$M''_3M'''_2(SiO_4)_3$		Light-colored varieties transparent; darker varieties opaque.
M'' M'''		
Ca Al *Grossularite, hessonite*		
Mg Al *Pyrope*	Yellow, brown.	
Fe Al *Almandite, carbuncle*	Ruby-red.	
Rhodolite	Deep red to black.	
	Rose-red to purple (mixture of almandite and pyrope).	
Ca Fe *Andradite*, includes:		
Topazolite	Yellow.	
Demantoid	Grass-green.	
Uralian emerald ...	Green.	
127 *Melanite*	Black.	
GOLD	Golden-yellow.	Metallic.
Au	Streak golden-yellow.	Opaque.
171		
GYPSUM		Pearly, silky, or dull.
$CaSO_4.2H_2O$ *Satin spar*	White, chatoyant, fibrous, silky luster.	Transparent to opaque.
Alabaster	Snow-white, fine-grained, opaque.	
177		
HEMATITE	Black.	Metallic splendent.
Fe_2O_3	Streak red.	Opaque.
172		
IOLITE	Smoky-blue to light blue.	Vitreous. Transparent to translucent.
Cordierite, dichroite Magnesium, iron, aluminum silicate.		
164		
JADE	White to leaf-green, emerald green, or dark green.	Subvitreous to pearly. Translucent to opaque.
Nephrite... $Ca(Mg,Fe)_3(SiO_3)_4$ *Jadeite* .... $NaAl(SiO_3)_2$		
154		

MATERIALS DESCRIBED IN THE TEXT, ARRANGED ALPHABETICALLY REFERENCE.—*Continued*

Hardness (H.), specific gravity (S.G.)	Crystallization, structure, cleavage (C), and fracture (F)	Optical properties n = mean index	Characteristics, occurrence, and principal localities
H. 4 S.G. 3.0–3.2	Cubic; cubical crystals; also cleavage masses or fibrous. C—Perfect octahedral.	Isotropic. n 1.434. Dispersion 0.006.	Crystals frequently twinned. In veins and pegmatites; England most important.
H. 6½–7½ S.G. 3.4–4.3 *Grossularite* 3.4–3.7 *Pyrope* 3.7–3.8 *Almandite* 3.9–4.2 *Andradite* 3.8–3.9	Cubic; good crystals, dodecahedron and tetragonal trisoctahedron; also as pebbles. F—Conchoidal.	Isotropic. n 1.70–1.90: *Grossularite* 1.735. *Pyrope* 1.705. *Almandite* 1.830. *Andradite* 1.895. Dispersion 0.024–0.028, for *demantoid* 0.057.	*Grossularite:* in metamorphosed limestones, with vesuvianite, diopside; with zircon in placers; Ceylon. *Pyrope:* rounded grains in peridotite and serpentine; South Africa, Bohemia, Arizona. *Almandite:* in metamorphic and igneous rocks, with staurolite, cyanite, andalusite; widespread. *Rhodolite:* North Carolina. *Andradite:* in igneous and metamorphic rocks; Urals, Saxony.
H. 2½–3 S.G. 16–19	Cubic; small crystals, or nuggets, or disseminated in quartz.		In quartz veins or placers. California, Alaska, other gold-mining districts.
H. 2 S.G. 2.2–2.4	Monoclinic; tabular crystals, cleavage masses, fibrous, granular. C—Perfect pinacoidal.	Biaxial; + n 1.525 γ-α 0.010.	In limestones, shales. *Satin spar:* England; Niagara Falls, New York. *Alabaster:* Leghorn, Italy; Michigan.
H. 5½–6½ S.G. 4.9–5.3	Hexagonal; tabular crystals, compact.		Elba, Norway, Sweden, England, Lake Superior district.
H. 7–7½ S.G. 2.6	Orthorhombic; massive. C—Pinacoidal. F—Conchoidal.	Biaxial; − n 1.55. γ-α 0.008.	Pleochroism very strong in light and dark blue and yellowish white. In metamorphic rocks, gravels. Ceylon.
H. 6½–7 S.G. 3.1 *Nephrite* 2.9 *Jadeite* 3.3	Monoclinic; always massive, compact. F—Splintery.	*Nephrite,* n 1.62. *Jadeite,* n 1.67.	Tough. Color often irregularly distributed. *Nephrite:* China, Turkestan, Siberia, New Zealand. *Jadeite:* Burma, Yunnan, Tibet, Mexico (?), South America (?).

TABLE XI.—SUMMARY OF THE PROPERTIES OF THE GEM
FOR READY

Name, page reference, composition, and varieties		Color	Luster, transparency
JET Largely carbon, with hydrogen, oxygen. 186		"Jet" black.	Resinous. Opaque.
LAZULITE $(Fe,Mg)(Al.OH)_2P_2O_8$ 179		Azure blue.	Vitreous. Translucent to opaque.
LAZURITE *Lapis lazuli* Complex silicate. 179		Deep blue, azure blue, Berlin blue, greenish blue.	Vitreous to greasy. Opaque.
MALACHITE $CuCO_3.Cu(OH)_2$ 173		Emerald green, grass green. Streak green.	Silky or dull. Opaque.
MOLDAVITE	*Tektite*	Green.	Vitreous. Transparent to translucent.
OBSIDIAN 165	*Volcanic glass.*	Black, red, brown, greenish.	
OLIVINE $(Mg,Fe)_2SiO_4$ 135	*Peridot*	Bottle green, olive green.	Vitreous to greasy. Transparent.
	Chrysolite	Yellow to greenish-yellow.	
OPAL $SiO_2.xH_2O$ 141			Vitreous to greasy.
	Gem opal includes:	Good play of colors.	Transparent to translucent.
	White opal	Light-colored.	
	Black opal	Dark gray, blue, black.	
	Harlequin opal.	Uniform patches of color.	
	Lechosos opal	Green play of colors.	
	Fire opal	Yellow, red; fiery play of colors.	
	Girasol	Blue white; red play of colors.	
	Opal matrix	Opal in its matrix.	

MATERIALS DESCRIBED IN THE TEXT, ARRANGED ALPHABETICALLY REFERENCE.—*Continued*

Hardness (H.), specific gravity (S.G.)	Crystallization, structure, cleavage (C), and fracture (F)	Optical properties n = mean index	Characteristics, occurrence, and principal localities
H. 2–2½ S.G. 1.1–1.4	Amorphous; compact. F—Conchoidal.		Tough. Takes good polish. Jet is a variety of brown coal (lignite). England; Spain; France, Wurttemburg; United States.
H. 5–6 S.G. 3.1	Monoclinic, pyramidal crystals, also massive.	Biaxial; – n 1.62 γ-α 0.036	Pleochroic. In quartz, slate, with corundum, and rutile. Austria, Georgia, North Carolina.
H. 5–5½ S.G. 2.4	Cubic; compact.	Isotropic. n 1.50.	Lapis lazuli is a mixture of lazurite and other minerals, including pyrite. In metamorphosed limestone. Afghanistan, Siberia, Chile.
H. 3½ S.G. 3.7–4.0	Monoclinic; fibrous, banded. F—Conchoidal, splintery.	Biaxial; – n 1.81 γ-α 0.26.	*Malachite matrix* contains gangue. Alteration product of other copper minerals, with azurite. Urals; Rhodesia; Chile; Arizona.
H. 5½ S.G. 2.5	Amorphous. F—Conchoidal, with sharp edges.	Isotropic. n 1.5–1.6.	Natural glasses of variable properties. *Obsidian* is of volcanic origin. *Moldavite*, of unknown origin; Bohemia, Moravia, Australia.
H. 6½–7 S.G. 3.2–3.6	Orthorhombic; prismatic crystals, granular masses, pebbles. F—Conchoidal.	Biaxial; + n 1.68. γ-α 0.04. Dispersion 0.018.	In basic igneous rocks, limestones, with spinel, pyrope. Zeboiget Island, Red Sea; Burma; Ceylon; Queensland; Brazil; Navajo country of Arizona and New Mexico.
H. 5½–6½ S.G. 2.1–2.3	Amorphous; compact masses. F—Conchoidal, good.	Isotropic. n 1.44–1.45.	Amount of water variable. In veins and cavities, deposited from hot waters. Hungary, Australia, Honduras, Mexico, Nevada.

TABLE XI.—SUMMARY OF THE PROPERTIES OF THE GEM
FOR READY

Name, page reference, composition, and varieties	Color	Luster, transparency
PEARL $CaCO_3$ and organic matter. *Baroque pearls*..irregular in shape. *Button pearls*...flat. *Blister pearls*..growths on shells. *Mother-of-pearl*..inner layer of pearl oyster shells 183	White, pink, yellow, purple, red, green, blue, brown, black.	Pearly. Translucent to opaque.
PHENACITE Be_2SiO_4 165	Colorless, yellowish, or pale rose-red.	Vitreous. Transparent.
PREHNITE $H_2Ca_2Al_2(SiO_4)_3$ 165	Light-green, apple-green, oil-green, or yellowish-green.	Waxy vitreous. Transparent to translucent.
PYRITE FeS_2 172	Brass yellow. Streak greenish black.	Metallic. Opaque.
QUARTZ SiO_2 *Phanerocrystalline varieties.* Vitreous, crystallized or crystalline, transparent to translucent. *Rock crystal*........Colorless. *Amethyst*...........Purple, violet. *Rose quartz*.........Pink, rose red. *Smoky quartz*.......Smoky brown. *Citrine*............Yellow. *Milky quartz*.......White. *Gold quartz*.........Milky quartz with native gold. *Siderite*...........Berlin blue. Continued on page 208 144		Vitreous to greasy. Transparent to opaque. *Cryptocrystalline varieties.* Less glassy than phanerocrystalline varieties; compact, homogeneous, microscopically crystalline. *Chalcedony*.......Light colored. *Carnelian*.........Red. *Chrysoprase*.......Apple-green. *Prase*............Dull leek- or sage-green. *Plasma*..........Green with white or yellowish spots. *Bloodstone*........Dark green with red spots. *Fortification agate*..Angular bands. *Moss agate*........With dark dendritic inclusions. *Agate*............Banded; curved bands. *Eye agate*........Circular bands resembling an eye.

MATERIALS DESCRIBED IN THE TEXT, ARRANGED ALPHABETICALLY REFERENCE.—*Continued*

Hardness (H.), specific gravity (S.G.)	Crystallization, structure, cleavage (C), and fracture (F)	Optical properties n = mean index	Characteristics, occurrence, and principal localities
H. 2½–3½ S.G. 2.5–2.7	Orthorhombic $CaCO_3$(aragonite) with amorphous organic matter (conchiolin).		Best pearls round or pear-shaped. Soft, affected by acids, perspiration. Formed about foreign particles within shells of pearl oysters and mussels. In *culture pearls* growth is artificially stimulated. Warm seas (pearl oysters) and streams of Europe and United States (mussels).
H. 7½–8 S.G. 3.0	Hexagonal; well-formed crystals. F—Conchoidal.	Uniaxial; + n 1.66. ϵ-ω 0.016.	Like quartz and topaz in appearance. Associated with them in pegmatites and metamorphic rocks. Urals; Minas Geraes, Brazil; Durango, Mexico; Stoneham, Maine.
H. 6–7 S.G. 2.8–3.0	Orthorhombic; in rounded masses, internal radial fibrous structure.	Biaxial; + n 1.63 γ-α 0.03.	In veins and cavities in basic igneous rocks, with datolite. Dauphiné, France; Lake Superior district; New Jersey.
H. 6–6½ S.G. 4.9–5.2	Cubic; brilliant crystals, cubes, octahedrons, pyritohedrons, frequently striated.		Widespread in occurrence, in all kinds of rocks. Clusters, small natural crystals used uncut.
H. 7 S.G. 2.7	Hexagonal; prismatic crystals, horizontally striated, well-developed, often twisted or distorted, right- and left-handed, often twinned. Massive forms in veins and cavities, nodular, or compact. F—Pronounced conchoidal.	Uniaxial; + n 1.55. ϵ-ω 0.009. Dispersion 0.013. Right-handed crystals rotate plane of polarization of light to right, left-handed crystals to the left.	Occurs everywhere in all types of rocks. *Agate:* Oberstein and Idar, Germany; Uruguay; Lake Superior district. *Amethyst:* Ceylon, India, Siberia, Uruguay, Brazil, Maine, North Carolina, Lake Superior district. *Aventurine:* Siberia, China, Madagascar. *Bloodstone:* India, Siberia. *Cat's eye:* Ceylon, India, Bavaria, Brazil. *Chalcedony:* Uruguay, Brazil, Lake Superior district. *Chrysoprase:* Silesia. *Citrine:* Brazil.

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TABLE XI.—SUMMARY OF THE PROPERTIES OF THE GEM
FOR READY

Name, page reference, composition, and varieties	Color	Luster, transparency.
QUARTZ (*Continued*)		
Phanerocrystalline varieties		*Cryptocrystalline varieties*
Aventurine	Yellow, brown, green, or red, containing glistening scales.	*Agatized wood*. Distinct woody structure.
Rutilated quartz	Contains fine needles of rutile.	*Onyx*. Banded; horizontal bands.
Tiger's eye	Fibrous, chatoyant; brown, blue, red.	*Sardonyx*. Alternately red and white bands.
Cat's eye	Fibrous, chatoyant; gray, brown, green.	*Jasper*. Opaque, red, yellow, brown, dark green, grayish blue.
		Riband jasper. Banded.
		Egyptian jasper. Yellow to brown, irregularly marked.
148		
RHODONITE $MnSiO_3$ 179	Rose-red, pink.	Vitreous to pearly. Opaque.
RUTILE $TiTiO_4$	Red-brown, blood-red, black.	Metallic adamantine. Opaque to transparent.
Rutilated quartz 166	Fine rutile needles in quartz.	
SEPIOLITE $H_4Mg_2Si_3O_{10}$ *Meerschaum* 181	White, yellowish, grayish.	Dull. Opaque.
SERPENTINE $H_4Mg_3Si_2O_9$		Dull, resinous, greasy, or waxy. Translucent to opaque.
Precious serpentine	Green or yellow.	
Bowenite	Green, resembling jade.	
Williamsite	Blackish green.	
Verd antique	Mottled-green and white.	
181		

MATERIALS DESCRIBED IN THE TEXT, ARRANGED ALPHABETICALLY
REFERENCE.—*Continued*

Hardness (H.), specific gravity (S.G.)	Crystallization, structure, cleavage (C), and fracture (F)	Optical properties n = mean index	Characteristics, occurrence, and principal localities
			Gold quartz: California, Alaska. *Prase:* Saxony. *Rock crystal:* Japan, Madagascar, Switzerland, Brazil, New York, Arkansas. *Rose quartz:* Japan, Madagascar, Bavaria, France, Brazil, Maine, South Dakota. *Rutilated quartz:* Madagascar, Brazil, Switzerland, Vermont. *Smoky quartz:* Scotland, Switzerland, Maine, Colorado. *Tiger's eye:* South Africa.
H. 5–6 S.G. 3.4–3.7	Triclinic; crystals or compact masses. C—Prismatic.	Biaxial; − n 1.73. γ-α 0.01.	Ekaterinburg, Ural Mountains; Franklin Furnace, New Jersey.
H. 6–6½ S.G. 4.2–4.3	Tetragonal; prismatic, vertically striated, often twinned crystals.	Uniaxial; + ω 2.62, ϵ 2.90. ϵ-ω 0.28.	Norway, Sweden, Urals, Tyrol, Switzerland, France, Madagascar, Brazil, Vermont, North Carolina.
H. 2–2½ S.G. 1–2	Monoclinic; always in earthy or nodular masses.	Biaxial; − n 1.55.	May float on water because of porosity. Formed by alteration of serpentine and magnesite. Asia Minor, Greece, Spain, Moravia, Morocco.
H. 2½–4 S.G. 2.5–2.8	Monoclinic; always massive. F—Conchoidal, splintery.	n 1.53.	Often spotted, clouded, or multicolored. Smooth, greasy feel. With pyrope. Sweden, Scotland, Silesia, Saxony, Rhode Island (*bowenite*), Vermont (*verd antique*), Massachusetts, Pennsylvania (*williamsite*), California. Results from alteration of other magnesian rocks and minerals.

TABLE XI.—SUMMARY OF THE PROPERTIES OF THE GEM
FOR READY

Name, page reference, composition, and varieties	Color	Luster, transparency
SMITHSONITE	Soft yellow, green, or blue.	Vitreous to pearly.
$ZnCO_3$		Translucent to opaque.
182		
SODALITE	Deep blue, similar to that of lazurite.	Vitreous to greasy.
Complex silicate.		Translucent.
183		
SPINEL		Vitreous.
$Mg(AlO_2)_2$ *Ruby spinel*	Deep red.	Transparent.
Balas ruby	Rose-red to pink.	
Rubicelle	Yellow, orange-red.	
Almandine	Violet, purple.	
Sapphirine	Blue.	
136 *Chlorospinel*	Grass-green.	
SPODUMENE		Transparent.
$LiAl(SiO_3)_2$ *Kunzite*	Pink to lilac.	Vitreous.
Hiddenite	Yellow-green to emerald-green.	
166		
STAUROLITE		Vitreous to dull.
$HFeAl_5Si_2O_{13}$		Translucent to opaque.
Cross-stone, fairy-stone	Reddish-brown.	
167		
THOMSONITE	White, red, green, and yellow; mottled.	Vitreous to pearly.
$2(Ca, Na_2)Al_2(SiO_4)_2.5H_2O$		Opaque.
168		
TITANITE		Adamantine.
$CaTiSiO_5$ *Sphene*	Yellow, green, brown, gray.	Transparent.
169		
TOPAZ		Vitreous.
$Al_2(OH,F)_2SiO_4$	Pale blue, green, violet, or red	Transparent.
Precious topaz	Wine-yellow.	
125		

MATERIALS DESCRIBED IN THE TEXT, ARRANGED ALPHABETICALLY REFERENCE.—*Continued*

Hardness (H.), specific gravity (S.G.)	Crystallization, structure, cleavage (C), and fracture (F)	Optical properties n = mean index	Characteristics, occurrence, and principal localities
H. 5 S.G. 4.1–4.5	Hexagonal; compact, banded, stalactitic. F—Splintery.	Uniaxial; − n 1.75. ω-ϵ 0.20.	Formed by alteration of zinc sulphide in limestone, dolomite. Laurium, Greece; Sardinia; Kelly, New Mexico.
H. 5–6 S.G. 2.2–2.4	Cubic; massive. F—Conchoidal.	Isotropic. n 1.48.	In igneous rocks. Urals, Mount Vesuvius, Norway, Ontario, and Litchfield, Maine.
H. 8 S.G. 3.5–3.7	Cubic; octahedral crystals, twinned, also in grains. C—Octahedral. F—Conchoidal.	Isotropic. n 1.72. Dispersion 0.020.	In limestones and placers with ruby. Ceylon; Burma; Siam; Åker, Sweden; Expailly, France; New Jersey; New York.
H. 6–7 S.G. 3.1–3.2	Monoclinic; long prismatic crystals. F—Prismatic.	Biaxial; + n 1.66. γ-α 0.026. Dispersion 0.017.	Somewhat pleochroic. Kunzite is strongly phosphorescent under radiations, with an orange-pink light. *Kunzite:* in pegmatites, with tourmaline, beryl; Madagascar; Pala, California. *Hiddenite:* in kaolin veins; North Carolina.
H. 7–7½ S.G. 3.4–3.8	Orthorhombic; in cross-shaped twins.	Biaxial; + n 1.74. γ-α 0.010. Dispersion 0.021.	Some pleochroism. In metamorphic rocks, with cyanite, garnet, tourmaline. Tyrol, Switzerland, Brazil, Georgia.
H. 5–5½ S.G. 2.3–2.4	Orthorhombic; spherical concretions, rounded pebbles, radial fibrous.	Biaxial; + n 1.51. γ-α 0.03.	"Eye markings" popular. Pebbles weathered out of basic igneous rocks along shores of Lake Superior.
H. 5–5½ S.G. 3.4–3.6	Monoclinic; wedge-shaped crystals. F—Conchoidal.	Biaxial; + α 1.90, γ 2.03. γ-α 0.13. Dispersion 0.050.	In schists and limestones. St. Gothard, Switzerland; Zillerthal, Tyrol; Maine; New York; Pennsylvania.
H. 8 S.G. 3.4–3.6	Orthorhombic; prismatic crystals rich in forms, also massive. C—Perfect basal. F—Conchoidal.	Biaxial; + n 1.62–1.63. γ-α 0.010. Dispersion 0.014.	Pink topaz often artificially produced by heating yellow topaz. Occurs in gneiss, schist, granite, pegmatite; with tourmaline, quartz, apatite, fluorite, beryl. Urals, Scotland, Ireland, Brazil, Saxony, Cornwall, Ceylon, Japan, Mexico, Thomas Range of Utah, Colorado, Maine.

TABLE XI.—SUMMARY OF THE PROPERTIES OF THE GEM
FOR READY

Name, page reference, composition, and varieties	Color	Luster, transparency
TOURMALINE		Vitreous. Transparent.
Complex silicate		
Achroite	Colorless.	
Rubellite	Rose-red.	
Brazilian emerald	Green.	
Brazilian sapphire	Blue.	
Brazilian peridot	Yellowish-green.	
Peridot of Ceylon	Honey-yellow.	
Siberite	Violet.	
131 *Indicolite*	Dark blue.	
TURQUOIS	Sky-blue, greenish-blue, apple-green.	Waxy. Opaque.
Basic phosphate of copper and aluminum		
Turquois matrix	Turquois in its limonitic matrix.	
Odontolite, fossil turquois	Fossil bone colored by vivianite. Not true turquois.	
153		
VARISCITE	Apple-green to blue-green. Compact.	Vitreous. Translucent to opaque.
$AlPO_4.2H_2O$ *Utahlite*		
154		
VESUVIANITE	Yellow, green, brown.	Vitreous to greasy. Translucent.
Calcium aluminum silicate		
Cyprine	Blue.	
Californite	Green, compact.	
169		
WILLEMITE	Yellow, green, brown, reddish.	Greasy vitreous. Transparent.
Zn_2SiO_4.		
170		
ZIRCON		Adamantine. Transparent.
$ZrSiO_4$ *Hyacinth, jacinth*	Yellow, orange, red, brown.	
Jargon	Other colors than the above (colorless, gray, smoky).	
Matura diamond	Colorless, either natural or produced artificially. Also blue and green.	
139		
ZOISITE		Vitreous. Transparent to translucent.
$Ca_2Al_2(Al.OH)(SiO_4)_3$		
Thulite	Rose-red.	
183		

MATERIALS DESCRIBED IN THE TEXT, ARRANGED ALPHABETICALLY REFERENCE.—*Continued*

Hardness (H.), specific gravity (S.G.)	Crystallization, structure, cleavage (C), and fracture (F)	Optical properties n = mean index	Characteristics, occurrence, and principal localities
H. 7–7½ S.G. 2.9–3.2	Hexagonal; prismatic, vertically striated crystals, with a rounded triangular outline. F—Subconchoidal.	Uniaxial; − n 1.63. ω-ϵ 0.020. Dispersion 0.016.	Vertical axis polar. Electrified on rubbing. Often zonally colored. Strong dichroism, ω more strongly absorbed than ϵ. Gem tourmaline rich in alkalies. In pegmatites, with quartz, beryl, apatite, topaz, fluorite. Ceylon, Madagascar, Siberia, Elba, Brazil, Maine, southern California.
H. 6 S.G. 2.6–2.8	Apparently amorphous; in veins, crusts, rounded masses. F—Conchoidal.	n 1.63.	Color unstable. Matrix usually limonitic. Formed by deposition from solutions. Persia, Sinai peninsula, Turkestan, Australia, New Mexico, Arizona, California, Nevada.
H. 4–5 S.G. 2.5	Orthorhombic; crusts, nodules, crystalline aggregates. F—Conchoidal.		In shales and slates. Utah.
H. 6½ S.G. 3.3–3.5	Tetragonal; prismatic crystals, compact.	Uniaxial; + n 1.72. ω-ϵ 0.006 and less.	Weak pleochroism. In contact metamorphic deposits, with garnet, tourmaline, epidote. Mount Vesuvius; Wilui River, Siberia; Eger, Hungary; California.
H. 5–6 S.G. 3.9–4.3	Hexagonal; small crystals, granular.	Uniaxial; + n 1.70. ϵ-ω 0.02.	Franklin Furnace, New Jersey.
H. 7½ S.G. 4.0–4.8	Tetragonal; prismatic crystals, lumps. C—Imperfect. F—Conchoidal.	Uniaxial; + ω 1.92, ϵ 1.95 ϵ-ω 0.05. Dispersion 0.038.	Often abnormally biaxial, n 1.70–1.84. Uranium varieties have a number of sharp, narrow absorption bands. Pale brown stones can be decolorized by heat (*Matura diamond*). In alluvial deposits. Ceylon; Australia; Expailly, France; Ilmen Mountains, Russia.
H. 6–6½ S.G. 3.3–3.4	Orthorhombic; disseminated prismatic crystals.	Biaxial; + n 1.70. γ-α 0.006.	Strongly pleochroic. Norway.

INDEX

Names of gem minerals and gem materials described or referred to in the text are printed in **heavy-faced** type, and general subjects in light-faced type. Where there is more than one reference, the important one is printed in **heavy-faced** type.